(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 487 832 A2**

(12) EUROPEAN PATENT APPLICATION

(21) Application number: **91113800.6**

(51) Int. Cl.^{5}: **H05B 6/06**, H05B 6/02

(22) Date of filing: **16.08.91**

(30) Priority: **30.11.90 JP 337069/90**

(43) Date of publication of application: **03.06.92 Bulletin 92/23**

(84) Designated Contracting States: **AT DE FR GB IT SE**

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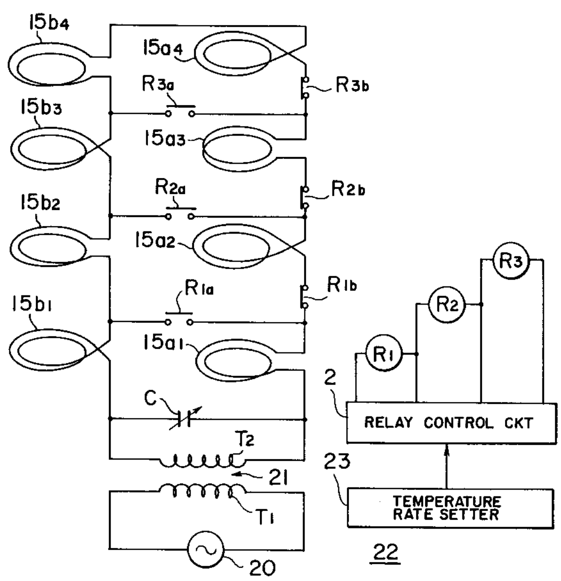
(54) Electromagnetic induction heater capable of realizing a wide variety of heating rates.

(57) In an electromagnetic induction heater for use in heating, by electromagnetic induction, a strip which is transported in a predetermined direction, a plurality of coil elements (15a,b) are selectively supplied from a power source (20) or sources with currents under control of a power controller (22). The power controller (22) has a plurality of relays (R1,R2,R3) which are selectively operable under control of a relay control circuit (2) and which have contacts (R1a...R3b) connected to the coil elements (15a,b). With this structure, the coil elements (15a,b) are selectively energized to locally generate magnetic fields, which serves to realize a wide variety of heating rates.

F I G. 3



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This invention relates to an electromagnetic induction heater for heating a strip by the use of electromagnetic induction.

In general, a conventional electromagnetic induction heater of the type described is helpful to heat a strip which is continuously fed from a feeder or the like at a predetermined speed in a predetermined direction, namely, a transport direction and which has a pair of principal surfaces. The strip may be conductive. Specifically, the conventional electromagnetic induction heater comprises a pair of heater units which are faced to both the principal surfaces with spaces left therebetween. Each of the heater units comprises a magnetic pole block which is juxtaposed to the strip and which is divisible into a plurality of subunits along the predetermined direction. A plurality of coil elements are wound around the subunits, respectively, and connected to a current source to cause electric current to flow through the coil elements to generate magnetic fields.

With this structure, it is possible to vary a heating rate by changing an amount of each current of the coil elements. This means that a heating rate can be varied in consideration of a material of the strip by changing the current supplied to the coil elements. In this event, all the currents are simultaneously changed and are caused to flow through all of the coil elements.

However, it has found out that variation of such a heating rate is restricted to a narrow range by only changing the current of each coil element. Accordingly, the conventional electromagnetic induction heater is not suitable for heating a wide variety of materials of the strips.

It is an object of this invention to provide an electromagnetic induction heater which is suitable for heating a wide variety of materials of a strip.

It is another object of this invention to provide an electromagnetic induction heater of the type described, which is capable of widely changing a heating rate of each strip.

An electromagnetic induction heater to which this invention is applicable is for use in heating, by electromagnetic induction, a strip which is fed in a predetermined direction. The strip has a pair of principal surfaces. The electromagnetic induction heater comprises a heater unit which is faced to a selected one of the principal surfaces. According to this invention, the heater unit comprises a magnetic pole block juxtaposed to the strip and divisible along the predetermined direction into a plurality of subunits each of which is located along the predetermined direction, a plurality of coil elements wound around the subunits, and current feeding means connected to the coil elements for selectively feeding current to the coil elements to make the subunits selectively generate magnetic fields.

The invention is described in detail in connection with the drawings in which:

Fig. 1 is a perspective view of an electromagnetic induction heater to which this invention is applicable;

Fig. 2 is a partial sectional view of the electromagnetic induction heater illustrated in Fig. 1;

Fig. 3 is a circuit diagram for use in describing an electromagnetic induction heater according to a first embodiment of this invention; and

Fig. 4 is a circuit diagram for use in describing an electromagnetic induction heater according to a second embodiment of this invention.

Referring to Fig. 1, an electromagnetic induction heater to which this invention is applicable is for use in heating a strip 11 or plate by electromagnetic induction. In the example being illustrated, the strip 11 is continuously transported at a predetermined speed in a predetermined direction, namely, a transport direction. The transport direction is directed downwards of Fig. 1, as shown by an arrowhead A in Fig. 1. The strip has first and second principal surfaces directed forwards and backwards of Fig. 1, respectively.

The electromagnetic induction heater comprises first and second magnetic pole blocks 121 and 122 juxtaposed to the first and the second principal surfaces with spaces left therebetween. Each of the first and the second magnetic pole blocks 121 and 122 has a plurality of magnetic pole segments 13 which are arranged in parallel to one another along the transport direction and which are extended along the transport direction. Each of the magnetic pole segments 13 has a plurality of grooves 14 which are adjacent to each of the first and the second principal surfaces of the strip 11 and which are extended along the transverse direction. As a result, each of the first and the second magnetic pole blocks 121 and 122 is divided along the transport direction into a plurality of subunits, namely, sub-pole blocks by the grooves 14. As a result, the subunits are arranged in parallel to one another in a direction transverse to the transport direction.

Referring to Fig. 2 together with Fig. 1, first and second coil elements 15a and 15b are wound around the subunits of the first and the second magnetic pole blocks 121 and 122 by embedding each coil element 15a and 15b into the grooves 14. In the example, the first coil elements 15a are depicted at $15a_1$ to $15a_4$ while the second coil elements 15b are depicted at $15b_1$ to $15b_4$. In this connection, the first and the second coil elements 15a and 15b and the subunits define, along the transport direction A of Fig. 2, first, second, third, and fourth heating zone lengths L1 to L4 which are gradually expanded with an increase of the zone length numbers. For example, the second, the third, and the fourth zone lengths L2 to L4 become equal to two times, third times, and fourth times the first zone length L1, respectively.

Referring to Fig. 3 together with Figs. 1 and 2, currents are caused to flow through the first and the second coil elements 15a and 15b in a manner to be described later in detail. To this end, the first and the second coil elements 15a and 15b are coupled to an a.c. power source 20 through a transformer 21 and an electric circuit which will be mentioned in detail. The transformer 21 has a primary winding T1 connected to the a.c. power source 20 and a secondary winding T2 connected to the electric circuit.

The illustrated electric circuit comprises a capacitor C connected in parallel to the secondary winding T2, the first coil elements 15a are connected in series to a point of connection between the secondary winding T2 and the capacitor C through normally-closed contacts R1b, R2b, and R3b to form a first series circuit. In this event, the first coil elements 15a are connected so that the current flows through two coil elements $15a_1$ and $15a_3$ in a direction inverse to the current flowing through the remaining coil elements $15a_2$ and $15a_4$.

On the other hand, the second coil elements 15b are also connected in series to another point of connection between the secondary winding T2 and the capacitor C to form a second series circuit. Like in the first series circuit, the second coil elements 15b are connected so that the current flows through two coil elements $15b_1$ and $15b_3$ in a direction inverse to the current flowing through the remaining coil elements $15b_2$ and $15b_4$. In addition, the first and the second series circuits are connected in series to each other, as illustrated in Fig. 3.

Furthermore, the coil elements $15a_1$ and $15b_1$ are connected to each other through a first normally-opened contact R1a. Likewise, the coil elements $15a_2$ and $15b_2$ and the coil elements $15a_3$ and $15b_3$ are connected to each other through second and third normally-opened contacts R2a and R3a, respectively.

With this structure, coil pairs of the first and the second coil elements that are opposite to each other through the strip 11 cause the current to flow therethrough in inverse directions, as understood from the above description.

Further referring to Fig. 3, the contacts, such as R1a, R1b, are controlled by a power controller 22. The power controller 22 comprises a temperature rate setter 23 for setting a temperature rate on heating the strip 11, a relay controller 24 connected to the temperature rate setter 23, and first, second, and third relays R1, R2, and R3 selectively energized by the relay controller 24. The first relay R1 has the first normally-opened contact R1a and the first normally-closed contact R1b while the second relay R2 has the second normally-opened contact R2a and the second normally-closed contact R2b. Likewise, the third relay R3 has the third normally-opened contact R3a and the normally-closed contact R3b.

At first, the temperature rate is determined in consideration of a material of the strip 11 and set in the temperature rate setter 23. The temperature rate is sent to the relay control circuit 24 to select the first through the third relays R1 to R3.

Herein, it is noted that the illustrated heater can vary the temperature rate over four stages from a lowest temperature stage to a highest temperature stage, as will become clear. More specifically, when the lowest temperature stage is set in the temperature rate setter 23, the relay control circuit 24 energizes the first relay R1 to open the first normally-closed contact R1b and to close the first normally-opened contact R1a. Therefore, an a.c. current flows through the coil elements $15a_1$ and $15b_1$ from the secondary winding T2 of the transformer 21. This shows that the strip 11 is heated only in the first zone depicted at L1 in Fig. 2. In this event, the temperature rate which is given by HR is represented by:

$$HR = \Delta T \cdot V/L1, \qquad (1)$$

where ΔT is representative of a heating rate within a unit zone; and V, velocity of the strip.

On the other hand, when the second relay R2 is selected and energized by the relay control circuit 24 in accordance with the temperature rate set in the temperature rate setter 23, the second normally-closed contact R2b is opened while the second normally-opened contact R2a is closed. With this structure, the current flows through the coil elements $15a_1$, $15a_2$, $15b_2$, and $15b_1$ from the secondary winding T2 of the transformer 21. Accordingly, the strip 11 is heated over the first and the second zones depicted at L1 and L2 in Fig. 2. Inasmuch as L2 is equal to 2L1, as mentioned above, the temperature rate HR is represented by:

$$HR = 1/2(\Delta T \cdot V/L1). \qquad (2)$$

Likewise, when the third relay R3 is selected and energized by the relay control circuit 24, the third normally-closed contact R3b is opened while the third normally-opened contact R3a is closed. Therefore, the current flows through the coil elements $15a_1$, $15a_2$, $15a_3$, $15b_3$, $15b_2$, and $15b_1$ to heat the strip 11 over the first through the third zones depicted at L1 to L3 in Fig. 2. In this case, the temperature rate HR is given by:

$$HR = 1/3(\Delta T \cdot V/L1). \qquad (3)$$

In addition, when none of the relays R1 to R3 is selected, the current flows through the coil elements $15a_1$ to $15a_4$ and $15b_4$ to $15b_1$ to heat the strip 11 over the first through the fourth zones depicted at L1 to L4 in Fig. 2. The temperature rate HR is given by:

$$HR = 1/4(\Delta T \bullet V/L1). \qquad (4)$$

From comparison of Equations (1) through (4), it is readily understood that the temperature rate HR can be varied over the four stages and that an optimum temperature rate can be obtained in consideration of the materials of the strip 11 even when the a.c. current and a frequency of the power source 20 is kept unchanged. This means that a wide variety of materials can be heated by the illustrated heater.

Referring to Fig. 4, an electromagnetic induction heater according to a second embodiment of this invention comprises first and second a.c. power sources 201 and 202 for supplying a.c. currents to first and second transformers 211 and 212 coupled to the first and the second a.c. power sources 201 and 202, respectively. The first a.c. power source 201 is connected to a primary winding T1 of the first transformer 211 which has a secondary winding T2 connected in parallel to a first variable capacitor C. The second a.c. power source 202 is connected to a primary winding T1' of the second transformer 212 which has a secondary winding T2' connected in parallel to a second variable capacitor C'.

In addition, the illustrated electromagnetic induction heater comprises a power controller 22a which comprises a temperature rate setter 23a and a relay control circuit 24a like in Fig. 3. The illustrated relay control circuit 24a serves to control first and second subsidiary relays depicted at R4 and R5, respectively.

In the example being illustrated, four of the first coil elements $15a_1$ to $15a_4$ are divided into a first group of the coil elements $15a_1$ and $15a_2$ and a second group of the coil elements $15a_3$ and $15a_4$. Likewise, four of the second coil elements $15b_1$ to $15b_4$ are also divided into a first group of the coil elements $15b_1$ and $15b_2$ and a second group of the coil elements $15b_3$ and $15b_4$.

The coil elements $15a_1$, $15a_2$, $15b_1$, and $15b_2$ are connected in series to the secondary winding T2 of the first transformer 211 with a first normally-closed contact R4b of the first subsidiary relay R4 interposed between the coil elements $15a_1$ and $15a_2$. The coil elements $15a_1$ and $15b_1$ are connected through a first normally-opened contact R4a of the first subsidiary relay R4.

On the other hand, the coil elements $15a_3$, $15a_4$, $15b_3$, and $15b_4$ are connected in series to one another with a second normally-closed contact R5b of the second subsidiary relay R5 while the coil elements $15a_3$ and $15b_3$ are connected through a second normally-opened contact R5a of the second subsidiary relay R5.

In the illustrated example, let the first subsidiary relay R4 be selected and energized by the temperature rate setter 23a and the relay control circuit 24a to open the first normally-closed contact R4b and to close the first normally-opened contact R4a. As a result, a current is caused to flow through the coil elements $15a_1$ and $15b_1$ from the first a.c. power source 201 via the first transformer 211. When the second subsidiary relay R5 is not energized during energization of the first subsidiary relay R4, a current is supplied from the second a.c. power source 202 through the second transformer 212 to the coil elements connected to the second transformer 212 and is caused to flow through the coil elements $15a_3$, $15a_4$, $15b_4$, and $15b_1$.

On the other hand, when the second subsidiary relay R5 alone is selected to be energized with the first subsidiary relay R4 not selected, the second normally-closed contact R5b is opened while the second normally-opened contact R5a is closed. In this event, a current is caused to flow through the coil elements $15a_3$ and $15b_3$. In addition, the first a.c. power source 201 supplies a current through the first transformer 211 to the coil elements $15a_1$, $15a_2$, $15b_2$, and $15b_1$. Consequently, magnetic fields are generated from the coil elements $15a_3$, $15b_3$, $15a_1$, $15b_1$, $15a_2$, and $15b_2$ to heat the strip at the third zone depicted at L3 in Fig. 2.

In addition, when both the first and the second subsidiary relays R4 and R5 are selected and energized under control of the temperature rate setter 23a and the relay controller 24a, the first and the second normally-closed contacts R4b and R5b are opened while the first and the second normally-opened contacts R4a and R5a are closed. As a result, a current is caused to flow through the coil elements $15a_1$ and $15b_1$ from the first a.c. power source 201 and through the coil elements $15a_3$ and $15b_3$ from the second a.c. power source 202. Therefore, the strip is heated under the coil elements $15a_1$, $15b_1$, $15a_3$, and $15b_3$.

Moreover, when neither the first subsidiary relay R4 nor the second subsidiary relay R5 is selected by the relay control circuit 24a, all the coil elements $15a_1$ to $15a_4$ and $15b_1$ to $15b_4$ are energized by causing the currents to flow therethrough from the first and the second a.c. power sources 201 and 202.

Alternatively, the first and the second a.c. power sources 201 and 202 may be turned on or off by switches (not shown) connected in series to the sources 201 and 202.

At any rate, combinations of the coil elements can be voluntarily selected by selecting combinations of the relays R4 and R5 and/or combinations of the power sources 201 and 202.

When the coil elements are selectively supplied with the current from a plurality of power sources, as mentioned with reference to Fig. 4, it is possible to vary electric power over a wide range and to reduce a power level in each of the power sources. This shows that the heating rate can be widely changed on the strip.

While this invention has thus far been described in conjunction with a few embodiments thereof, it will readily be possible for those skilled in the art to put this invention into practice in various other manners. For example, the coil elements may be controlled by electronic switches or the like instead of the relays and the contacts.

Claims

1. An electromagnetic induction heater for use in heating, by electromagnetic induction, a strip which is fed in a predetermined direction, said strip having a pair of principal surfaces, said electromagnetic induction heater comprising a heater unit which is faced to a selected one of said principal surfaces and which comprises:

a magnetic pole block juxtaposed to said strip and divisible along said predetermined direction into a plurality of subunits which are arranged in parallel to one another in a direction transverse to said predetermined direction;

a plurality of coil elements wound around said subunits; and

current feeding means connected to said coil elements for selectively feeding current to said coil elements to make said subunits selectively generate magnetic fields.

2. An electromagnetic induction heater as claimed in Claim 1, wherein said current feeding means comprises:

a single power source for generating said current;

current delivery means coupled to said single power source and said coil elements for selectively delivering said current to said coil elements; and

control means for controlling said current delivery means to make said current delivery means selectively deliver said current to said coil elements.

3. An electromagnetic induction heater as claimed in Claim 1, wherein said current feeding means comprises:

a plurality of power sources for generating said current;

first current delivering means coupled to selected ones of said coil elements and a selected one of said power sources for selectively delivering said current of said selected one of the power sources to said selected ones of the coil elements; and

second current delivering means coupled to the remaining coil elements and the remaining power sources for selectively delivering the current of the remaining power sources to the remaining coil elements.

4. An electromagnetic induction heater as claimed in any of claims 1 to 3, wherein said magnetic pole block comprises:

a plurality of magnetic pole segments arranged in parallel to one another along said predetermined direction with said subunits arranged in parallel to one another in said direction transverse to said predetermined direction.

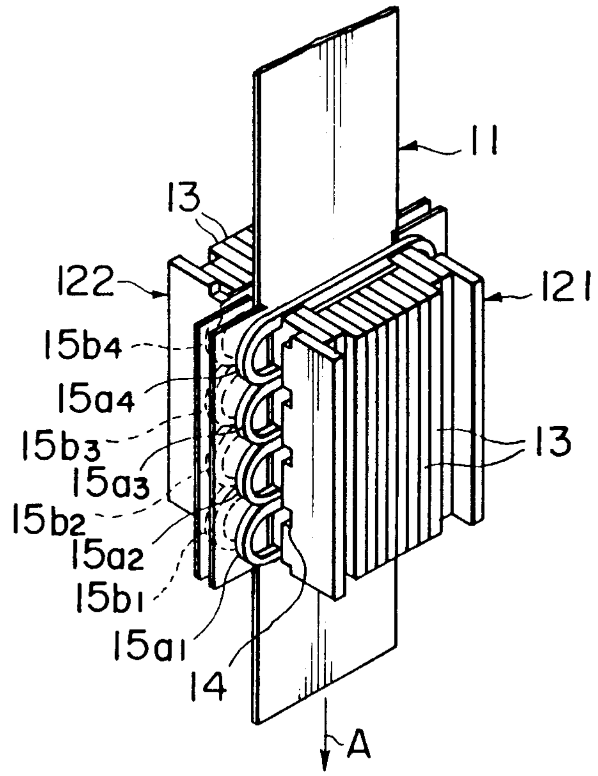
5. An electromagnetic induction heater for use in heating, by electromagnetic induction, a strip which is fed at a predetermined speed in a predetermined direction, said strip having a pair of principal surfaces, said electromagnetic induction heater comprising a pair of heater units which are faced to said principal surfaces, respectively, each of said heater units comprising:

a magnetic pole block juxtaposed to said strip and divisible along said predetermined direction into a plurality of subunits which are arranged in parallel to one another in a direction transverse to said predetermined direction;

a plurality of coil elements wound around said subunits; and

current feeding means connected to said coil elements for selectively feeding current to said coil elements to make said subunits selectively generate magnetic fields.

F I G. 1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13
122
121
15b4
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15b3
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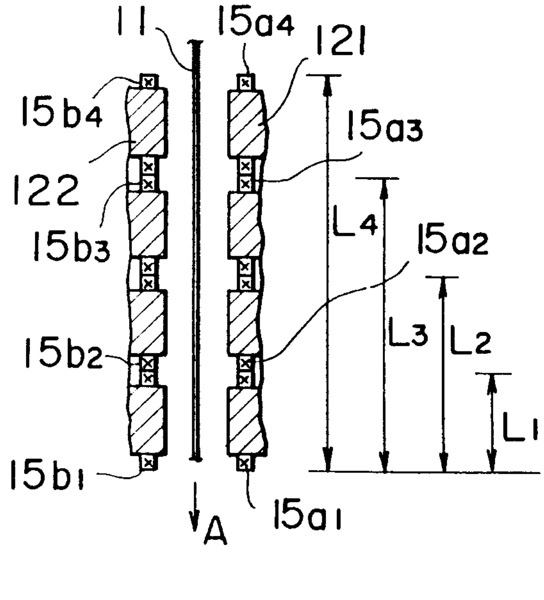
15a1
14
13
A

F I G. 2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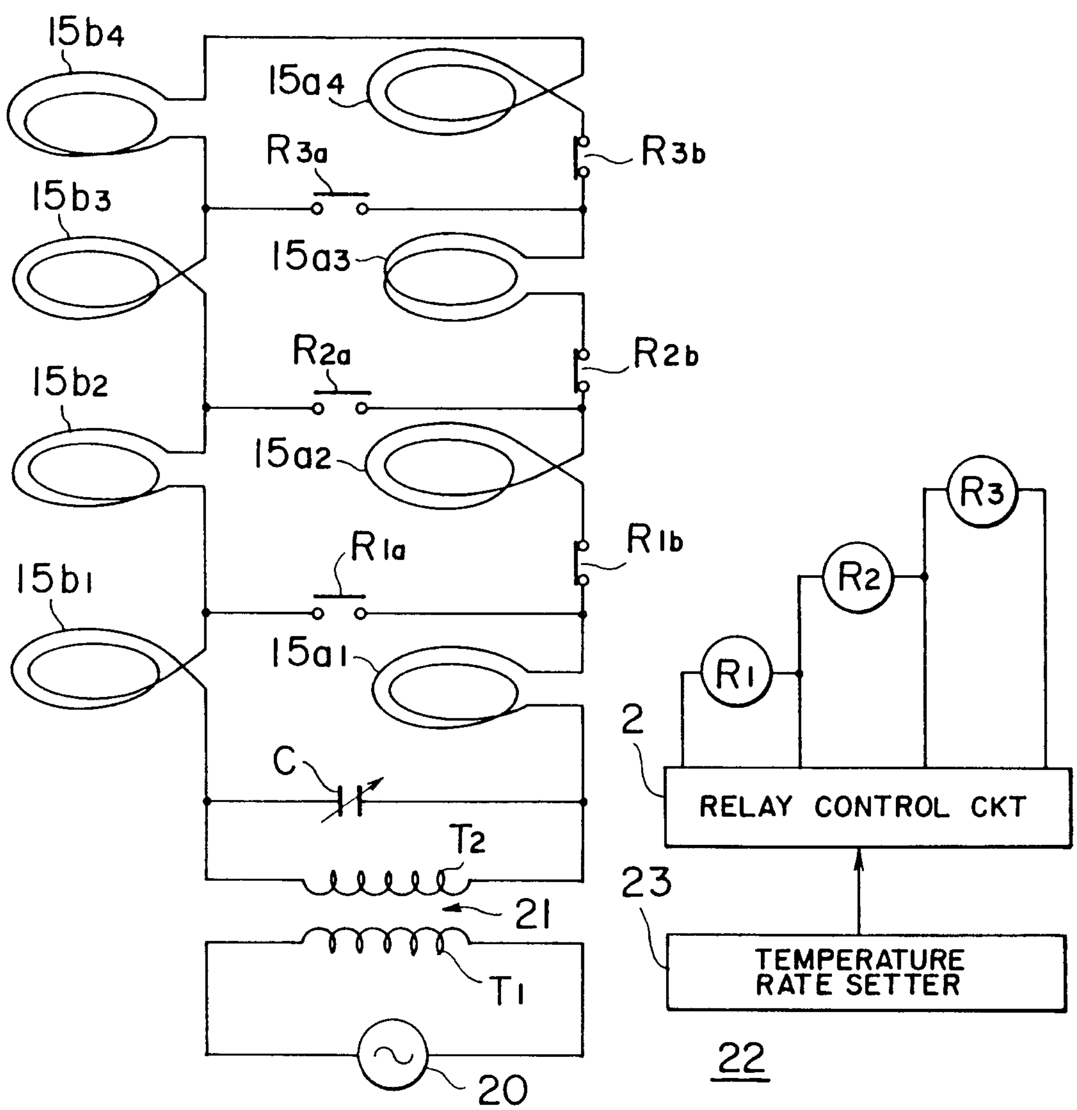
15a1

F I G. 3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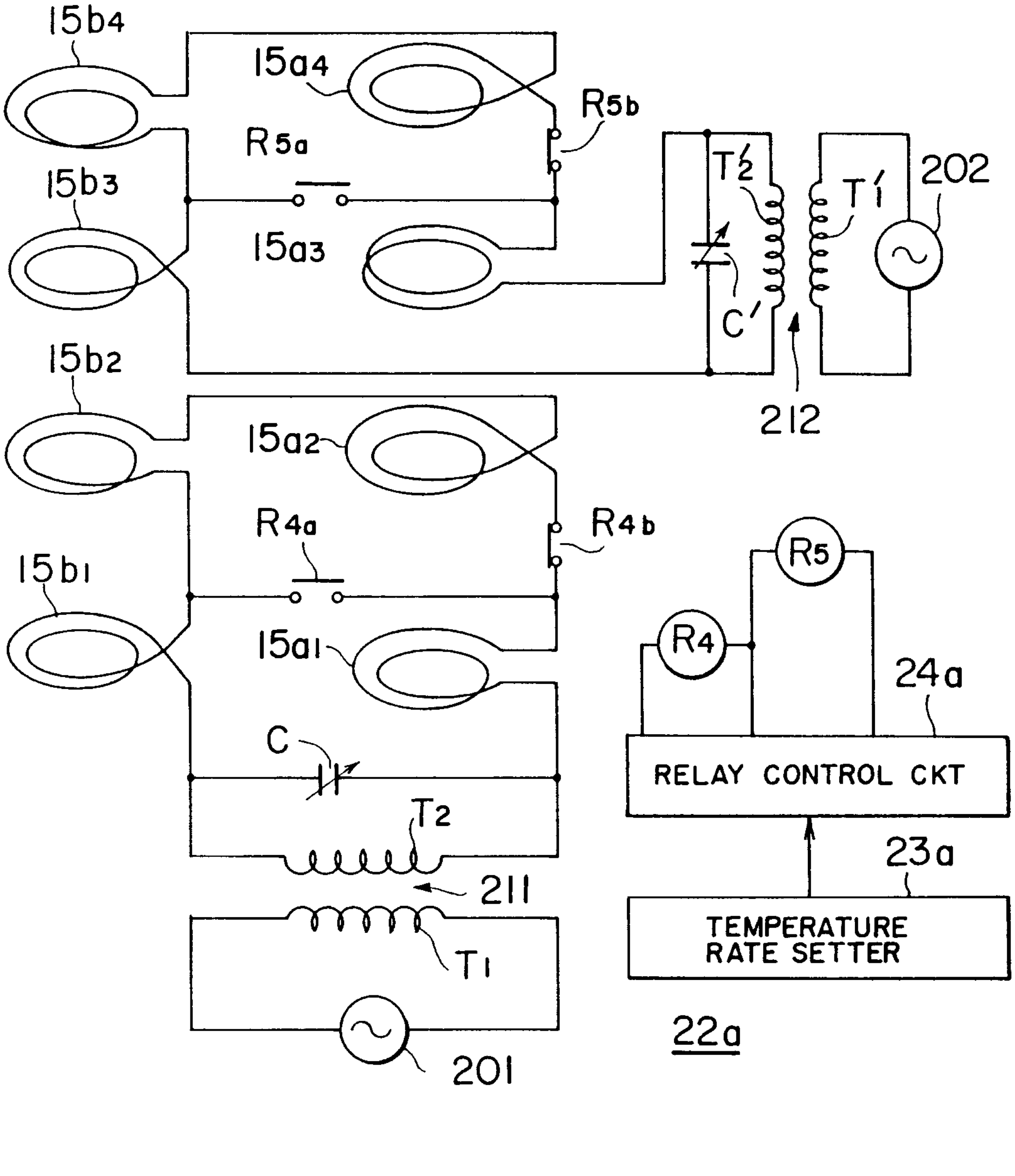
15a1
C
T2
21
T1
20
R1
R2
R3
2
RELAY CONTROL CKT
23
TEMPERATURE
RATE SETTER
22

FIG. 4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15b1
R5
15a1
R4
24a
C
RELAY CONTROL CKT
T2
23a
211
TEMPERATURE
RATE SETTER
T1
22a
201