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(71) Applicant: **Albatros Trade S.r.l.**
54033 Carrara (MS) (IT)

(72) Inventors:
- **FRATI, Nicola**
55041 CAMAIORE (LU) (IT)
- **BERTI, Massimo**
54033 CARRARA (MS) (IT)

(74) Representative: **ABM Agenzia Brevetti & Marchi**
Viale Giovanni Pisano, 31
56123 Pisa (IT)

(54) AN INDUCTION HEATING METHOD FOR HEATING A METAL BODY, AND AN APPARATUS FOR CARRYING OUT SAID METHOD

(57) An induction heating method and apparatus for heating a metal body by electromagnetic induction, wherein an electric generation unit (40) is configured to supply a working current into an inductor winding (32) of an inductor circuit (30) of a portable induction heating device (1) comprising a hollow handle portion or hand-piece (10) that includes such electric components as a current transformer (50), and wherein a cooling air feed section (60) is arranged for conveying a flow of pressurized cooling air (2) in a cooling flowpath (70) defined within the inductor winding (32) and within the hollow handle portion (10). A control unit (80) is configured block a step (150) of supplying a working alternating current to inductor circuit (30) after a maximum heating time (τ_H), preferably 10-30 seconds has elapsed since when the step (150) of supplying said working alternating current is started, and for inhibiting further heating during an inhibition time (τ_I) preferably of 40-80 seconds, allowing a safe heating operation while avoiding a more expensive and troublesome liquid heating. (Figs. 1, 10]

Fig. 1

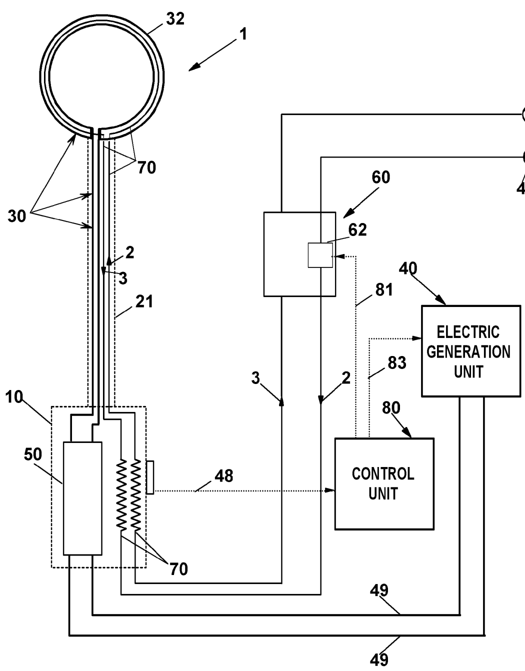
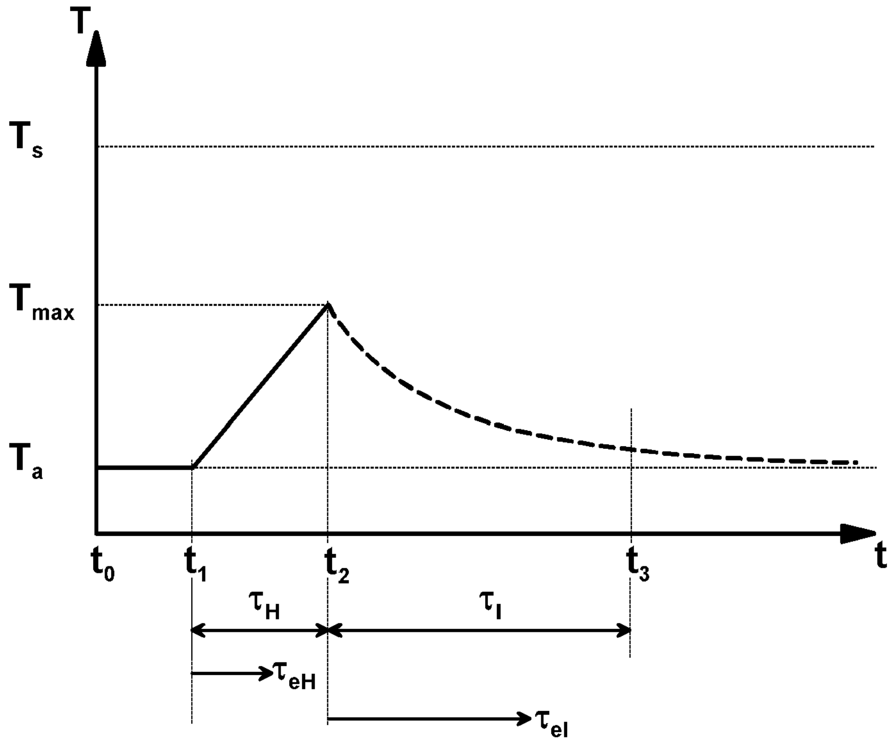


Fig. 10



Description

Field of the invention

[0001] The present invention relates to an induction heating method of a metal body, namely for inducing in it heating currents heating by electromagnetic induction, and to an induction heating apparatus for carrying out this method.

[0002] More in detail, the invention relates to a method for cooling an induction heating device.

Description of the prior art

[0003] Induction heaters are known that are cooled by water, as described in US3495063, US3022368, WO2017186963. These tools are adapted to heat mechanical workpieces, for example bolts for assisting unscrewing or parts to be worked. Such heaters comprise a handpiece that contains power electronics and an induction tip that, by electromagnetic induction piloted by the electronics, heats the metal workpiece.

[0004] In particular, a supply unit is provided, which can be made with various known techniques and is connected to the induction tip, which consists of a tube of copper that ends with a tubular coil, always consisting of a copper tube portion, of various shape according to the type and the shape of the workpiece. On an end of the winding a core of ferrite can be mounted that increases the induction heating efficiency.

[0005] The known devices provide a circuit to let a coolant flow, normally containing water. In particular, the tube of copper of the induction tip is a conduit through which the coolant flows.

[0006] The fact that the coolant is a liquid is required for dissipating the electric power that turns into heat and that could damage the power electronics that feeds the heating induction tip. Moreover, efficient cooling is necessary to handle the tool safely, taking into account that a handling temperature that exceed 50-60°C is not allowed.

[0007] The fact that the coolant is a liquid, however, for supplying and receiving the cooling liquid requires to connect the cooling circuit to a reservoir, which in turn also has to be cooled. Therefore, it is necessary to provide a heat exchanger as a cooling radiator. All this causes an additional weight and a higher encumbrance of the tool, as well as a supply circuit and a heat exchange system of, in addition to a more complex structure to be placed in a workshop. Moreover, the availability of the liquid coolant in the reservoir has to be monitored.

[0008] Furthermore, the co-presence of a circuit of the liquid coolant, in particular water, and of electric connections in the device, in particular the use of the same tube for passage of power cables and for conveying the liquid coolant, requires a high quality, to provide sealed and electrically insulated connections, to ensure a safe use.

Summary of the invention

[0009] It is therefore an object of the present invention to provide an induction heating method and apparatus for heating a metal body that does not require the use of bulky parts as storage reservoirs and heat exchangers, and that provides easier installation, use and maintenance with respect to prior art apparatuses.

[0010] It is also an object of the invention to provide such an apparatus that is constructionally much easier than the devices of prior art, in particular, in connection to the necessary electric insulation.

[0011] It is then an object of the invention to provide such an apparatus that is inherently safer than the devices of prior art.

[0012] The objects indicated above are achieved by an induction heating method and by an induction heating apparatus for heating a metal body, for example a bolt to be unscrewed or a workpiece, as defined in claims 1 and 7, respectively. Exemplary and advantageous embodiments of said method and of said device are defined in the dependent claims.

[0013] According to an aspect of the invention, a method for performing an induction heating of a metal body comprises a step of prearranging an induction heating apparatus, the induction heating apparatus comprising:

- a hollow handle portion;
- an inductor circuit, wherein at least one hollow inductor winding is arranged at an end portion of an elongated support extending from the hollow handle portion;
- a cooling flowpath, i.e., a cooling passageway, defined within the hollow handle portion and within the at least one hollow inductor winding;
- an electric generation unit arranged for supplying an alternating current to the inductor circuit;
- a current transformer between the electric generation unit and the inductor circuit, the current transformer arranged within the hollow handle portion; and
- a start/stop drive element arranged to be operated by an operator and configured to generate a heating start/stop signal;

the method also comprising the steps of:

- defining a maximum heating time per heating cycle, and a maximum inhibition time;
- identifying an electric power required for the induction heating; and
- starting a heating cycle through the drive element;

said heating cycle comprising the steps of:

- conveying a flow of a pressurized cooling air at a predetermined pressure through the cooling flowpath;

- supplying a working alternating current through the inductor circuit, the step of conveying the flow of the pressurized cooling air being continued during the step of supplying the working alternating current;
- counting an elapsed heating time starting from when the step of supplying the working alternating current begins;
- checking the presence of the heating stop signal; and
- comparing the elapsed heating time with the maximum heating time,

wherein, upon occurring at least one condition selected between

- a condition in which the elapsed heating time becomes equal to or longer than the maximum heating time, and
- a condition in which the heating stop signal is present,

the steps are carried out of:

- discontinuing the step of supplying the working alternating current, and
- disabling the drive element;

wherein further steps are provided of:

- counting an elapsed inhibition time since the step of discontinuing the step of supplying the working alternating current; and
- comparing the elapsed inhibition time with the maximum inhibition time,

  wherein, upon occurring a condition in which the elapsed inhibition time becomes equal to or longer than the maximum inhibition time, a step is carried out of restoring the drive element;
  wherein the working alternating current has a working frequency close to a resonance frequency of a combination of the inductor circuit and of the metal body, and a working intensity suitable for providing said electric power through the at least one hollow inductor winding.

[0014] According to another aspect of the invention, an apparatus for performing an induction heating of a metal body comprises:

- a hollow handle portion;
- an elongated support extending from the hollow handle portion;
- an electric inductor circuit comprising at least one hollow inductor winding arranged at an end portion of the elongated support;
- a cooling flowpath, i.e. a cooling passageway, defined within the hollow handle portion and within the at least one hollow inductor winding;
- an electric generation unit arranged for supplying an alternating current to the inductor circuit;
- a current transformer between the electric generation unit and the inductor circuit, the current transformer arranged within the hollow handle portion,
- a pressurized cooling air feed section for feeding the pressurized cooling air into the cooling flowpath, said feed section comprising a flow-actuation device configured for causing/blocking a flow of a pressurized cooling air from a pressurized cooling air source into the cooling flowpath;
- a start/stop drive element arranged to be operated by an operator and configured to generate a heating start/stop signal; and
- a control unit configured for receiving the heating start/stop signal from the drive element,
  said control unit being further configured for, upon receiving the heating start signal,
- transferring an opening signal to the flow-actuation device for conveying the flow of the pressurized cooling air through the cooling flowpath, and for
- transferring an electric supply signal to the electric generation unit for supplying a working alternating current to the inductor circuit, the working alternating current having a working intensity suitable for determining a delivery of said electric power through the at least one hollow inductor winding;
  wherein the working alternating current has a working frequency close to a resonance frequency of a combination of the inductor circuit and of the metal body;

the control unit being configured for:

- receiving a set value of a maximum heating time per heating cycle;
- receiving a set value of a maximum inhibition time;
- counting an elapsed heating time;
- checking a reception of the heating stop signal; and
- comparing the elapsed heating time with the maximum heating time;
  the control unit also configured for, upon occurring at least one condition selected between a condition in which the elapsed heating time becomes equal to or longer than the maximum heating time and a condition in which the heating stop signal is received:
- transferring an electric supply interrupt signal to the electric generation unit for blocking the working alternating current;
- disabling the drive element;
- counting an elapsed inhibition time;
- comparing the elapsed inhibition time with the maximum inhibition time;
  the control unit being also configured for restoring the drive element upon occurring a condition in which the elapsed inhibition time becomes equal to or longer than the maximum inhibition time.

[0015] Upon occurring a condition in which the elapsed inhibition time becomes equal to or longer than the maximum inhibition time, a step can also be carried out of discontinuing the step of conveying the flow of the pressurized cooling air. To this purpose, the control unit of the apparatus defined above can also be configured to transferring a closure signal to the flow-actuation device for discontinuing the flow of the pressurized cooling air, upon occurring the condition in which the elapsed inhibition time becomes equal to or longer than the maximum inhibition time. This prevents compressed air waste and compression costs possibly associated thereto.

[0016] The method and the apparatus defined above are based on the use of compressed air as a cooling fluid, and allow then to avoid the drawbacks, above described, connected to the use of a liquid coolant, in particular the handle portion and the electric/electronic components thereof. At the same time, the method and the apparatus of the present invention allow to contain the temperature of the inductor device within acceptable limits for protecting the functionality of the electric components and the maneuverability by the operators, notwithstanding the more limited heat exchange coefficient that a gas like air can offer than a liquid.

[0017] This is kept possible owing to the combined effect of at least two features.

[0018] On the one hand, the use of compressed air, for example at the pressures specified hereinafter, makes it possible to obtain a reasonable heat exchange coefficient, even if less than that of a liquid used as cooling fluid.

[0019] On the other hand, the limitation applied to the duration of the heating step below a maximum time of a few of seconds, prevents that too high temperatures are reached that could not be compensated by using air for cooling, instead of, for example, water. Therefore, an acceptable maximum waiting time is required, following the heating time and during which the operator cannot use the inductor circuit for allowing to cool the tool enough in order execute a further induction heating cycle safely.

[0020] The inventors have in fact detected that a heating time as above indicated is widely enough to carry out most of the operations of induction heating which are normally carried out in a workshop, for example heating bolts from unscrewing operations.

[0021] Moreover, the maximum inhibition time imposed to an operator is not an impediment or a limit to the operability of the apparatus, with respect to the traditional devices cooled by water. In fact the inventors have also considered that normally, also in case of heating operations that require heating heating in succession many workpieces, for example a plurality of bolts that join two mechanical parts, the steps of heating are generally followed by steps of working on of the workpieces, for example the hammering and/or unscrewing the bolts, in such a way that it is not generally necessary to wait further time for starting induction heating after each previous heating step.

[0022] The drive element has preferably the shape of a key arranged for example at the hollow handle portion or anywhere on the handpiece. In particular, a same key can be provided bot for activation and for discontinuing the heating cycle. In particular, the step of supplying the working alternating current to the induction circuit of can be turned of with a simple pressure on the key, as well as it is turned off by the control unit of the apparatus when the maximum predetermined heating time is reached. In the latter case, the system remains in a status of "recovery" for a time necessary to cooling the electric components contained in the handpiece, and of the handpiece same. Such status of recovery time is preferably communicated to the user by the drive electronics. At the end of the recovery time, the solenoid valve of the pressurized cooling air can advantageously, but not necessarily closed again, and the activation key enabled again, in such a way that the apparatus returns to ready for a further induction heating cycle. Also this case a notification message, can be advantageously provided to the user by the drive electronics.

[0023] The step of supplying the working alternating current to the inductor circuit can in any case also advantageously, turned off, as described hereinafter, to achieve a maximum admissible safety temperature for the electronics and/or for the transformer contained in the handpiece.

[0024] The handpiece can also comprise a key for driving the power supply . This way, by the drive electronics, the level of power with which the metal workpiece is heated can be easily selected.

[0025] For example, the pressurized cooling air source can be a network of compressed air available in a workshop or in an industrial plant, or a compressed air reservoir equipped with a pressure-reducing valve, or supplied by a commercial compressor, and, in the first two cases the flow-actuation device can be a shut-off valve 62 equipped with electric solenoid actuator, whereas in the last case the flow-actuation device can be a relay configured to operate a compressor.

[0026] In particular, the pressure of the compressed air is set between 1 and 4 bar g, more in particular, between 1 and 2 bar g. Such pressures are easily obtainable by a common network of compressed air available in a workshop or in an industrial plant, or, in absence, by a compressed air reservoir equipped with pressure-reducing valve, or also using machines of cost limited as small compressors.

[0027] Preferably, the maximum heating time per heating cycle is set between 10 and 30 seconds, more preferably between 15 and 25 seconds, even more preferably the maximum heating time is about 20 seconds.

[0028] Preferably, the maximum inhibition time is set between 40 and 80 seconds, more preferably between 50 and 70 seconds, even more preferably this maximum inhibition time is about 60 seconds.

[0029] Advantageously, the heating cycle also provides, before the step of supplying the working alternating current, a step of checking the connection of a load to the inductor circuit, in turn comprising the steps of:

- checking the presence of the metal body at the hollow inductor winding by supplying a predetermined test current into the inductor circuit, the test current having an intensity lower than the working intensity;
- upon occurring a condition in which the metal body is not present, block the step of supplying the working alternating current and, preferably, generating a related notification message.

[0030] Preferably, during the heating cycle, a step is carried out of checking the flow of the pressurized cooling air, comprising in turn the steps of:

- detecting the air pressure or flowrate at a section of the cooling flowpath, preferably at the outlet of the cooling flowpath,
- comparing the above pressure or flowrate with a respective minimum predetermined value;
- upon occurring a deficient flow condition, in which the pressure or flowrate is lower than the respective minimum value, discontinuing or blocking the step of supplying the working alternating current and, preferably, generating a related notification message.

[0031] To this purpose, the apparatus defined above can also comprise a sensor configured to work as an instrument selected between a pressure switch and a flow switch, said sensor arranged along the cooling flowpath, preferably at an outlet of the cooling flowpath, the sensor configured to transfer an alarm signal to the control unit, the alarm signal selected between a low-pressure signal and a low-air flowrate signal, respectively, in the cooling flowpath, and the control unit can also be configured for:

- checking the presence of the alarm signal;
- in the presence of the alarm signal, disabling the electric supply signal to the generation unit, interrupting therefor the step of supplying the working alternating current to the inductor circuit and, advantageously, generating a related notification message.

[0032] This way, if at any stage of the induction heating process the flow of a pressurized cooling air is discontinued, or if a flow anomalous condition occurs, the supply of the current to the inductor circuit is also discontinued, thus preventing local overheating, which could damage the transformer contained in the handpiece and cause discomfort or harm to an operator while holding the handpiece.

[0033] The sensor can be a pressure or flow switch, or a combination thereof, or a pressure and/or flow sensor for continuous measurement, including a threshold set means for setting a pressure or flowrate threshold value, below which a deficient flow condition occurs.

[0034] By arranging such a sensor in the return portion of the pressurized cooling air circuit, various flow-related unfavorable conditions can be taken into account, in particular, missing cooling air at the inlet of the circuit, a failure of a cooling air solenoid valve, a significant cooling air leakage from the air cooling circuit, a blockage of the air cooling circuit and the like.

[0035] In particular if the step of checking the flow of the pressurized cooling air is carried out immediately after the step of starting the heating cycle, steps are provided of:

- counting a cooling check time since when the step of conveying has started;
- comparing the elapsed cooling check time with a predetermined maximum cooling check time;

and the step of blocking the step of supplying the working alternating current is carried out upon simultaneously occurring the deficient flow condition and a condition in which the elapsed cooling check time becomes equal to or longer than the maximum cooling check time. In other words, if within a few seconds since the step of starting the heating cycle the pressure or flow switch has not confirmed a suitable cooling air flow, the supply of the working alternating current to the inductor circuit is discontinued, the pressure or flow switch being preferably mounted to the return portion of the pressurized cooling air circuit.

[0036] To this purpose, the control unit of the apparatus is also configured, upon receiving the heating start signal, for:

- counting an elapsed cooling check time since when the heating start signal is received;
- comparing the elapsed cooling check time with a predetermined maximum cooling check time;
- upon occurring of both the deficient flow condition and a condition in which the elapsed cooling check time becomes equal to or longer than the maximum cooling check time, disabling the electric supply signal and, advantageously, generating a related notification message.

[0037] Even in this case, the occurring event on condition can be associated with a notification message trat can be a general anomaly or alert message, or a message specifying which event has caused the block.

[0038] Preferably, the maximum cooling check time is set between 3 and 10 seconds, more preferably between 5 and 8 seconds.

[0039] In particular, before the step of supplying the working alternating current, a step is provided of determining the working frequency, i.e., a step of guessing the working frequency of the alternating current to be supplied to the inductor circuit, the working frequency determination including in turn steps of:

- supplying a predetermined trial current to the inductor circuit, the trial current having an intensity lower than the working intensity and a trial frequency higher than an expected resonance frequency;
- progressively decreasing the trial frequency, during which steps are carried out of:
  - measuring a phase shift between the trial current and a corresponding voltage applied to the inductor circuit;
  - comparing the phase shift with a maximum admissible phase shift, so as to consider the phase shift value as a substantially zero value;

and, upon occurring a condition selected between a condition in which the phase shift is lower than the maximum admissible phase shift and a condition in which a minimum admissible phase shift value is attained, steps are carried out of:

- discontinuing the step of progressively decreasing the trial frequency;
- increasing the intensity of the trial current until the trial current reaches the working intensity.

[0040] Preferably, the working frequency of the alternating current supplied to the inductor circuit is controlled or "tracked" during the whole step of supplying the working alternating current to the inductor circuit, by the same procedure including providing a technically zero phase shift value between the supplied current and the voltage applied to the inductor circuit.

[0041] Advantageously, a temperature control routine is carried out during the heating cycle, in order to control the temperature attained in the power supply components of the apparatus, in particular, by the transformer enclosed in the handpiece to be used by the operator, in connection with a predetermined maximum admissible safety temperature for these components. To this purpose, the apparatus provides a temperature sensor arranged at the handpiece. In particular, the temperature control routine can include the steps of:

- detecting the temperature of a power supply component;
- comparing the power supply component temperature with the maximum admissible safety temperature;
- upon occurring a condition in which the power supply component temperature becomes equal to or higher than the maximum admissible safety temperature, discontinuing the step of supplying the working alternating current, and, preferably, generating a related notification message;
- comparing the power supply component temperature with a predetermined re-enablement temperature, lower than the maximum admissible safety temperature by a predetermined re-enablement temperature drop;
- upon occurring a condition in which the temperature at the power supply component temperature becomes lower than the re-enablement temperature, discontinuing the step of supplying the working alternating current, restoring the drive element and, preferably, generating a related notification message.

[0042] This way, the apparatus becomes fully operative again when the power supply component temperature has dropped below the maximum admissible safety temperature by at least the re-enablement temperature drop.

[0043] Preferably the maximum admissible safety temperature is set between 45°C and 65°C, more preferably between 50°C and 60°C.

Brief description of the drawings

[0044] Further characteristic and/or advantages of the present invention will be made clearer with the following description of exemplary embodiments and modifications thereof, exemplifying but not limitative, with reference to the attached drawings, in which:

- Fig. 1 is a block diagram of an induction heating apparatus for heating a metal body, according to the invention;
- Fig. 2 is a flow-sheet of an induction heating method for heating a metal body, according to the invention;
- Fig. 3 is a flow-sheet of a step of preliminarily checking the flow of a pressurized cooling air, according to a modification of the method according to the invention;
- Fig. 4 is a flow-sheet of a step of preliminarily checking the flow of a pressurized cooling air, according to a modification of the method according to the invention;
- Fig. 5 is a flow-sheet of a preliminary step of determining the frequency of the working alternating current, according to a further modification of the method according to the invention;
- Fig. 6 is a diagrammatical longitudinal sectional view of a portable device for heating an apparatus according to an exemplary embodiment of the invention;
- Figs. 7 and 8 are enlarged longitudinal sectional views of some details of the device of Fig. 6;
- Fig. 9 is a block diagram showing an electric generation unit and a cooling air feed and discharge unit of an apparatus according to the invention;
- Fig. 10 is a diagram showing how the measured power supply component temperature changes during a heating cycle.

Description of some preferred exemplary embodiments and modifications

[0045] With reference to Fig. 1, an induction heating apparatus for heating a metal body, typically a workpiece, not shown, comprises a portable induction heating device 1, an electric generation unit 40 and a cooling air feed and discharge unit 60 for feeding and discharging a cooling air 2,3 to/from portable induction heating device 1.

[0046] Portable induction heating device 1 comprises a hollow handle portion or handpiece 10, an elongated support 21 extending from handpiece 10 and at least one hollow inductor winding 32 arranged at one end of elongated support 21 opposite to handpiece 10. Hollow inductor winding 32 belongs to an inductor circuit 30 that receives an electric supply by a current transformer 50 housed within handpiece 10. A cooling passageway 70, i.e., a cooling flowpath 70 is provided within handpiece 10 and hollow inductor winding 32 for conveying pressurized cooling air 2, in order to at least partially remove the heat generated by a current flowing in the coils of transformer 50 and in hollow inductor winding 32, along with heat that hollow inductor winding 32 receives from the body heated by induction.

[0047] Cooling air feed and discharge unit 60 comprises a flow-actuation device 62 configured for causing/blocking a flow of pressurized cooling air 2 from a pressurized cooling air source 4 to cooling flowpath 70. Pressurized cooling air source 4 can be any device capable of delivering compressed air, in particular at a pressure set between 1 and 4 bar g, preferably set between 1 and 2 bar g. For instance, pressurized cooling air source 4 can be a common compressed air network of a workshop or an industrial plant, or a compressed air reservoir equipped with a pressure-reducing valve, or even a compressor. In the former two cases, flow-actuation device 62 can be a shut-off valve 62 equipped with a electric solenoid actuator, as shown in Fig. 9, whereas, in the latter case, flow-actuation device 62 can be a relay configured to operate a compressor.

[0048] Cooling air feed and discharge unit 60 arranged for supplying and discharging compressed air is also configured for transferring used cooling air 3 flowing out of cooling flowpath 70 to an air discharge device 5, usually arranged to discharge air into atmosphere.

[0049] As shown in Fig. 9, electric generation unit 40 is arranged for supplying an alternating current to current transformer 50 through connection conductors 49. Electric generation unit 40 and current transformer 50 are cooperatively configured to supply a working alternating current to inductor circuit 30.

[0050] As shown in Fig. 1, the apparatus also includes a start/stop drive element 41 arranged to be operated by an operator, preferably mounted to handpiece 10, in particular in the form of a push button, and configured to generate heating start/stop signals 48. In the apparatus, a control unit 80 is configured to receive heating start/stop signals 48 from start/stop drive element 41.

[0051] Control unit 80 is further configured to carry out the steps of the method of Fig. 2 for heating a metal body by inducing eddy currents therein.

[0052] The method comprises a preliminary step 101 of defining a maximum heating time τ_H per heating cycle and a maximum inhibition time τ_I, In the apparatus according to the invention, control unit 80 is configured to receive and store the set values of parameters τ_H and τ_I. A further preliminary step 102 is provided of identifying the electric power required for heating the metal workpiece, not shown, in order to properly set a driving electronics 42 of electric generation unit 40 so that the latter can provide the required power.

[0053] Subsequently, a step 103 is provided of starting a heating cycle, i.e. of starting an induction heating of the metal body or workpiece, through start/stop drive element or button 41.

[0054] The heating cycle essentially comprises a step 110 of conveying a flow of pressurized cooling air 2 through cooling flowpath 70, and a step 150 of supplying a working alternating current to inductor circuit 30, during which step 110 of conveying compressed air 2 is maintained.

[0055] In particular, control unit 80 is configured to receive a heating start signal 48 from start/stop drive element 41 and for operating, on the one hand, flow-actuation device 62 of cooling air feed and discharge unit 60 arranged for supplying the compressed air, for example, in the exemplary embodiment of Fig. 9, by transferring an opening signal 81 to shut-off valve 62, in order to allow a flow of pressurized cooling air 2. On the other hand, control unit 80 is configured to operate driving electronics 42, in order to supply the working alternating current to inductor circuit 30 through connection conductors 49 and current transformer 50 (Fig. 1).

[0056] As described hereinafter, before performing step 150 of supplying the working alternating current, some modifications of the method and in corresponding exemplary embodiments of the apparatus can include checking steps for protecting the apparatus against failure and/or for improving safety and effectiveness thereof.

[0057] As well known, in the induction heating technique, the working alternating current has preferably a working frequency substantially equal to the resonance frequency of the assembly consisting of inductor circuit 30 and the metal body to be heated. The working alternating current intensity is selected in such a way to obtain the power required for heating, through inductor circuit 30, more in particular, through hollow inductor winding(s) 32.

[0058] Step 150 of supplying the working alternating current, for each heating cycle, has a predetermined maximum duration, equal to previously set maximum heating time τ_H, (step 101).

[0059] A step 160 of counting the elapsed heating time τ_{eH} is also carried out simultaneously to step 150 of supplying the working alternating current. To this purpose, a timer is provided that can be resident in control unit 80.

[0060] However, the timer 160 can be interrupted and the heating cycle discontinued before the maximum heating time τ_H has elapsed. To this purpose, the operator can use start/stop drive element 41 once again. In this case, in particular, a heating stop signal 48 is emitted that control unit 80 is configured to receive.

[0061] In other words, according to the method, if at least at one condition occurs between a condition in which elapsed heating time τ_{eH} becomes equal to or longer than maximum heating time τ_H and a condition in which heating stop signal 48 is present, a step 168 is carried out of discontinuing step 150 of supplying the working alternating current. More in detail, as shown in Fig. 2, steps are provided of checking 161 the presence of heating stop signal 48 and of comparing 162 the elapsed heating time τ_{eH} with maximum heating time τ_H.

[0062] In particular, upon occurring at least one of these conditions, control unit 80 is configured to transfer an electric supply interrupt signal 83 to driving electronics 42 for blocking the working alternating current and disabling start/stop drive element 41, so that any further action of an operator on start/stop drive element 41 cannot cause supplying the alternating current to current transformer 50 and to inductor circuit 30.

[0063] Maximum heating time τ_H per heating cycle is preferably set between 10 and 30 seconds, more preferably between 15 and 25 seconds, in particular maximum heating time is about 20 seconds.

[0064] In most practical cases, maximum duration τ_H of step 150 of supplying the working alternating current and of induction heating is long enough to bring the heated workpiece to temperature suitable for further processing, for instance, for easily unscrewing a bolt. At the same time, the cooling effect of pressurized cooling air 2 flowing in cooling flowpath 70 is strong enough to limit the temperature increase of handpiece 10, so that the operator can harmlessly handle it, and of hollow inductor winding 32, so that the latter is not damaged.

[0065] Moreover, by disabling start/stop drive element 41, a new steo of heating cannot be started immediately, which prevents portable induction heating device 1 from overheating.

[0066] After step 168 of discontinuing the working alternating current and step 169 of disabling start/stop drive element 41, the latter remains disabled during a time equal to previously set maximum inhibition time τ_I. This condition is indicated as a "recovery" condition of the apparatus according to the invention.

[0067] To this purpose, as soon as steps 168 of discontinuing the supply of working alternating current and 169 of disabling start/stop drive element 41 take place, a further timer is started for performing a step 170 of counting an elapsed inhibition time τ_{eI}.

[0068] Upon elapsing of maximum inhibition time τ_I, a step 178 of restoring start/stop drive element 41 is performed. More in detail, as shown in Fig. 2, a step 171 is provided of comparing elapsed inhibition time τ_{eI} with maximum inhibition time τ_I. Upon occurring a condition in which elapsed inhibition time τ_{eI} has achieved maximum inhibition time τ_{HI}, step 178 of restoring restoring start/stop drive element 41 is carried out.

[0069] In particular, upon occurring this condition, control unit 80 is configured to recover start/stop drive element 41, so that the operator can start a new induction heating cycle. Preferably, control unit 80 is also configured to emit a newly enabled start/stop drive element signal.

[0070] Maximum inhibition time τ_I is preferably set between 40 and 80 seconds, more preferably between 50 and 70 seconds, in particular maximum inhibition time is about 60 seconds. In most practical cases, such a time τ_I during which the apparatus cannot be used is not disadvantageous, since the operator, before starting a new heating cycle of a workpiece, must accomplish a hot operation on the just heated workpiece. Moreover, the heat transfer coefficient allowed by compressed air is high enough to cool down portable induction heating device 1, in particular, handpiece 10, to a temperature at with the same can be safely handled by the operator, without any risk of burning or discomforted.

[0071] In a modification of the method, upon occurring a condition in which elapsed inhibition time τ_{eI} has achieved maximum inhibition time τ_{HI}, a step 179 can also be carried out of discontinuing 179 step 110 of conveying the flow of the pressurized cooling air 2 through cooling flowpath 70.

[0072] In particular, in this case, control unit 80 is configured to disable flow-actuation device 62 of cooling air feed and discharge unit 60. This can be carried out, for instance (Fig. 9) by transferring a closing signal 81 to shut-off valve 62 so that the flow of pressurized cooling air 2 is blocked.

[0073] Fig. 10 qualitatively shows how the temperature of handpiece 10 changes during a normal heating cycle, i.e., one in which the heating is not discontinued by the operator before maximum heating time τ_H has elapsed since instant t_1 at which step 150 of supplying the working alternating current to inductor circuit 30 is started. Therefore, at instant $t_2 = t_1 + \tau_H$, step 150 of supplying the working alternating current is automatically discontinued and a maximum temperature T_{max} is achieved at handpiece 10. Maximum heating time τ_H is selected so that maximum temperature T_{max} does not exceed a maximum admissible safety temperature, so that the operator can safely handle handpiece 10 and the power supply components of the apparatus are not damaged. At instant t_2, a recovery step follows in which start/stop drive element 41 is disabled and the hot portions of the apparatus, in particular handpiece 10, are allowed to cool down during maximum inhibition time τ_I. At instant $t_3 = t_2 + \tau_I$, start/stop drive element 41 is recovered, i.e., it is enabled again and a new heating cycle can be started by the operator acting on start/stop drive element 41.

[0074] With reference to Fig. 3, in a modification of the method, a step 120 of checking the flow of pressurized cooling air 2,3 is provided, i.e., a step of checking the effectiveness of the conveying system of pressurized cooling air 2,3. This check step 120 is preferably carried out before step 150 of supplying the working alternating current to inductor circuit 30. Step 120 of checking the pressurized cooling air flow consists in testing if the flow of pressurized cooling air 2,3 becomes strong enough to suitably mitigate the temperature of portable induction heating device 1 within a maximum cooling check time τ_C of a few seconds since when step 110 of conveying the flow of pressurized cooling air 2 is started. For example, maximum cooling check time τ_C can be set between 3 and 10 seconds, more in particular, between 5 and 8 seconds.

[0075] If such a condition is fulfilled, the workpiece heating cycle is allowed to proceed by above-described step 150 of supplying the working alternating current to inductor circuit 30. On the contrary, if the above condition is not fulfilled, step 150 of supplying the working alternating current is blocked 125 and the heating cycle is stopped, and a related notify message is preferably emitted 126 by control unit 80.

[0076] More in detail, in step 120 of checking the flow of pressurized cooling air 2,3 a timer is starting to carry out a step 121 of counting an elapsed cooling check time τ_{eC} since when step 110 of conveying the flow of pressurized cooling air 2 is started, and a step 122 of cyclically measuring a quantity related to the cooling air conveying conditions of the system. In particular, such a related quantity can be a cooling air pressure and/or a cooling air flowrate detected at a predetermined section of cooling flowpath 70. Preferably, the cooling air pressure and/or flowrate is measured at a section close to the outlet of cooling flowpath 70. Once maximum cooling check time τ_C has elapsed, the detected cooling air pressure and/or flowrate value is compared 124 with a predetermined minimum pressure and/or flowrate value, respectively, below which the flow of pressurized cooling air 2 is not considered high enough to perform a suitable cooling.

[0077] A low pressure or flowrate can be related to an obstruction within cooling flowpath 70, or to an unacceptable air loss from cooling flowpath 70 or from cooling air feed and discharge unit 60 to the outside, or to a fault of a component of cooling air feed and discharge unit 60, for instance an inappropriately closed shut-off valve, a compressor failure, a cooling air source low pressure and the like.

[0078] If a detected flowrate or pressure P is larger than a predetermined minimum value P_{min}, the heating cycle is allowed to proceed by above-described step 150 of supplying the working alternating current to inductor circuit 30. On the contrary, step 150 of supplying the working alternating current is blocked 125 and the heating cycle is stopped, and a related notify message is preferably emitted 126 by control unit 80.

[0079] In particular, the apparatus comprises a sensor 63 selected between a flow switch and a pressure switch, or a combination thereof, as shown for instance in Fig. 9, or in any case a device configured to work as a flow switch or a pressure switch, arranged along cooling flowpath 70, in particular at an outlet 18 of cooling flowpath 70. Sensor 63 is configured to provide control unit 80 with an alarm signal that can be a low-pressure signal and/or a low-flowrate signal. The timer for counting the elapsed cooling check time τ_{eC} can be resident in control unit 80, which is also configured to receive and store predetermined maximum cooling check time τ_C, as well as the pressure and/or flowrate detected or sampled at subsequent instants during step 120 of checking the flow of pressurized cooling air 2,3. Moreover, control unit 80 is also configured, upon receiving heating start signal 48, for disabling the electric supply signal and, in particular, to generate a related notification message.

[0080] With reference to Fig. 4, in a further modification of the method, a step 130 of checking the connection of a load to the apparatus, i.e., the presence of a metal body at hollow inductor winding 32 is provided. This check step 130 is preferably carried out before step 150 of supplying the working alternating current to inductor circuit 30. step 130 of checking the connection of a load includes a step 131 of supplying an alternating low-intensity test current to inductor circuit 30, i.e. an alternating current is supplied whose intensity is remarkably lower than the intensity of working alternating current. If the presence of a metal body at hollow inductor winding 32 is, the heating cycle is allowed to proceed by above-described step 150 of supplying the working alternating current to inductor circuit 30. On the contrary, if the above condition is not fulfilled, step 150 of supplying the working alternating current is blocked 133 and the heating cycle is stopped, and a related notify message is preferably emitted 134 by control unit 80.

[0081] With reference to Fig. 5, in a still further modification of the method, before starting step 150 of supplying the working alternating current to inductor circuit 30, a step 140 is performed of determining the frequency that this working alternating current will have, indicated as the working frequency. This frequency determination step 140 includes a step 141 of generating and supplying a trial current, whose intensity is lower than the intensity of the working current, and whose frequency is higher than an expected resonance frequency of the circuit connected to the terminals of generation unit 40, i.e. of the combination of inductor circuit 30 and of the metal body to be heated. A sequence of iterative steps follows of progressively decreasing 142 the frequency of the trial current, of measuring 143, at each frequency decrease, the phase shift between the intensity of the trial current and the corresponding voltage at the end of generation unit 40, and of comparing 144 the measured phase shift with a very small reference phase shift, in order to check whether the measured phase shift is practically zero. The iterations of the steps 142, 143, 144 are continued until this condition does not take place.

[0082] Once a zero-phase shift is detected, or a condition in which the frequency has a minimum admissible value is detected, the decrease 142 of the frequency of the trial current is discontinued, and the current frequency value is maintained, which is considered to be or to best approximate the searched resonance frequency. This frequency value is elected as the working frequency for the working alternating current. A step 145 of increasing the intensity of the supplied current is then carried out until the intensity becomes equal to the working intensity IL so as to start step 150 of supplying a working alternating current to inductor circuit 30 and, therefore, of supplying the predetermined required power.

[0083] In any case, the process of "tracking" the resonance frequency described above can be continued during the heating cycle.

[0084] With reference to Figs. 6-8, in an apparatus according to a preferred exemplary embodiment of the invention, elongated support 21 comprises an outer tubular element 22 and an inner tubular element 23 coaxial to each other, therefore elongated support 21 includes an annular outer lumen 25 and an annular inner lumen 26. Preferably, hollow inductor winding 32 pneumatically communicates with annular inner lumen 26, through an own first end portion, and with annular outer lumen 25 through an own second end portion opposite to the first end portion.

[0085] Inductor winding(s) 32 form(s) a magnetic field flux concentrator 31. The assembly including elongated support 21 and magnetic flux concentrator 31 is indicated as an induction tip 20 of portable induction heating device 1.

[0086] As shown in Fig. 8, in an exemplary embodiment, handpiece 10 comprises an outer tubular body 12 and a tubular inner body 13 coaxial to each other, in such a way that handpiece 10 includes an outer annular chamber 15 and an inner annular chamber 16. Outer annular chamber 15 encloses current transformer 50 comprising coils, not shown, arranged to form a ring structure coaxial to outer and inner tubular bodies 12,13. These coils are advantageously incorporated in a annular resin block. In particular, an annular gap 15' is defined between the outer surface of transformer 50 and the inner surface of outer tubular body 12 of handpiece 10.

[0087] Preferably, elongated support 21 and handpiece 10 are coassially mounted to each other, i.e. about a common longitudinal axis 9.

[0088] Preferably, annular gap 15' between transformer 50 and outer tubular body 12 pneumatically communicates with annular outer lumen 25 of elongated support 21 through an own first end portion, and has a second end portion communicating with a first pneumatic connection fitting 11 protruding from a lower base portion 10' of handpiece 10 opposite to an upper base portion 10" from which preferably extends elongated support 21, in particular, eccentrically with respect to common axis 9 of outer and inner tubular bodies 12,13. Preferably, the diameter of inner tubular body 13 is about the same as the diameter of inner tubular element 23 of elongated support 21. Moreover, inner tubular body 13 pneumatically communicates with inner tubular element 23 of elongated support 21 through an own first end portion, preferably also through an inner pneumatic connection fitting 19', whereas the opposite end has is provided with a pneumatic connection fitting 18, coaxially protruding from the same lower base portion 10' of handpiece 10.

[0089] As shown in Fig. 9, first pneumatic connection fitting 11 is preferably connected to pressurized cooling air source 4, whereas second pneumatic connection fitting 18 is connected to discharge device 5 of used cooling air 3, which is preferably equipped with a silencer device 65, and is normally open to atmosphere. Therefore, cooling flowpath 70 of pressurized cooling air 2,3 comprises, in the colling air flow direction, first pneumatic connection fitting 11, annular gap 15 of handpiece 10, annular outer lumen 25 of elongated support 21, an inner lumen of hollow inductor winding 32, annular inner lumen 26 of elongated support 21, inner annular chamber 16 of handpiece 10 and second pneumatic connection fitting 18.

[0090] An opening is also provided on handpiece 10, preferably in the form of a third connection fitting 19 to allow the passage of electric cables 49 connecting electric generation unit 40 and current transformer 50. Preferably, also third connection fitting 19 extends from lower base portion 10' of handpiece 10, preferably in a eccentric position like second pneumatic connection fitting 18, and is advantageously arranged parallel to first and second pneumatic connection fittings 11, 18.

[0091] Preferably, cables (not shown) connecting transformer 50 with hollow inductor winding 32 are arranged within annular inner lumen 26 of elongated support 21.

[0092] In particular, elongated support 21 is inserted into handpiece 10 through upper base portion 10" thereof, an airtight seal element being provided between elongated support 21 and upper base portion 10". A seal element 29 is also arranged between annular gap 15' of handpiece 10 and the assembly of inner tubular body 13 of handpiece 10 and outer tubular element 22 of elongated support 21.

[0093] With reference to Fig. 9, in an apparatus according to an exemplary embodiment of the invention, generation unit 40 comprises a driving electronics 42, and a power electronics 43.

[0094] Power electronics 43 is connected to current transformer 50 along connection conductors or cables 49 and respective resonating condensers 44.

[0095] The apparatus, as seen from power electronics 43, can be considered equivalent to a series resonating circuit that, at the above-mentioned resonance frequency, provides the minimum impedance at which power is supplied. The final step of power electronics 43 consists of a full bridge, not shown, works at a predetermined phase shift between conductors 49. Therefore, a measurement electronics 45 is provided along both conductors 49 is then present to measure the mesh currents of the circuit.

[0096] A hardware protection mechanism, not shown, for protecting the power supply components of the apparatus is operated if the intensity of the alternating working current exceeds an upper safety value, depending and set responsive to the use condition of the instrument. A protection firmware mechanism, not shown, is operated when the current intensity measured by an current intensity sensor 45 arranged along outlet conductor 49 of the bridge exceeds a predetermined threshold, defined according to the application. The same current intensity sensor 45 is used for adjusting the power supplied during normal operation of the apparatus.

[0097] Fig. 9 also shows cooling air feed and discharge unit 60, comprising in this case a solenoid valve 62 as a flow actuation device to allow/block the flow of pressurized cooling air 2 from a pressurized cooling air source 4 to cooling flowpath 70 of portable induction heating device 1 (Fig. 6). In this case, pressurized cooling air source 4 can be a compressed air network of a workshop or an industrial plant, or a compressed air reservoir. In an alternative exemplary embodiment, not shown, flow actuation device 62 can be a compressor. Regardless of the form of cooling air source 4 and of flow actuation device 62, cooling air feed and discharge unit 60 can comprise a pressure switch 63 to perform step 120 of checking the flow of pressurized cooling air 2,3, as described above.

[0098] During step 120 of checking the flow of pressurized cooling air 2,3, while solenoid valve 62 allows the flow of pressurized cooling air 2, the status of pressure switch 63 is continuously monitored. Control unit 80 is configured to receive a low-pressure signal from pressure switch 63 and to block step 150 of supplying the working alternating current upon receiving such a low-pressure signal. As anticipated, pressure switch 63 Is preferably mounted to the return portion of cooling flowpath 70. In this case, a low-pressure signal is generated by pressure switch 63 for any condition reducing the effectiveness of cooling flowpath 70 below an acceptable level, e.g. if compressed air 2 is missing at air source 4 and/or if solenoid valve 62 doesn't work properly and/or if an unacceptable air leakage or loss is present from cooling flowpath 70 in handpiece 10 elsewhere, or from cooling air feed and discharge unit 60, or if there is a problem of different nature such as an obstruction in the cooling flowpath 70 of pressurized cooling air 2,3 upstream of pressure switch 63.

[0099] In an advantageous modification of the method, during the operation of the apparatus and, in particular, during the heating cycle, a temperature control routine is provided in which the temperature of power electronics 43 and/or transformer 50 contained in handpiece 10 is measured and compared with a maximum admissible safety temperature T_s. If the temperature of power electronics 43 and/or transformer 50 becomes equal to or higher than maximum admissible safety temperature T_s, control unit 80 is configured to block the operation of the apparatus, and preferably to generate a related notify message as well.

[0100] More in detail, to this purpose, the apparatus comprises at least one temperature sensor, not shown, which can be arranged at handpiece 10 to detect the temperature close to current transformer 50, and/or elsewhere in the power electronics 43. The above-mentioned temperature control routine includes, in particular steps of detecting this temperature by the temperature sensor or sensors, comparing said temperature(s) with maximum admissible safety temperature T_s and, upon occurring a condition in which the temperature at power electronics 43 and/or at transformer 50 exceeds maximum admissible safety temperature T_s, discontinuing step 150 of supplying the working alternating current to inductor circuit 30, disabling start/stop drive element 41 and, preferably, generating a related notification message. In order to allow a restoration of the apparatus, the routine also comprises a step of comparing temperature at power electronics 43 and/or at transformer 50 with a predetermined re-enablement temperature lower than maximum admissible safety temperature T_s by a predetermined amount. Upon occurring a condition in which the temperature at power electronics 43 and/or at transformer 50 becomes lower than the re-enablement temperature, a step takes place of restoring start/stop drive element 41 and, preferably, of generating a related notification message.

[0101] Therefore, the machine returns fully operative when the temperature of the electronic has dropped below the maximum admissible safety temperature by a predetermined amount.

[0102] Preferably the maximum admissible safety temperature is set between 45°C and 65°C, more preferably between 50°C and 60°C.

[0103] The foregoing description of some exemplary specific embodiments will so fully reveal the invention according to the conceptual point of view, so that others, by applying current knowledge, will be able to modify and/or adapt in various applications the specific exemplary embodiments without further research and without parting from the invention, and, accordingly, it is meant that such adaptations and modifications will have to be considered as equivalent to the specific embodiments. The means and the materials to put into practice the different functions described herein could have a different nature without, for this reason, departing from the field of the invention. It is meant that the phraseology or terminology employed herein is for the purpose of description and not of limitation.

Claims

1. A method for performing an induction heating of a metal body, said method comprising a step of prearranging (100) an induction heating apparatus, the induction heating apparatus comprising:

- a hollow handle portion (10);

- an inductor circuit (30) wherein at least one hollow inductor winding (32) is arranged at an end portion of an elongated support (21) extending from said hollow handle portion (10);
- a cooling flowpath (70) defined within said hollow handle portion (10) and within said at least one hollow inductor winding (32);
- an electric generation unit (40) arranged for supplying an alternating current to said inductor circuit (30);
- a current transformer (50) between said electric generation unit (40) and said inductor circuit (30), said current transformer (50) arranged within said hollow handle portion (10); and
- a start/stop drive element (41) arranged to be operated by an operator and configured to generate a heating start/stop signal (48);

said method also comprising the steps of:

- defining (101) a maximum heating time (τ_H) per heating cycle, and a maximum inhibition time (τ_I)
- identifying (102) an electric power required for said induction heating; and
- starting (103) a heating cycle through said drive element (41);

said heating cycle comprising the steps of:

- conveying (110) a flow of a pressurized cooling air (2) at a predetermined pressure through said cooling flowpath (70);
- supplying (150) a working alternating current through said inductor circuit (30), said step of conveying (110) said flow of said pressurized cooling air (2) being continued during said step of supplying (150) said working alternating current;
- counting (160) an elapsed heating time (τ_{eH}) starting from when said step of supplying (150) said working alternating current begins;
- checking (161) a presence of said heating stop signal (48); and
- comparing (162) said elapsed heating time (τ_{eH}) with said maximum heating time (τ_H), wherein, upon occurring at least one condition selected between
- a condition in which said elapsed heating time (τ_{eH}) becomes equal to or longer than said maximum heating time (τ_H), and
- a condition in which said heating stop signal (48) is present,

steps are carried out of:

- discontinuing (168) said step of supplying (150) said working alternating current, and
- disabling (169) said drive element (41);

wherein further steps are provided of:

- counting (170) an elapsed inhibition time (τ_{eI}) since said step of discontinuing said step of supplying said working alternating current; and
- comparing (171) said elapsed inhibition time (τ_{eI}) with said maximum inhibition time (τ_I),

wherein, upon occurring a condition in which said elapsed inhibition time (τ_{eI}) becomes equal to or longer than said maximum inhibition time (τ_I), a step is carried out of restoring (178) said drive element (41); wherein said working alternating current has: a working frequency close to a resonance frequency of a combination of said inductor circuit (30) and of said metal body, and a working intensity suitable for providing said electric power through said at least one hollow inductor winding (32).

2. The method according to claim 1, wherein, upon occurring a condition in which said elapsed inhibition time (τ_{eI}) becomes equal to or longer than said maximum inhibition time (τ_I), a step is also carried out of:

- discontinuing (178) said step of conveying (110) said flow of said pressurized cooling air (2).

3. The method according to claim 1, wherein said maximum heating time (τ_H) per heating cycle is set between 10 and 30 seconds, in particular between 15 and 25 seconds, more in particular, said maximum heating time is about 20 seconds, and said maximum inhibition time (τ_I) is set between 40 and 80 seconds, in particular between 50 and 70 seconds, even more in particular, said maximum inhibition time is about 60 seconds.

4. The method according to claim 1, wherein, during said heating cycle, a step is carried out of checking (120) said flow of said pressurized cooling air (2), comprising the steps of:

- detecting (121) an air pressure or flowrate at a section of said cooling flowpath (70), in particular at an outlet (18) of said cooling flowpath,
- comparing (124) said pressure or flowrate with a respective minimum predetermined value;
- upon occurring a deficient flow condition, in which said pressure or flowrate is lower than said respective minimum value, discontinuing or blocking (125) said step of supplying (150) said working alternating current and, in particular, generating (126) a related notification message,

in particular, said step of checking (120) said flow of said pressurized cooling air is carried out immediately after said step of starting (103) said heating cycle, and steps are provided of:

- counting (121) a cooling check time since when said step of conveying (110) said flow of said pressurized cooling air (2) has started;
- comparing (124) said elapsed cooling check time with a predetermined maximum cooling check time (τ_C);

and said step of discontinuing or blocking (125) said step of supplying (150) said working alternating current is carried out upon occurring said deficient flow condition and a condition in which said elapsed cooling check time (τ_{eC}) becomes equal to or longer than said maximum cooling check time (τ_C), in particular, said maximum cooling check time (τ_C) is set between 3 and 10 seconds, more in particular, between 5 and 8 seconds.

5. The method according to claim 1, wherein said heating cycle also provides, before said step of supplying (150) said working alternating current, steps of:

- checking (130) a presence of said metal body at said hollow inductor winding (32) by supplying (131) a predetermined test current into said inductor circuit (30), said test current having a test intensity lower than said working intensity;
- upon occurring a condition in which said metal body is not present, blocking (133) said step of supplying (150) said working alternating current and, in particular, generating (134) a related notification message.

6. The method according to claim 1, wherein, before said step of supplying (150) said working alternating current, a step is provided (140) of determining said working frequency, comprising in turn steps of:

- supplying (141) a predetermined trial current into said inductor circuit (30), said trial current having an intensity lower than said working intensity and a trial frequency higher than an expected resonance frequency;
- progressively decreasing (142) said trial frequency; during said step of progressively decreasing said trial frequency,

- measuring (143) a phase shift between said trial current and a corresponding voltage applied to said inductor circuit (30);
- comparing (144) said phase shift with a maximum admissible phase shift;

upon occurring a condition selected between a condition in which said phase shift is lower than said maximum admissible phase shift and a condition in which a minimum admissible phase shift value is attained,
- discontinuing said step of progressively decreasing said trial frequency;
- increasing (145) said intensity of said trial current until said trial current reaches said working intensity, thus supplying said working current to said inductor circuit.

7. An apparatus for performing an induction heating of a metal body, said apparatus comprising:

- a hollow handle portion (10);
- an elongated support (21) extending from said hollow handle portion (10);
- an electric inductor circuit (30) comprising at least one hollow inductor winding (32) arranged at an end portion of said elongated support (21);
- a cooling flowpath (70) defined within said hollow handle portion (10) and within said at least one hollow inductor winding (32);
- an electric generation unit (40) arranged for supplying an alternating current to said inductor circuit (30);
- a current transformer (50) between said electric generation unit (40) and said inductor circuit (30), arranged within said hollow handle portion (10),
- a cooling air feed section (60), comprising a flow-actuation device (62) configured for causing/blocking a flow of a pressurized cooling air (2) from a pressurized cooling air source (4) into said cooling flowpath (70);
- a start/stop drive element (41) arranged to be operated by an operator and configured to generate a heating start/stop signal (48); and
- a control unit (80) configured for receiving said heating start/stop signal (48) from said drive element (41);

said control unit (80) being also configured for, upon receiving said heating start signal (48), transferring an opening signal (81) to said flow-actuation device (62) for conveying said flow of said pressurized cooling air (2,3) through said cooling flowpath (70), and for transferring an electric supply signal (83) to said electric generation unit (40) for supplying a working alternating current to said inductor circuit (30), said working alternating current having a working intensity suitable for determining a delivery of said electric power through said at least one hollow inductor winding (32);
characterized in that

said working alternating current has a working frequency close to a resonance frequency of a combination of said inductor circuit (30) and of said metal body;
said control unit being configured for:

- receiving a set value of a maximum heating time (τ_H) per heating cycle;
- receiving a set value of a maximum inhibition time (τ_I);
- counting an elapsed heating time (τ_{eH});
- checking a reception of said heating stop signal (48); and
- comparing said elapsed heating time (τ_{eH}) with said maximum heating time (τ_H);

said control unit (80) being also configured for, upon occurring at least one condition selected between a condition in which said elapsed heating time (τ_{eH}) becomes equal to or longer than said maximum heating time (τ_H) and a condition in which said heating stop signal (48) is received:

- transferring an electric supply interrupt signal (83) to said electric generation unit (40) for blocking said working alternating current;
- disabling said drive element (41);
- counting an elapsed inhibition time (τ_{eI}); and
- comparing said elapsed inhibition time with said maximum inhibition time (τ_I);

said control unit (80) being also configured for restoring said drive element (41) upon occurring a condition in which said elapsed inhibition time (τ_{eI}) becomes equal to or longer than said maximum inhibition time (τ_I).

8. The apparatus according to claim 7, wherein, upon occurring said condition in which said elapsed inhibition time (τ_{eI}) becomes equal to or longer than said maximum inhibition time (τ_I), said control unit (80) is also configured for:

   - transferring a closure signal (81) to said flow-actuation device (62) for discontinuing said flow of said pressurized cooling air (2).

9. The apparatus according to claim 7, also comprising a sensor configured to work as an instrument selected between a pressure switch (63) and a flow switch, said sensor (63) arranged along said cooling flowpath (70), in particular at an outlet (18) of said cooling flowpath, said sensor (63) configured to transfer an alarm signal to said control unit (80), said alarm signal selected between a low-pressure signal and a low-air flowrate signal in said cooling flowpath (70), respectively, and
said control unit (80) is also configured for:

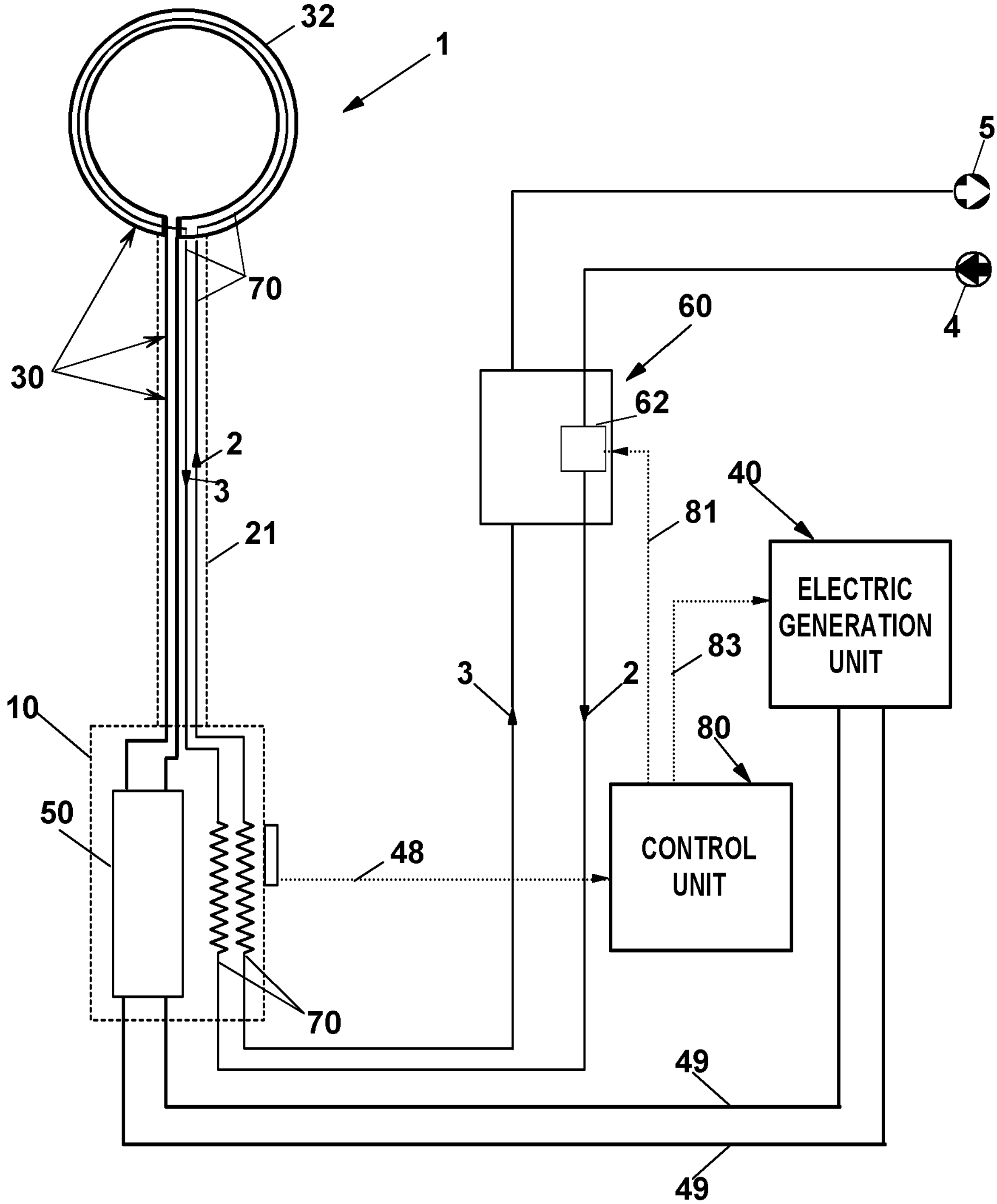
   - checking a presence of said alarm signal;
   - in the presence of said alarm signal, disabling said electric supply signal (83) and, in particular, generating a related notification message.

10. The apparatus according to claim 9, wherein said control unit (80) is also configured, upon receiving said heating start signal (48), for:

   - counting an elapsed cooling check time (τ_{eC}) since when said heating start signal (48) is received;
   - comparing said elapsed cooling check time (τ_{eC}) with a predetermined maximum cooling check time (τ_C);
   - upon occurring of both said deficient flow condition and a condition in which said elapsed cooling check time (τ_{eC}) becomes equal to or longer than said maximum cooling check time (τ_C), disabling said electric supply signal (83) and, in particular, generating a related notification message,

   in particular, said maximum cooling check time (τ_C) is set between 3 and 10 seconds, more in particular, between 5 and 8 seconds.

Fig. 1


32
1
5
70
4
30
60
62
2
3
40
21
81
ELECTRIC
GENERATION
UNIT
3
2
83
10
80
50
CONTROL
UNIT
48
70
49
49

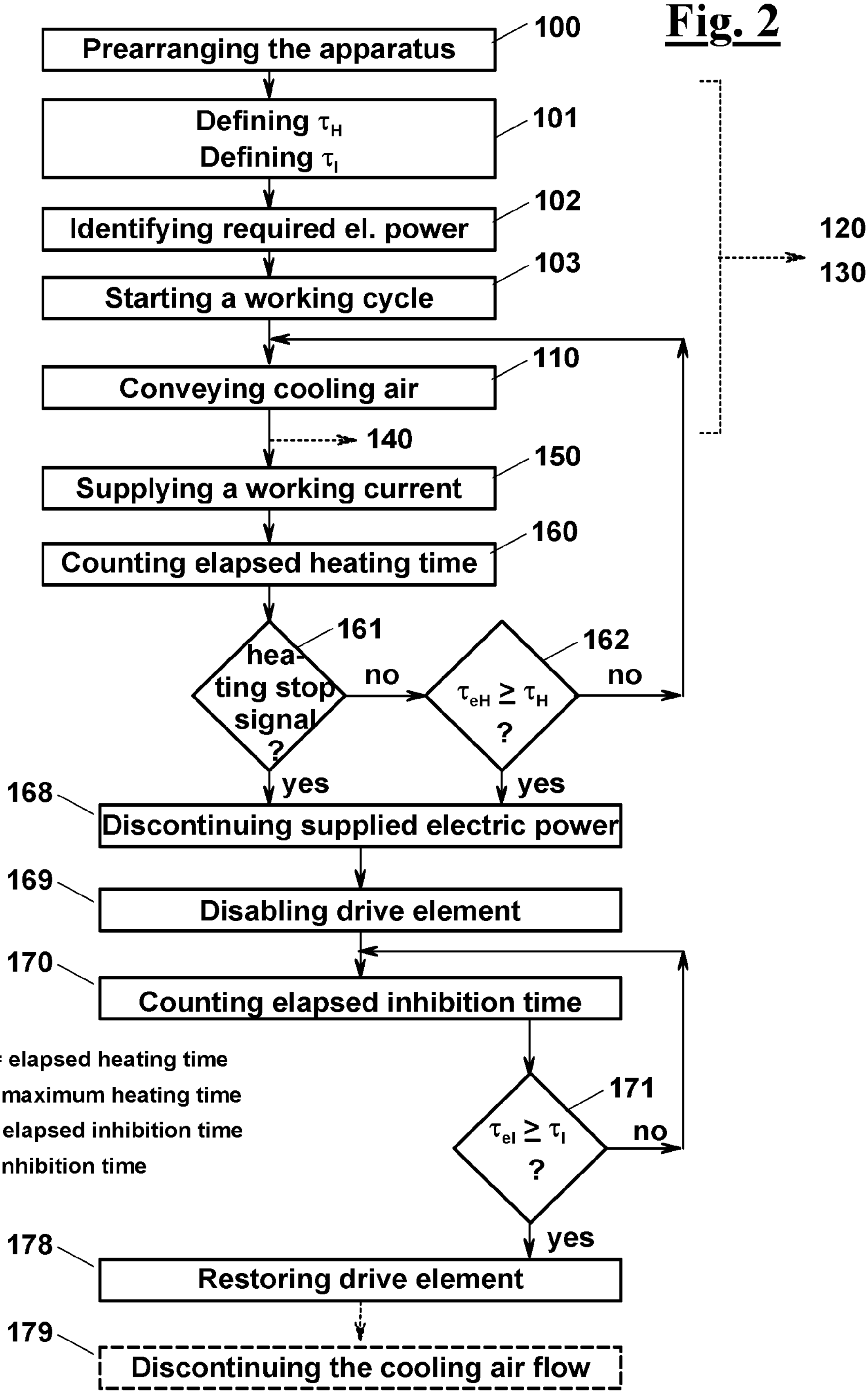
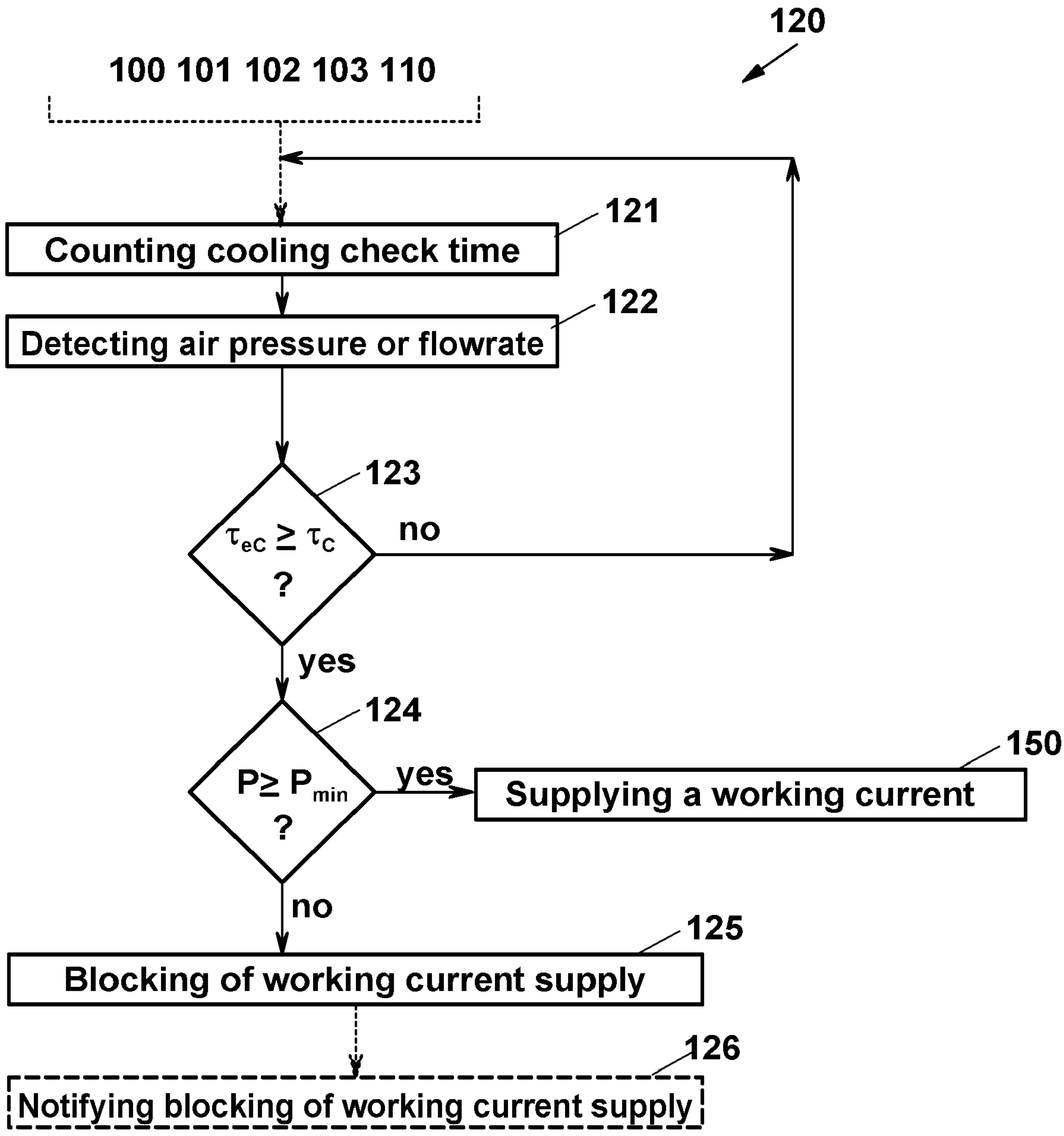


Fig. 2

τ_{eH} = elapsed heating time
τ_H = maximum heating time
τ_{eI} = elapsed inhibition time
τ_I = inhibition time

Fig. 3



τ_{eC} = elapsed cooling check time

τ_C = maximum cooling check time

P = pressure in the cooling flowpath

P_{min} = minimum pressure in the cooling flowpath

Fig. 4

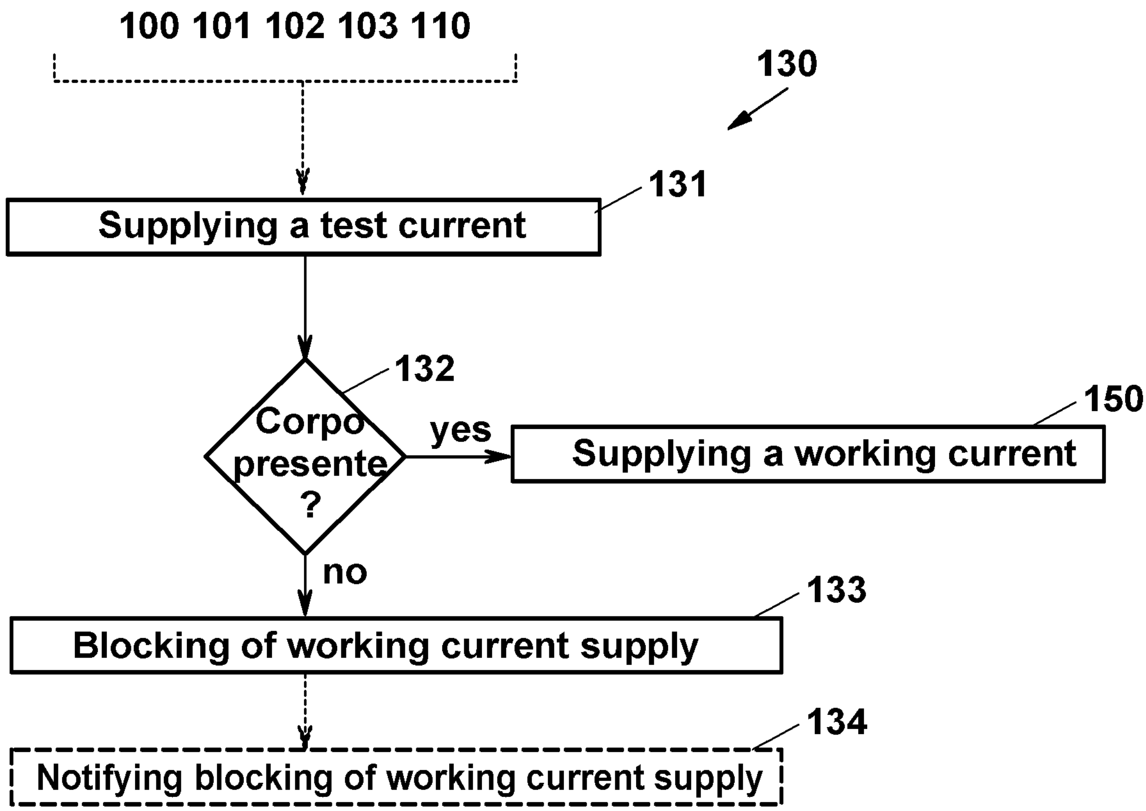

100 101 102 103 110
130
131
Supplying a test current
132
Corpo presente ?
yes
150
Supplying a working current
no
133
Blocking of working current supply
134
Notifying blocking of working current supply

Fig. 5

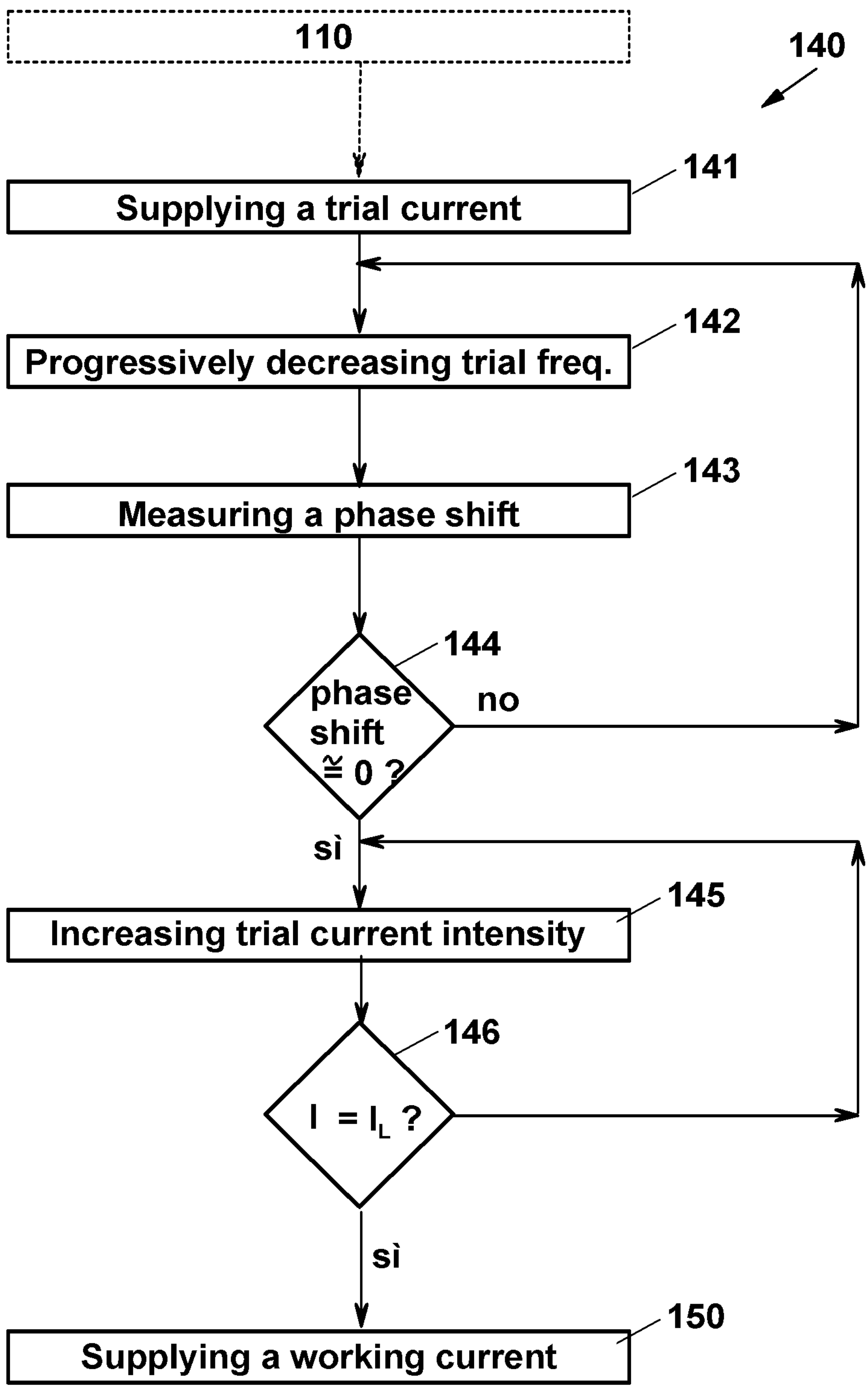

110
140
141
Supplying a trial current
142
Progressively decreasing trial freq.
143
Measuring a phase shift
144
phase shift ≅ 0 ?
no
sì
145
Increasing trial current intensity
146
$I = I_L$?
sì
150
Supplying a working current

Fig. 6

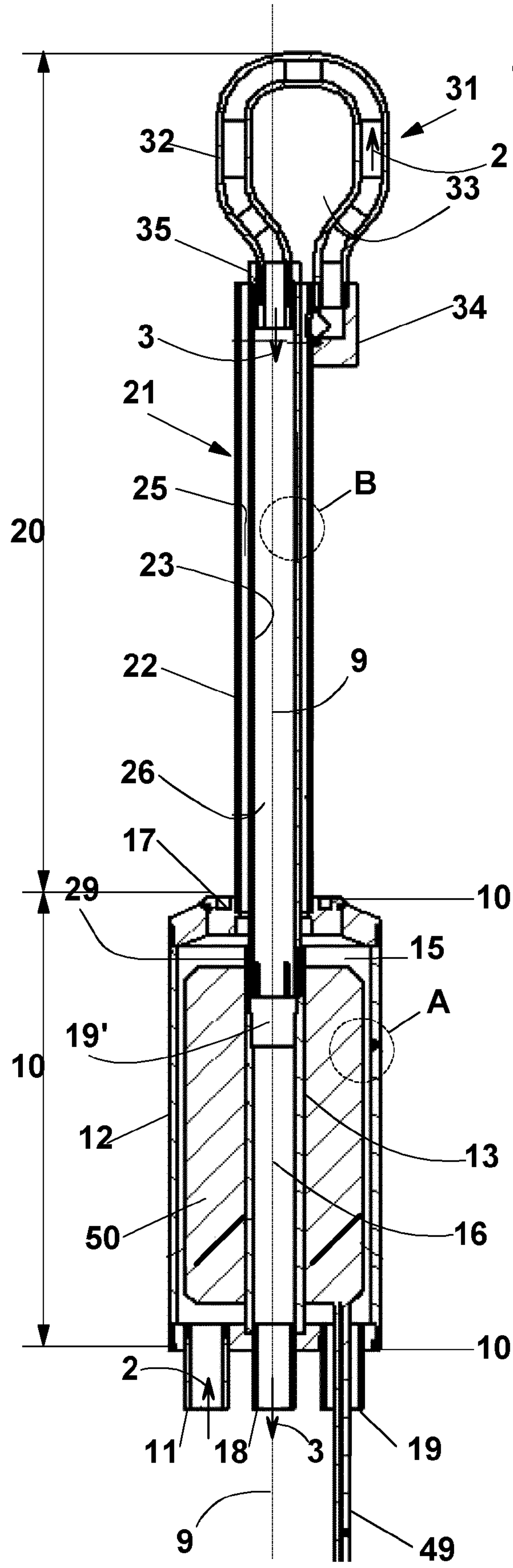


Fig. 7

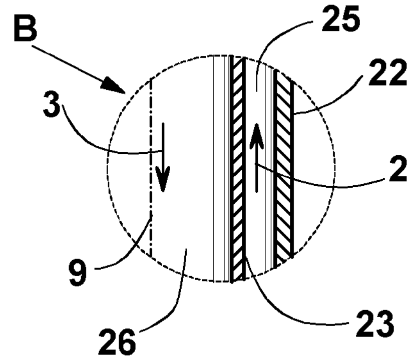


Fig. 8

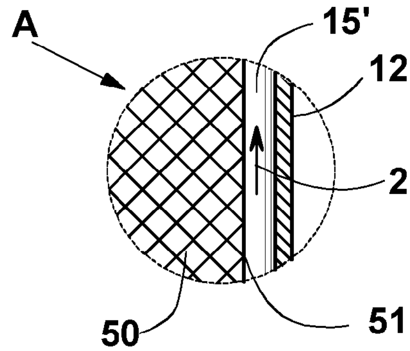


Fig. 9

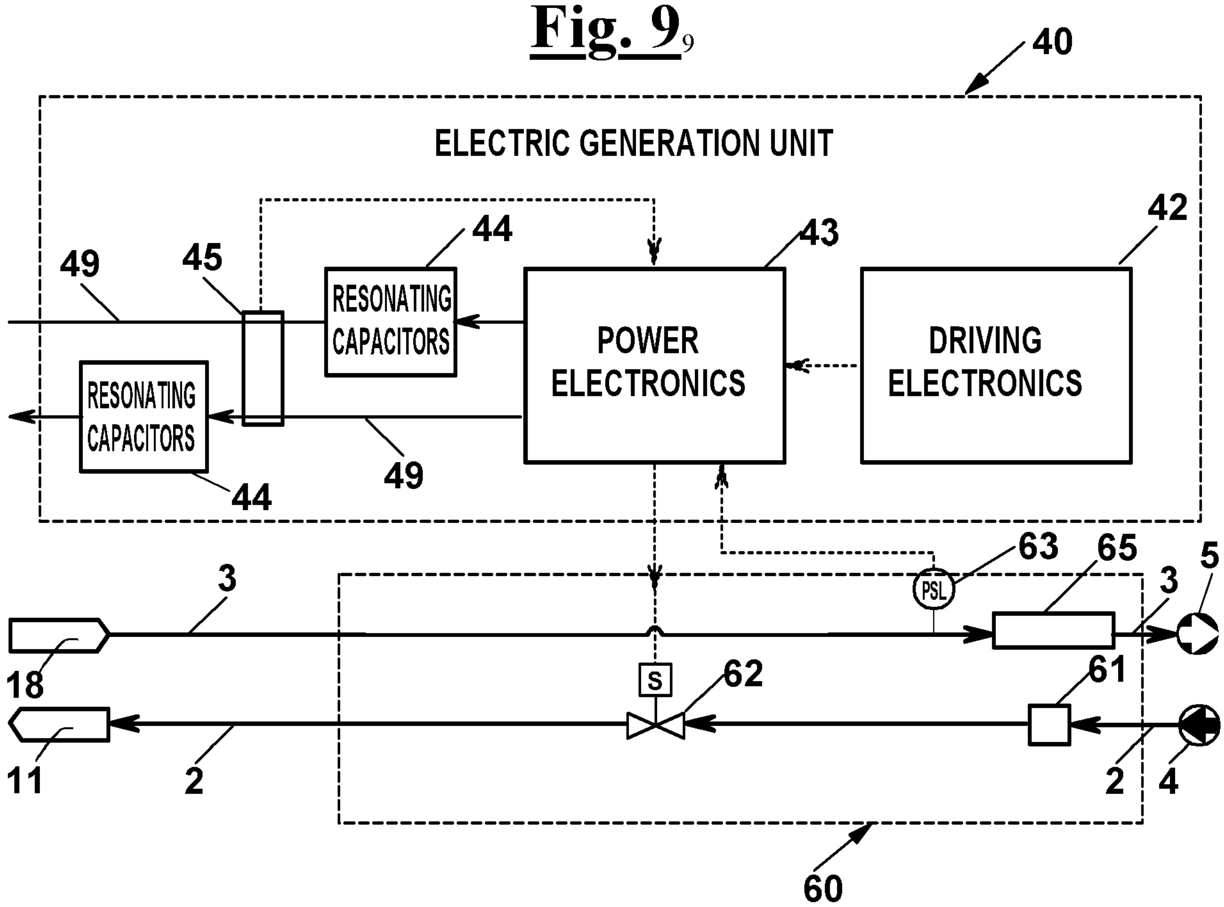

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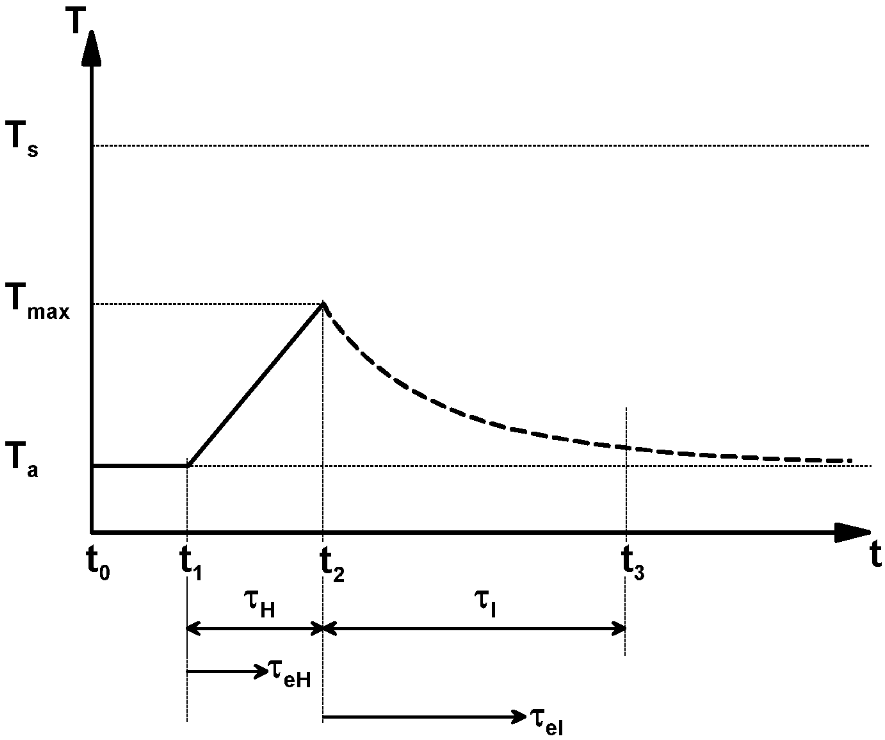
Fig. 10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EUROPEAN SEARCH REPORT

Application Number
EP 22 17 7698

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A	US 2012/248093 A1 (ULRICH MARK ANDREW [US] ET AL) 4 October 2012 (2012-10-04) * paragraphs [0020], [0026], [0028]; figures 1,3 * -----	1-10	INV. H05B6/10 H05B6/42 H05B6/06
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H05B

The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
Munich	13 October 2022	Garcia Congosto, M

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