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(54) Title: CONTROLLING THE TEMPERATURE OF A MOVING ELEMENT

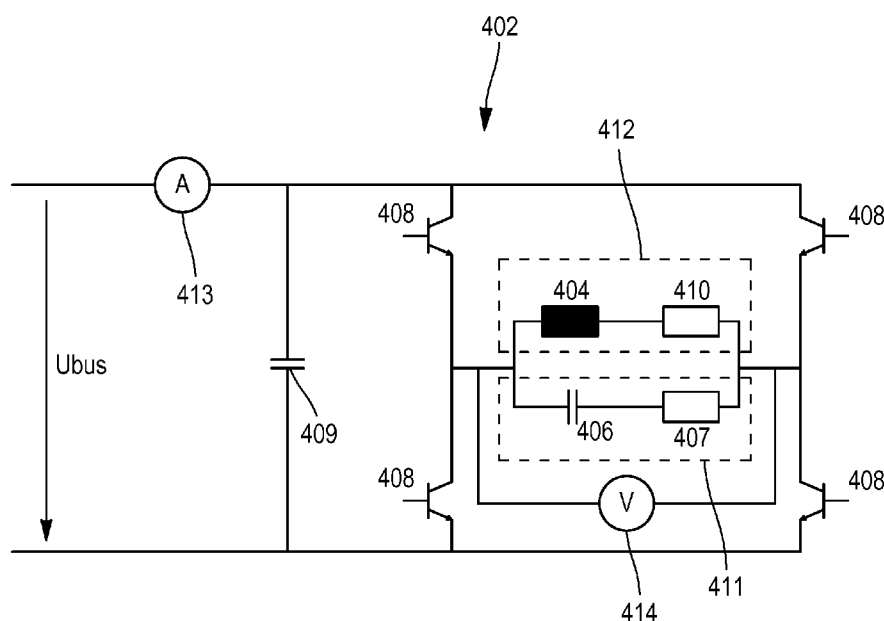


FIG. 3

(57) Abstract: The invention relates to a method for heating and controlling the temperature of a moving element which has properties of an electrical conductor. The method comprises the step of providing a heating circuit (402) comprising an induction coil (412) and a capacitor (411), connected in parallel and forming a resonant circuit. The heating circuit (402) is supplied with a continuous supply voltage (Ubus). The current consumed by the power supply of the heating circuit (402) is measured, and the power supplied by the power supply of the heating circuit (402) is calculated. The temperature of the element is estimated, and the temperature of the element is controlled at a predetermined setpoint temperature.





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CONTROLLING THE TEMPERATURE OF A MOVING ELEMENT

TECHNICAL FIELD

- 5 The invention relates in a general way to a method and a system for controlling the temperature of an element to be heated, for a moving element having properties of an electrical conductor.

CONTEXT

- 10 Heating may be generated by wrapping a heating coil that is supplied with alternating current. This type of heating, known as “induction heating”, is known for the heating of elements having properties of electrical conductors. When the electrical conductor is manufactured, its properties are determined by the conductive material chosen, including metallic materials (such as steel, copper,
15 aluminium, carbon fibre, etc.). The properties of each conductive material are known (for example, relative permeability is found from the inductance at the coil), and therefore an element having properties of an electrical conductor also has these properties. In the remainder of the description, the terms “element” and “element having properties of an electrical conductor” are used interchangeably.
20 An “element” or an “element having properties of an electrical conductor” could include a metal wire, as is known.

- In induction heating processes, the temperature of an element is measured and monitored. For an element which moves during heating, the temperature of the element must be measured and maintained at a stable value for a predetermined
25 time. By means of the induction heating of the element and the measurement of the absorbed power, the element may be used to estimate and control its own temperature.

SUMMARY

- 30 The invention relates to a method for heating and controlling the temperature of a moving element which has properties of an electrical conductor. The method comprises the following steps: providing a heating circuit comprising an induction coil and a capacitor connected in parallel and forming a resonant circuit; supplying the heating circuit with a continuous supply voltage; measuring

the current consumed by the power supply to the heating circuit; calculating the power supplied by the heating circuit power supply; estimating the temperature of the element; and controlling the temperature of the element at a predetermined setpoint temperature.

- 5 The power corresponding to the measurement of the current consumed by the heating circuit power supply represents the electrical power consumed for heating the element.

 In some embodiments, the step of controlling the temperature of the element comprises the step of establishing a control period in order to make the
10 temperature of the element dependent on the predetermined setpoint temperature. In some embodiments, this control period is established every 100 ms.

 In some embodiments, the method also comprises the step of varying a heating time which is calculated during the control period.

 In some embodiments, the continuous supply voltage is split by transistors
15 so as to form an alternating voltage at the terminals of the induction coil and the capacitor. The voltage applied to the induction coil is sinusoidal.

 In some embodiments, the method also comprises the step of driving the element at a predetermined constant speed while passing the element through the inside of the induction coil.

20 The invention also relates to a system for controlling the temperature of moving elements having properties of electrical conductors. The system comprises a heating installation which executes a method as described.

 The invention also relates to an element formed by this system.

 Other aspects of the present invention will become apparent from the
25 following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

 The nature and the various advantages of the present invention will be more readily understood upon reading the following detailed description, together with
30 the attached drawings, in which the same reference numerals denote identical parts throughout, and in which:

 Figure 1 shows a schematic view of an embodiment of a system for heating a moving wire having properties of an electrical conductor.

 Figure 2 shows an embodiment of the induction coil of the heating system

of Figure 1.

Figure 3 shows an embodiment of a heating circuit which comprises the induction coil of Figure 2 and a capacitor, and which is used to heat a wire and to measure its temperature.

5

DETAILED DESCRIPTION

With reference now to the figures, in which the same numbers denote identical items, Figure 1 shows an embodiment of a system 10 comprising a series of installations which can be used to heat a wire in continuous movement at
10 constant speed (for example, in the direction of the arrow A of Figure 1) so that the wire has the desired properties at its exit from the installation. The wire could be moving in other systems which are not shown.

The system 10 comprises an unwinding and adjustment installation 100 which carries out processes of unwinding and adjusting a wire 50. The wire 50
15 comprises a conductive material so that the wire is an element having properties of an electrical conductor. The wire 50 may be a metal wire having a small diameter (for example, a diameter of about 0.2 mm to 1 mm).

The wire 50 is supplied on a wire bobbin 110 at the installation 100. This wire may be round or of a simple shape (for example, square, oval, rectangular,
20 etc.) to ensure that the heating is uniform. At the installation 100, a tension controller 120 controls a constant unwinding tension for the wire 50. The wire bobbin 110 and the tension controller 120 may be selected from various devices available on the market, and the unwinding and adjustment processes are known to those skilled in the art.

25 After leaving the unwinding and adjustment installation 100, the wire 50 is transported to a heating installation 400 which enables the temperature of the wire to be raised to an appropriate value for the desired properties of the wire upon leaving the installation. At the heating installation 400, the wire 50 travels at high speed, and is heated by induction heating.

30 With reference to Figures 2 and 3, the induction heating consists of an electronic control card supplying an induction coil 412 and a capacitor 411. The temperature of the wire 50 is increased by means of the induction coil 412 placed around the wire 50. The electrical conductivity and resistance of the material of the wire 50 depend on the temperature. The resistance of the material may be

calculated from the electrical conductivity, given that resistance and conductivity are inversely proportional.

When the induction coil 412, through which the wire 50 to be heated passes, is supplied with an electric current, it creates a magnetic field. This magnetic field induces eddy currents in the metal wire 50. It is the Joule effect, due to the eddy currents, that is responsible for increasing the temperature of the object to be heated (that is to say the wire 50).

The electrical power consumed to heat an element which is a cylinder of material may be described thus:

$$P = \pi \cdot d \cdot h \cdot H^2 \cdot \sqrt{\pi \cdot \rho \cdot \mu_0 \cdot \mu_r \cdot f} \cdot C \cdot F$$

where:

- d: Diameter of the cylinder [m]
- h: Height of the cylinder [m]
- H: Magnetic flux intensity [A/m]
- ρ: Resistivity [Ω.m] of the conductive material of the element
- μ₀: Magnetic permeability of a vacuum (4π.10⁻⁷ H/m)
- μ_r: Relative permeability of the conductive material of the element
- f: Frequency [Hz]
- C: Coupling factor which decreases with the length of the inductance
- F: Power transmission factor

It will be noted that the heating power depends on the resistance of the cross section of the element to be heated (that is to say the wire 50).

Figure 3 shows the electrical circuit diagram of the induction furnace represented by a heating circuit 402. The heating circuit 402 is supplied with a continuous supply voltage (U_{bus}). The continuous supply voltage is then split by transistors 408 so as to form an alternating voltage at the terminals of the coil 412 (that is to say an ideal inductor 404 and an inductor resistance 410) and the capacitor 411 (that is to say an ideal capacitor 406 and a capacitor resistance 407), and this voltage is measured by a voltage measurement (V) 414. Although the supply voltage of the heating circuit is continuous, that of the coil is alternating and has a frequency close to the resonance frequency.

The supply voltage of the induction furnace is controlled by the electronic card, and its amplitude is therefore known. The power supplied by the heating may therefore be ascertained by measuring the current flowing through the circuit,

using a current sensor (see the current measurement (A) 413 in Figure 3) and multiplying this current by the amplitude of the supply voltage of the heating circuit. Setting a frequency close to the resonance frequency minimizes the power that is supplied.

5 This is because, primarily, the power supply of the induction furnace only has to compensate for the losses of the system. These losses are mainly eddy current losses in the element to be heated. Eddy current losses depend on the resistance of the wire to be heated, which increases with an increase in its temperature. When the temperature of the wire is increased, the losses, and
10 consequently the power to be provided by the power supply, also increase.

By measuring the power supplied by heating, we can therefore ascertain the temperature of the wire 50 by correspondence. By appropriate control, therefore, the temperature of the wire 50 can be regulated precisely, in order to avoid degrading the mechanical properties of the wire, for example.

15 The heating circuit 402 is constantly supplied with a continuous voltage (Ubus). During a first heating phase, the coil (412) and the capacitor (411) are supplied, for a predetermined time, with a sinusoidal voltage obtained by splitting the continuous voltage by means of the transistors 408. This time is predetermined by the heating controller, and depends, among other things, on the temperature
20 error (between the setpoint and the measurement). During this phase, the current consumed by the heating circuit 402 is measured. Since the supply voltage (Ubus) of the heating circuit (412) is known, we can deduce from this the power consumed by the heating circuit, from which the temperature of the wire 50 can therefore be deduced.

25 The power supply to the induction coil 412 and the capacitor 411 is then switched off. After this switch-off, the part of the heating circuit 402 that comprises an inductance-capacitor circuit (412 and 411) continues to oscillate at the resonance frequency of the circuit. It is at this moment that the resonance frequency is measured by the voltage measurement 414, mainly for the purpose of
30 process control.

Finally, when the temperature of the wire is known, a controller determines the heating time for a control period, in order to make the temperature of the wire 50 dependent on the setpoint temperature. In one embodiment, a control period is established every 100 ms. The value of the control period may be different;

additionally, in the case cited here, the heating time varies between 5 and 95 ms. In another embodiment, the control period is established every 250 ms, and the heating time varies between 5 and 245 ms. If a different control period is selected, the heating time will vary.

5 The temperature of the wire 50 is controlled by varying the heating time calculated by the controller during the control period (for example, the heating time calculated by the controller every 100 ms, every 250 ms, etc.). The wire 50 (or a portion of wire considered here) enters the coil 412 with a temperature equal to the ambient temperature. Each portion of wire considered here moves forwards
10 into the coil 412, and each portion undergoes heating. At the exit 412b from the coil 412, the temperature of the wire 50 has reached the setpoint temperature.

 The temperature is maintained over the whole length of the wire, or for the time required by the method. In all the control periods (every 100 ms, for example), the temperature controller calculates the heating time, which will be
15 dependent on the temperature error. In some embodiments, the method passes through a plurality of control periods, with a different heating time and a decreasing temperature error on each occasion. Control takes place throughout, and the temperature is maintained throughout. A small amount of heating is provided if the temperature is close to the setpoint, and more heating is provided if the
20 temperature is a long way from the setpoint.

 The speed of travel must be constant to enable the temperature to be measured. The geometry of the wire 50 must also be constant; that is to say, the cross section of the wire must be constant along its length. The electrical resistivity and the magnetic permeability of the wire 50 must be stable for a given
25 temperature.

 With reference to Figure 1 again, a wire 50 is driven by a drive installation 500 which drives the wire 50 at a given constant speed. In some embodiments, the wire may move at a speed of about 5 m/min. In some embodiments, the deposition method enables deposition to take place at a speed of advance of the wire varying
30 from several metres per minute up to 100 m/min. The drive installation 500 may be selected from a variety of devices available on the market.

 The drive installation 500 transports the wire 50 from the heating installation 400 (where it passes through the induction coil 412 in the direction of the arrow A) to a rewinding and adjustment installation 600. The rewinding and

adjustment installation 600 carries out a process of rewinding and adjusting the tension of the wire 50 that is fed to a receiving bobbin 610 of the installation 600. At the installation 600, a tension controller 620 controls a constant rewinding tension for the wire 50. The receiving bobbin 610 and the tension controller 620
5 may be selected from various commercially available devices. The rewinding and adjustment processes are known to those skilled in the art.

One or more sensors and/or types of sensors may be used if necessary, including, but not limited to, environmental sensors (for detecting atmospheric conditions such as the temperature, pressure and/or humidity during the execution
10 of the method, for example) and verification sensors (for detecting a deviation from a specified property, for example). Thus the invention makes it possible to treat a wide variety of elements according to the product to be manufactured.

At least some of the various techniques may be used in association with hardware or software, or with a combination of these where justified. As used here,
15 the term “method” or “procedure” may cover one or more steps executed at least by an apparatus which is electronic or based on a computer having a processor with the function of carrying out instructions which execute the steps.

The terms “at least one” and “one or more” are used interchangeably. The ranges described as being located “between a and b” incorporate the values of “a”
20 and “b”.

Although particular embodiments of the disclosed apparatus have been illustrated and described, it is to be understood that various changes, additions and modifications may be made without departure from the spirit or scope of the present description. It follows that no limitation is to be placed on the scope of the
25 invention described, except for those stated in the attached claims.

CLAIMS

1. A method for heating and controlling the temperature of a moving element having properties of an electrical conductor, wherein the method comprises the following steps:
 - 5 providing a heating circuit (402) comprising an induction coil (412) and a capacitor (411), connected in parallel and forming a resonant circuit;
supplying the heating circuit (402) with a continuous supply voltage (U_{bus});
measuring the current consumed by the power supply of the heating circuit
10 (402);
calculating the power supplied by the power supply of the heating circuit (402);
estimating the temperature of the element; and
controlling the temperature of the element at a predetermined setpoint
15 temperature.
2. A method according to claim 1, wherein the power corresponding to the measurement of the current consumed by the power supply of the heating circuit (402) represents the electrical power consumed for heating the element.
20
3. A method according to claim 1 or claim 2, wherein the step of controlling the temperature of the element comprises the step of establishing a control period in order to make the temperature of the element dependent on the predetermined setpoint temperature.
25
4. A method according to claim 3, wherein the control period is established every 100 ms.
5. A method according to claim 3 or claim 4, further comprising the step
30 of varying a heating time which is calculated during the control period.
6. A method according to any of claims 1 to 5, wherein the continuous supply voltage (U_{bus}) is split by transistors (408) so as to form an alternating voltage at the terminals of the induction coil (412) and the capacitor (411), and the

voltage applied to the induction coil (412) is sinusoidal.

7. A method according to any of claims 1 to 6, further comprising the step of driving the element at a predetermined constant speed while passing the
5 element through the inside of the induction coil (412).

8. A system for controlling the temperature of moving elements having properties of electrical conductors, comprising a heating installation (400) that executes a method according to any of claims 1 to 7.
10

9. A system according to claim 8, further comprising:
an unwinding and adjustment installation (100) that carries out processes of unwinding and adjusting an element having properties of an electrical conductor;
15 a drive system (500) which drives the element at a given constant speed; and
a rewinding and adjustment installation (600) which carries out a process of rewinding and adjusting the tension of the element.

- 20 10. An element formed by a system according to claim 8 or claim 9.

11. An element according to claim 10, comprising a metal wire (50).

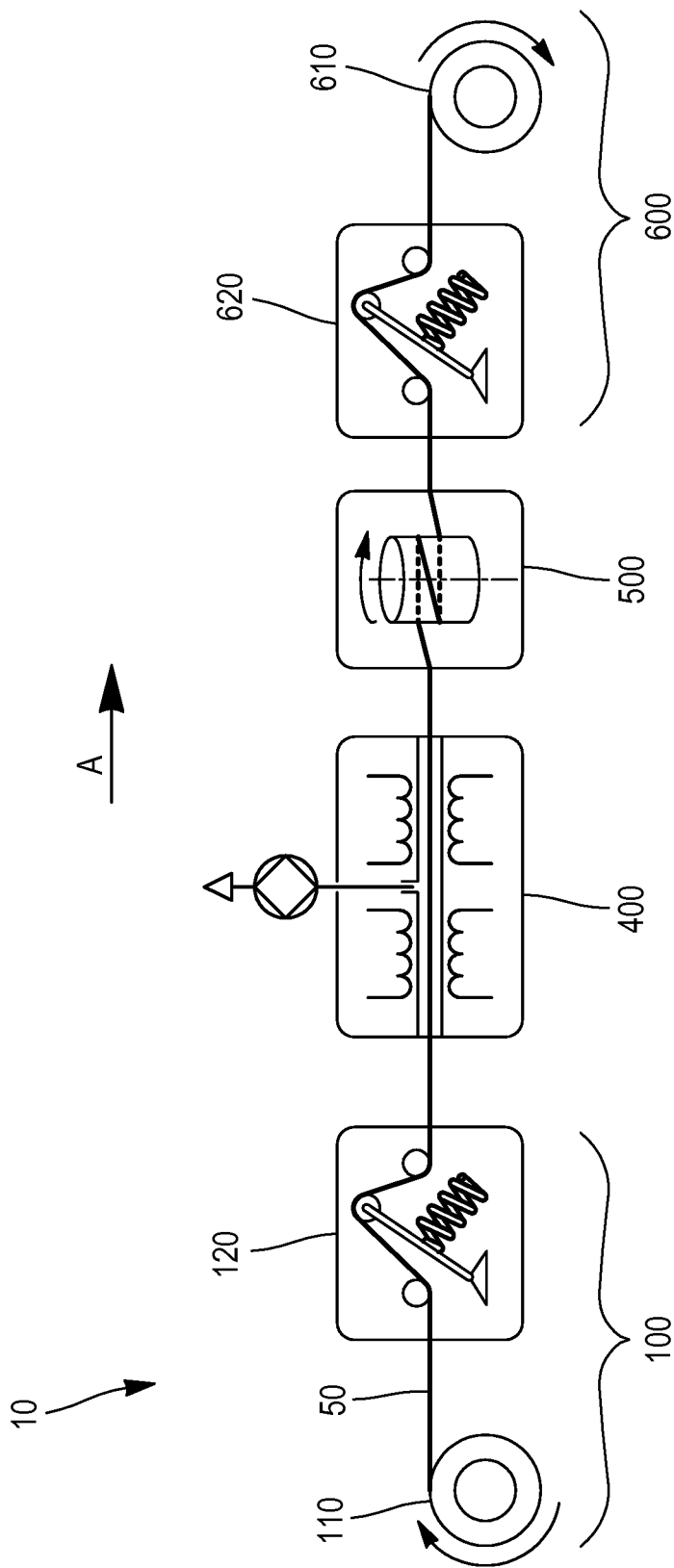


FIG. 1

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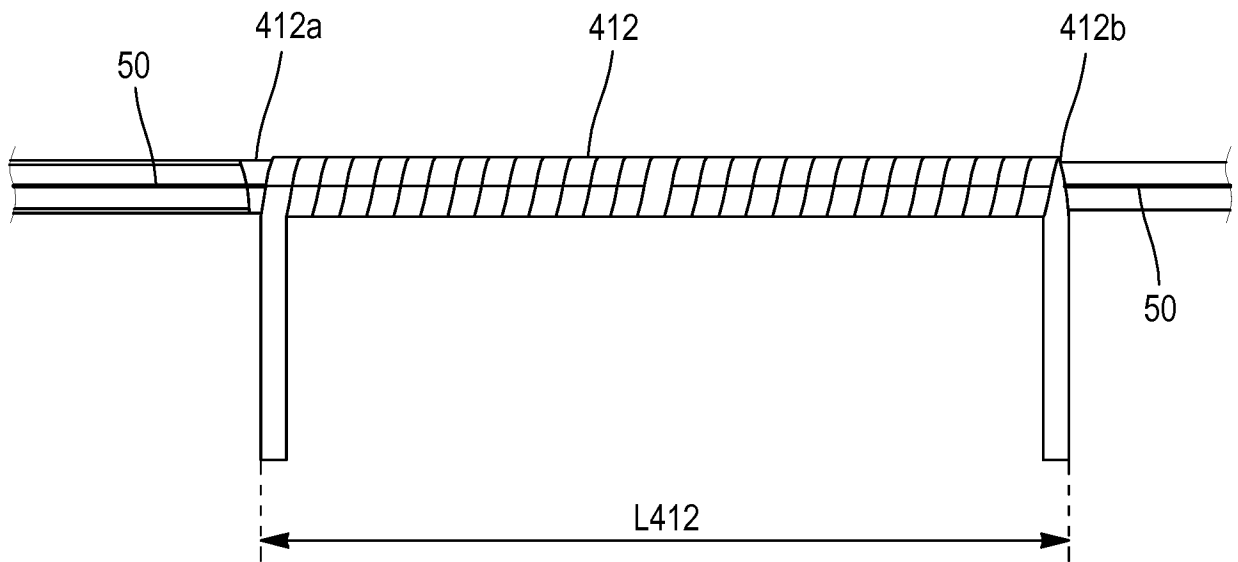


FIG. 2

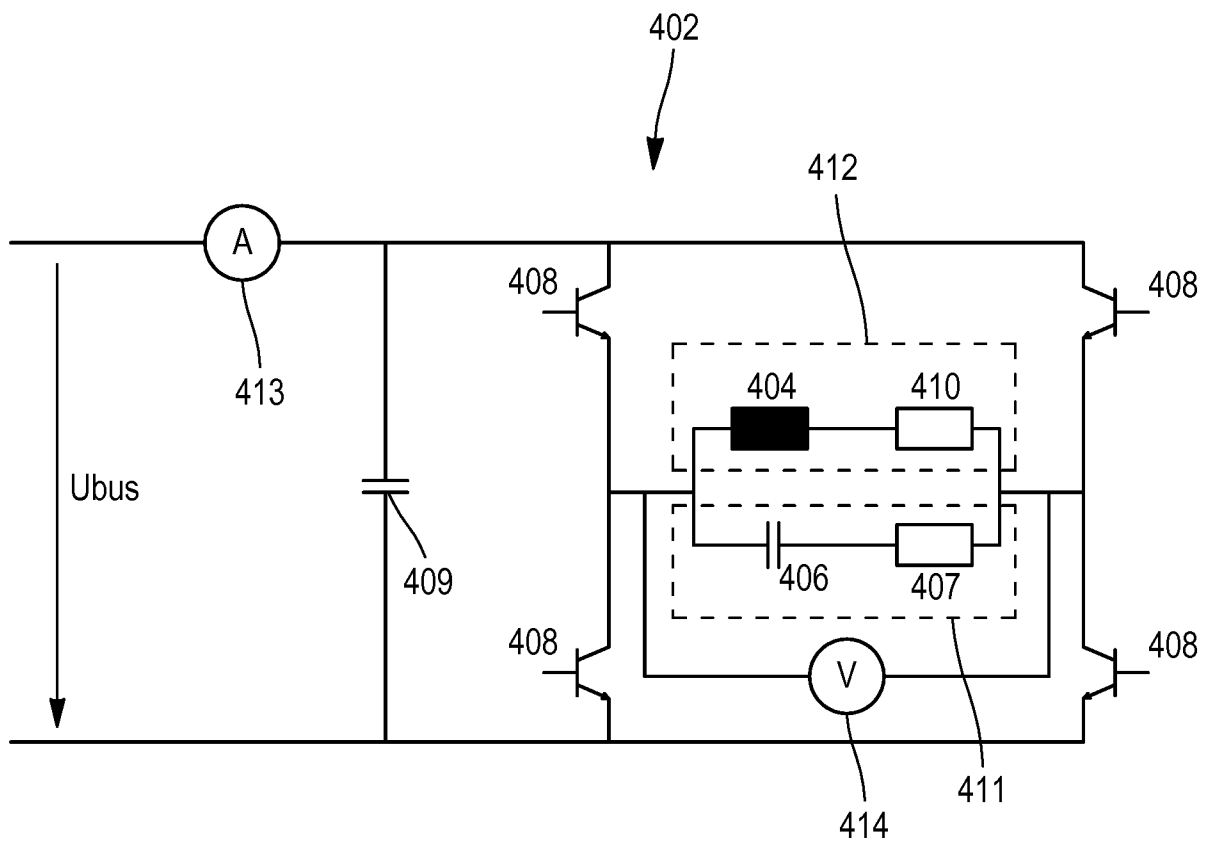


FIG. 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/076904

A. CLASSIFICATION OF SUBJECT MATTER
INV. H05B6/06 H05B6/10
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H05B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	US 4 845 332 A (JANCOSSEK DAVID G [US] ET AL) 4 July 1989 (1989-07-04) column 10, line 27 - line 55; figure 1A -----	1-11
Y	DE 10 2013 108963 A1 (RITTER ELEKTRONIK GMBH [DE]) 26 February 2015 (2015-02-26) claim 1; figures 1,2 -----	1-11
Y	DE 10 2010 051559 A1 (ERDMANN WOLFGANG [DE]) 22 March 2012 (2012-03-22) claim 1; figures 1,2 ----- -/-	1-11



Further documents are listed in the continuation of Box C.



See patent family annex.

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Name and mailing address of the ISA/

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/076904

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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