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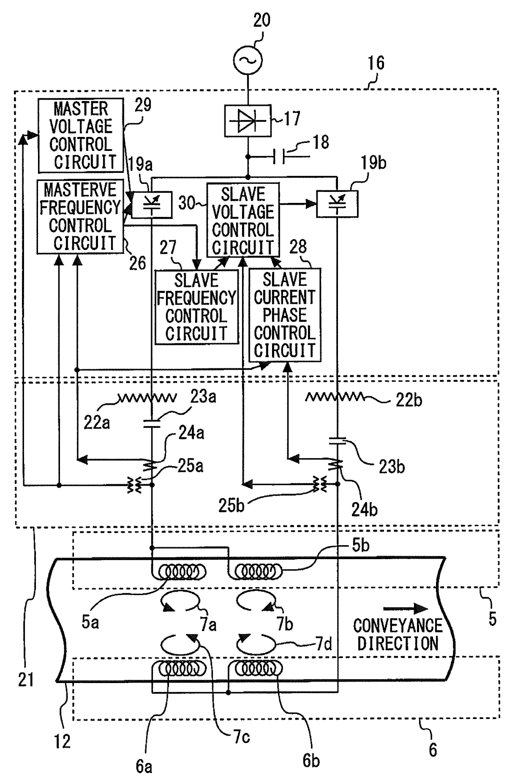
(54) CONTROL DEVICE FOR INDUCTION HEATING UNITS

(57) Provided is a control device for induction heating units which is capable of individually controlling amounts of temperature rise in one side portion and the other side portion of a material to be heated while preventing the occurrence of an abnormal mutual induction phenomenon between two induction heating units. To this end, the control device includes: a master frequency control part that sets an operation frequency of a master inverter, which drives a master C-shaped induction heating unit provided on one side of a material to be heated, so that a phase of an output voltage and a phase of an output current from the master inverter are synchronized; a slave frequency control part that synchronizes an operation frequency of a slave inverter, which drives a slave C-shaped induction heating unit provided on the other side of the material to be heated, with the operation frequency of the master inverter; a slave current phase control part that synchronizes a phase of an output current from the slave inverter with the phase of the output current from the master inverter; a master voltage control part which sets a pulse width of the output voltage from the master inverter; and a slave voltage control part which sets a pulse width of an output voltage from the slave inverter.

FIG. 3



EP 2 890 217 A1

Description

Technical Field

[0001] The present invention relates to a control device for induction heating units.

Background Art

[0002] There have been proposed control devices in which a pair of induction heating units arranged in the vicinity of both side portions of a material to be heated is connected in parallel to one power source. According to these control devices, phases of current of the two induction heating units are synchronized. For this reason, an abnormal mutual induction phenomenon does not occur between the two induction heating units (refer to Patent Literature 1, for example).

Citation List

Patent Literature

[0003] Patent Literature 1: Japanese Patent No. 3156746

Summary of Invention

Technical Problem

[0004] However, the same voltage is applied to the two induction heating units described in Patent Literature 1. For this reason, it is impossible to individually control the power supplied to each of the induction heating units. That is, it is impossible to individually control amounts of temperature rise in one side portion and the other side portion of a material to be heated.

[0005] The present invention has been made in order to solve the above-described problem and an object of the present invention is to provide a control device for induction heating units which is capable of individually controlling amounts of temperature rise in one side portion and the other side portion of a material to be heated while preventing the occurrence of an abnormal mutual induction phenomenon between two induction heating units.

Means for Solving the Problems

[0006] A control device for induction heating units of the present invention includes a master frequency control part that sets an operation frequency of a master inverter, which drives a master C-shaped induction heating unit provided on one side of a material to be heated, so that a phase of an output voltage and a phase of an output current from the master inverter are synchronized;
a slave frequency control part that synchronizes an operation frequency of a slave inverter, which drives a slave C-shaped induction heating unit provided on the other side of the material to be heated, with the operation frequency of the master inverter; a slave current phase control part that synchronizes a phase of an output current from the slave inverter with the phase of the output current from the master inverter; a master voltage control part that sets a pulse width of the output voltage from the master inverter; and a slave voltage control part that sets a pulse width of an output voltage from the slave inverter.

Advantageous Effect of Invention

[0007] According to the present invention, it is possible to individually control amounts of temperature rise in one side portion and the other side portion of a material to be heated while preventing the occurrence of an abnormal mutual induction phenomenon between two induction heating units.

Brief Description of the Drawings

[0008]

Figure 1 is a perspective view of an induction heating unit to which a control device for induction heating units in Embodiment 1 of the present invention is applied.
Figure 2 shows induction heating loops of the induction heating unit for which the control device for induction heating units in Embodiment 1 of the present invention is used.
Figure 3 is a block diagram of the control device for induction heating units in Embodiment 1 of the present invention.
Figure 4 shows a master-side circuit and a slave-side circuit which are used in the control device for induction heating units in Embodiment 1 of the present invention.
Figure 5 is an explanatory diagram for the setting procedure for the operation of the master inverter and slave inverter which are used in the control device for induction heating units in Embodiment 1 of the present invention.
Figure 6 shows Q-values of the master-side circuit and slave-side circuit of the control device for induction heating units in Embodiment 1 of the present invention.
Figure 7 is a block diagram of a control device for induction heating units in Embodiment 2 of the present invention.
Figure 8 is an explanatory diagram for the resonance frequency of the control device for induction heating units in Embodiment 2 of the present invention.
Figure 9 corresponds to Figure 5 in Embodiment 2 of the present invention.
Figure 10 corresponds to Figure 6 in Embodiment 2 of the present invention.
Figure 11 is a block diagram of a control device for

induction heating units in Embodiment 3 of the present invention.

Figure 12 is an explanatory diagram for the resonance frequency of the control device for induction heating units in Embodiment 3 of the present invention.

Figure 13 is a block diagram of a control device for induction heating units in Embodiment 4 of the present invention.

Figure 14 corresponds to Figure 8 in Embodiment 4 of the present invention.

Figure 15 is a block diagram of a control device for induction heating units in Embodiment 5 of the present invention.

Figure 16 corresponds to Figure 12 in Embodiment 5 of the present invention.

Description of Embodiments

[0009] Embodiments of the present invention will be described in accordance with the accompanying drawings. In each of the drawings, identical or corresponding parts are referred to by identical and either not described repeatedly or described simply as appropriate.

Embodiment 1

[0010] Figure 1 is a perspective view of an induction heating unit to which a control device for induction heating units in Embodiment 1 of the present invention is applied.

[0011] As shown in Figure 1, a material to be heated 1 is supported by an entry conveyor roller 2 and a delivery conveyor roller 3. Both end portions of the entry conveyor roller 2 and both end portions of the delivery conveyor roller 3 are connected to grounds 4.

[0012] A master C-shaped heating unit 5 is arranged in the vicinity of one side of the material to be heated 1. The master C-shaped heating unit 5 includes a master entry C-shaped inductor 5a and a master delivery C-shaped inductor 5b. The master entry C-shaped inductor 5a and the master delivery C-shaped inductor 5b are arranged along the conveyance direction of the material to be heated 1. The master entry C-shaped inductor 5a and the master delivery C-shaped inductor 5b are formed in such a manner that the directions of magnetic flux are reverse to each other.

[0013] A slave C-shaped heating unit 6 is arranged in the vicinity of the other side of the material to be heated 1. The slave C-shaped heating unit 6 includes a slave entry C-shaped inductor 6a and a slave delivery C-shaped inductor 6b. The slave entry C-shaped inductor 6a and the slave delivery C-shaped inductor 6b are arranged along the conveyance direction of the material to be heated 1. The slave entry C-shaped inductor 6a and the slave delivery C-shaped inductor 6b are formed in such a manner that the directions of magnetic flux are reverse to each other.

[0014] The master entry C-shaped inductor 5a and the slave entry C-shaped inductor 6a are formed in such a manner that the directions of magnetic flux are reverse to each other. The master delivery C-shaped inductor 5b and the slave delivery C-shaped inductor 6b are formed in such a manner that the directions of magnetic flux are reverse to each other.

[0015] When a current flows in the master entry C-shaped inductor 5a, an entry inductor magnetic flux is formed. A material current 7a flows in the material to be heated 1 by this entry inductor magnetic flux. When a current flows in the master delivery C-shaped inductor 5b, a delivery inductor magnetic flux is formed. A material current 7b flows in the material to be heated 1 by this delivery inductor magnetic flux. One side portion of the material to be heated 1 is heated by the material currents 7a and 7b.

[0016] When a current flows in the slave entry C-shaped inductor 6a, an entry inductor magnetic flux is formed. A material current 7c flows in the material to be heated 1 by this entry inductor magnetic flux. When a current flows in the slave delivery C-shaped inductor 6b, a delivery inductor magnetic flux is formed. A material current 7d flows in the material to be heated 1 by this delivery inductor magnetic flux. The other side portion of the material to be heated 1 is heated by the material currents 7c and 7d.

[0017] On this occasion, between one end of the entry conveyor roller 2 and a portion in the vicinity of the master entry C-shaped inductor 5a, a ground current 8a can flow in the material to be heated 1. Between one end of the delivery conveyor roller 3 and a portion in the vicinity of the master delivery C-shaped inductor 5b, a ground current 8b can flow in the material to be heated 1. Between the other end of the entry conveyor roller 2 and a portion in the vicinity of the slave entry C-shaped inductor 6a, a ground current 8c can flow in the material to be heated 1. Between the other end of the delivery conveyor roller 3 and a portion in the vicinity of the slave delivery C-shaped inductor 6b, a ground current 8d can flow in the material to be heated 1.

[0018] In a case where the ground current 8a is high, an arc 9 can be formed at a contact point between one end of the entry conveyor roller 2 and the material to be heated 1. In a case where the ground current 8b is high, an arc 9 can be formed at a contact point between one end of the delivery conveyor roller 3 and the material to be heated 1. In a case where the ground current 8c is high, an arc 9 can be formed at a contact point between the other end of the entry conveyor roller 2 and the material to be heated 1. In a case where the ground current 8d is high, an arc 9 can be formed at a contact point between the other end of the delivery conveyor roller 3 and the material to be heated 1.

[0019] Next, a method of preventing the formation of the arc 9 will be described with the aid of Figure 2.

[0020] Figure 2 shows induction heating loops of the induction heating unit for which the control device for induction heating units in Embodiment 1 of the present invention is used.

[0021] A first material loop circuit 10, a second material loop circuit 11, and a ground loop circuit 12 are formed on the master side and the slave side.

[0022] The first material loop circuit 10 includes an entry material resistor R1 and an entry material end resistor R2 of the material to be heated 1. The second material loop circuit 11 includes a delivery material resistor R3 and a delivery material end resistor R4 of the material to be heated 1. The ground loop circuit 12 includes a ground resistor R0, the entry material end resistor R2, and the delivery material end resistor R4.

[0023] An entry inductor magnetic flux $\phi 1$ penetrates through the first material loop circuit 10. An entry material current 13 flows by this penetration. In contrast to this, a delivery inductor magnetic flux $\phi 2$ penetrates through the second material loop circuit 11. A delivery material current 14 flows by this penetration.

[0024] In contrast to this, in the ground loop circuit 12, the amount of the entry inductor magnetic flux $\phi 1$ and the amount of the delivery inductor magnetic flux $\phi 2$ are identical in the directions reverse to each other. For this reason, the composite magnetic flux of the entry inductor magnetic flux $\phi 1$ and the delivery inductor magnetic flux $\phi 2$ is zero. As a result, a ground current 15 flowing between the entry conveyor roller 2 and the ground 4, the ground current 15 flowing in the material to be heated 1, and the ground current 15 flowing between the delivery conveyor roller 3 and the ground 4 are zero. For this reason, the arc 9 is not formed. That is, arc damage does not occur on the surface of the entry conveyor roller 2, the surface of the delivery conveyor roller 3, and the surface of the material to be heated 1, either.

[0025] Next, the control device for induction heating units will be described with the aid of Figure 3.

[0026] Figure 3 is a block diagram of the control device for induction heating units in Embodiment 1 of the present invention.

[0027] In Figure 3, a voltage-fed inverter power source 16 includes a rectifier 17, a smoothing capacitor 18, a master inverter 19a, and a slave inverter 19b.

[0028] The rectifier 17 has the function of rectifying an AC power source 20. The smoothing capacitor 18 has the function of smoothing a DC voltage output from the rectifier 17. The master inverter 19a and the slave inverter 19b are connected in parallel. The master inverter 19a and the slave inverter 19b have the function of exerting a PWM control over the DC voltage smoothed by the smoothing capacitor 18.

[0029] A voltage-fed matching device 21 includes a master matching transformer 22a, a master series resonance capacitor 23a, a master current detector 24a, a master voltage detector 25a, a slave matching transformer 22b, a slave series resonance capacitor 23b, a slave current detector 24b, and a slave voltage detector 25b.

[0030] The master matching transformer 22a is connected between the master inverter 19a and the master C-shaped heating unit 5. The master series resonance capacitor 23a is connected between the master matching transformer 22a and the master C-shaped heating unit 5. The master current detector 24a is connected between the master series resonance capacitor 23a and the master C-shaped heating unit 5. The master voltage detector 25a is connected between the master current detector 24a and the master C-shaped heating unit 5.

[0031] The slave matching transformer 22b is connected between the slave inverter 19b and the slave C-shaped heating unit 6. The slave series resonance capacitor 23b is connected between the slave matching transformer 22b and the slave C-shaped heating unit 6. The slave current detector 24b is connected between the slave series resonance capacitor 23b and the slave C-shaped heating unit 6. The slave voltage detector 25b is connected between the slave current detector 24b and the slave C-shaped heating unit 6.

[0032] In this embodiment, there are provided a master frequency control circuit (a master frequency control part) 26, a slave frequency control circuit (a slave frequency control part) 27, a slave current phase control circuit (a slave current phase control part) 28, a master voltage control circuit (a master voltage control part) 29, and a slave voltage control circuit (a slave voltage control part) 30.

[0033] The master frequency control circuit 26 has the function of setting an operation frequency of the master inverter 19a by receiving the feedback of a detection value of the master current detector 24a and a detection value of the master voltage detector 25a. The slave frequency control circuit 27 has the function of setting an operation frequency of the master inverter 19a set by the master frequency control circuit 26 to an operation frequency of the slave inverter 19b. The slave current phase control circuit 28 has the function of setting the phase of an output current of the slave inverter 19b by receiving the feedback of a detection value of the master current detector 24a and a detection value of the slave current detector 24b.

[0034] The master voltage control circuit 29 has the function of setting the pulse width of an output voltage from the master inverter 19a by receiving an instruction from the outside and the feedback of a detection value of the master voltage detector 25a. The slave voltage control circuit 30 has the function of setting the pulse width of an output voltage from the slave inverter 19b by receiving an instruction from the outside and the feedback of a detection value of the slave voltage detector 25b.

[0035] Next, operation frequencies of the master inverter 19a and the slave inverter 19b will be described with the aid of Figure 4.

[0036] Figure 4 shows a master-side circuit and a slave-side circuit which are used in the control device for induction heating units in Embodiment 1 of the present invention.

[0037] As shown in Figure 4, an electrostatic capacity of the master series resonance capacitor 23a is denoted by Cm, a load resistance on the master side is denoted by Rm, and a load inductance is denoted by Lm. In this case, a resonance frequency Fm0 of the master-side circuit is expressed by Equation (1) below.

[0038] [Equation 1]

$$Fm0(Hz) = \frac{1}{2\pi\sqrt{LmCm}} \qquad (1)$$

[0039] As shown in Figure 4, an electrostatic capacity of the slave series resonance capacitor 23b is denoted by Cs, a load resistance on the slave side is denoted by Rs, and a load inductance is denoted by Ls. In this case, a resonance frequency Fs0 of the slave-side circuit is expressed by Equation (2) below.

[Equation 2]

$$Fs0(Hz) = \frac{1}{2\pi\sqrt{LsCs}} \qquad (2)$$

[0040] If the master inverter 19a operates with the resonance frequency Fm0, the power factor of the master inverter 19a is 1. In contrast to this, if the slave inverter 19b operates with the resonance frequency Fs0, the power factor of the slave inverter 19b is 1.

[0041] However, usually, Fm0 and Fs0 are different. For this reason, if the master inverter 19a operates with the resonance frequency Fm0 and the slave inverter 19b operates with the resonance frequency Fs0, then an abnormal mutual inductance phenomenon occurs between the master C-shaped heating unit 5 and the slave C-shaped heating unit 6.

[0042] Therefore, the control device of this embodiment synchronizes the operation frequency of the master inverter 19a with the operation frequency of the slave inverter 19b.

[0043] Next, a setting procedure for the operation of the master inverter 19a and the slave inverter 19b will be described with the aid of Figure 5.

[0044] Figure 5 is an explanatory diagram for the setting procedure for the operation of the master inverter and slave inverter which are used in the control device for induction heating units in Embodiment 1 of the present invention.

[0045] The upper part of Figure 5 shows currents flowing in the master C-shaped heating unit 5 and the slave C-shaped heating unit 6. The middle part of Figure 5 shows an output voltage from the master inverter 19a. The lower part of Figure shows an output voltage from the slave inverter 19b.

[0046] First, the master frequency control circuit 26 sets the operation frequency of the master inverter 19a to the resonance frequency Fm0 so that the power factor of the master inverter 19a is equal to 1. That is, as shown in the upper part and middle part of Figure 5, the operation frequency of the master inverter 19a is set so that the phase of an output voltage Vlm from the master inverter 19a is synchronized with the phase of an output current (a master inductor current Im). As a result, as shown in the upper part and middle part of Figure 5, the cycle time of the master-side circuit is set to t0.

[0047] Thereafter, the slave frequency control circuit 27 sets the resonance frequency Fm0 of the master-side circuit as the operation frequency of the slave inverter 19b. As a result, as shown in the lower part of Figure 5, the cycle time of the slave-side circuit is also set to t0.

[0048] Thereafter, as shown in the upper part of Figure 5, the slave current phase control circuit 28 synchronized the phase of an output current (a slave inductor current Is) from the slave inverter 19b with the phase of an output current (a master inductor current Im) from the master inverter 19a. As a result, in the master C-shaped heating unit 5 and the slave C-shaped heating unit 6, the generation of a beat current by a mutual induction current is suppressed. That is, the master C-shaped heating unit 5 and the slave C-shaped heating unit 6 can avoid failures by the flow of an overcurrent.

[0049] Next, Q-values of the master-side circuit and slave-side circuit will be described with the aid of Figure 6.

[0050] Figure 6 shows Q-values of the master-side circuit and slave-side circuit of the control device for induction heating units in Embodiment 1 of the present invention.

[0051] As shown in Figure 6, a case where the resonance frequency Fm0 of the master-side circuit deviates from the resonance frequency F0s of the slave-side circuit is considered. In this case, an operation frequency F0 of the master inverter 19a and slave inverter 19b is set to the resonance frequency Fm0 of the master-side circuit. In this case, a Q-value Qm0 of the master-side circuit is a maximum value on a Q-value curve Qm of the master-side circuit. For this reason, maximum power that can be applied to the master C-shaped heating unit 5 is maintained. In contrast to this, a Q-value Qs0 of the slave-side circuit is not a maximum value on a Q-value curve Qs of the slave-side circuit. For this reason, maximum power that can be applied to the slave C-shaped heating unit 6 decreases.

[0052] According to Embodiment 1 described above, the phase of the output current from the slave inverter 19b is synchronized with the phase of the output current from the master inverter 19a. Pulse widths of output voltages from the master inverter 19a and slave inverter 19b are individually set. For this reason, it is possible to individually control amounts of temperature rise in one side portion and the other side portion of the material to be heated 1 while preventing the occurrence of the abnormal mutual induction phenomenon between the two induction heating units.

Embodiment 2

[0053] Figure 7 is a block diagram of a control device for induction heating units in Embodiment 2 of the present invention. Parts which are the same as those in Embodiment 1 or corresponding parts bear identical reference numerals and are not described herein.

[0054] The control device of Embodiment 2 is such that a frequency synchronizing capacitor 31, a disconnecting switch 32, and a slave voltage phase control circuit 33 are added to the control device of Embodiment 1.

[0055] The slave frequency synchronizing capacitor 31 is connected in parallel to the slave series resonance capacitor 23b between the slave matching transformer 22b and the slave C-shaped heating unit 6. The disconnecting switch 32 is connected in parallel to the slave series resonance capacitor 23b and connected in series to the slave frequency synchronizing capacitor 31. The slave voltage phase control circuit 33 has the function of opening and closing the disconnecting switch 32 by receiving the feedback of the detection value of the slave current detector 24b and the detection value of the slave voltage detector 25b.

[0056] Next, the resonance frequency of the slave-side circuit will be described with the aid of Figure 8.

[0057] Figure 8 is an explanatory diagram for the resonance frequency of the control device for induction heating units in Embodiment 2 of the present invention.

[0058] As shown in Figure 8, an electrostatic capacity of the slave frequency synchronizing capacitor 31 is denoted by Css. In a case where the disconnecting switch 32 is closed, the resonance frequency Fs0 of the slave-side circuit is expressed by Equation (3) below.

[Equation 3]

$$Fs0(Hz) = \frac{1}{2\pi\sqrt{Ls(Cs + Css)}} \qquad (3)$$

[0059] Next, a setting procedure for operation frequencies of the master inverter 19a and the slave inverter will be described with the aid of Figure 9.

[0060] Figure 9 corresponds to Figure 5 in Embodiment 2 of the present invention.

[0061] Similarly to Figure 5, in Figure 9 the phase of the output current from the master inverter 19a is synchronized with the phase of the output current from the slave inverter 19b. Thereafter, the slave voltage phase control circuit 33 synchronizes the phase of the output voltage from the slave inverter 19b with the phase of the output voltage from the master inverter 19a by opening and closing the disconnecting switch 32.

[0062] Next, Q-values of the master-side circuit and slave-side circuit will be described with the aid of Figure 10.

[0063] Figure 10 corresponds to Figure 6 in Embodiment 2 of the present invention.

[0064] As shown in Figure 10, the resonance frequency Fm0 of the master-side circuit is synchronized with the resonance frequency Fs0 of the slave-side circuit. In this case, the Q-value Qm0 of the master-side circuit and the Q-value Qs0 of the slave-side circuit are maximum values. For this reason, maximum power that can be applied to the master C-shaped heating unit 5 and the slave C-shaped heating unit 6 is maintained.

[0065] According to Embodiment 2 described above, the phase of the output voltage from the slave inverter 19b is synchronized with the phase of the output voltage from the master inverter 19a by opening and closing the disconnecting switch 32. For this reason, it is possible to prevent a decrease in the heating efficiency of the slave C-shaped heating unit 6.

Embodiment 3

[0066] Figure 11 is a block diagram of a control device for induction heating units in Embodiment 3 of the present invention. Parts which are the same as those in Embodiment 2 or corresponding parts bear identical reference numerals and are not described herein.

[0067] The control device of Embodiment 3 is such that the disconnecting switch 32 of Embodiment 2 is replaced with a slave voltage phase control device 34.

[0068] The slave voltage phase control circuit 33 controls a voltage applied to the slave frequency synchronizing capacitor 31 through the use of the slave voltage phase control device 34. As a result, the phase of the output voltage from the slave inverter 19b is synchronized with the phase of the output voltage from the master inverter 19a.

[0069] Next, the resonance frequency of the slave-side circuit will be described with the aid of Figure 12.

[0070] Figure 12 is an explanatory diagram for the resonance frequency of the control device for induction heating units in Embodiment 3 of the present invention.

[0071] In Figure 12, the resonance frequency Fs0 of the salve-side circuit changes continuously by controlling the voltage applied to the slave frequency synchronizing capacitor 31.

[0072] According to Embodiment 3 described above, it is possible to control the voltage applied to the slave frequency synchronizing capacitor 31 through the use of the slave voltage phase control device 34. For this reason, it is possible to ensure synchronizing the phase of the output voltage from the slave inverter 19b with the phase of the output voltage from the master inverter 19a.

Embodiment 4

[0073] Figure 13 is a block diagram of a control device for induction heating units in Embodiment 4 of the present invention. Parts which are the same as those in Embodiment 2 or corresponding parts bear identical reference numerals and are not described herein.

[0074] The control device of Embodiment 2 uses the slave frequency synchronizing capacitor 31. On the other hand, the control device of Embodiment 4 uses a slave frequency synchronizing reactor 35.

[0075] The slave frequency synchronizing reactor 35 is connected in series to the slave series resonance capacitor 23b and connected in parallel to the slave C-shaped heating unit 6. The disconnecting switch 32 is connected in series to the slave series resonance capacitor 23b and the slave frequency synchronizing reactor 35 and connected in parallel to the slave C-shaped heating unit 6. The slave voltage phase control circuit 33 has the function of synchronizing the phase of the output voltage from the slave inverter 19b with the phase of the output voltage from the master inverter 19a by opening and closing the disconnecting switch 32.

[0076] Next, the resonance frequency of the slave-side circuit will be described with the aid of Figure 14.

[0077] Figure 14 corresponds to Figure 8 in Embodiment 4 of the present invention.

[0078] As shown in Figure 14, inductance of the slave frequency synchronizing reactor 35 is denoted by Lss. In a case where the disconnecting switch 32 is closed, the resonance frequency Fs0 of the slave-side circuit is expressed by Equation (4) below.

[Equation 4]

$$Fs0(Hz) = \frac{1}{2\pi\sqrt{\frac{LsLss}{Ls+Lss}Cs}} \qquad (4)$$

[0079] According to Embodiment 4 described above, as in Embodiment 2, it is possible to prevent a decrease in the heating efficiency of the slave C-shaped heating unit 6.

Embodiment 5

[0080] Figure 15 is a block diagram of a control device for induction heating units in Embodiment 5 of the present invention. Parts which are the same as those in Embodiment 3 or corresponding parts bear identical reference numerals and are not described herein.

[0081] The control device of Embodiment 3 uses the slave frequency synchronizing capacitor 31. On the other hand, the control device of Embodiment 4 uses the slave frequency synchronizing reactor 35.

[0082] Next, the resonance frequency of the slave-side circuit will be described with the aid of Figure 16.

[0083] Figure 16 corresponds to Figure 12 in Embodiment 5 of the present invention.

[0084] In Figure 16, the resonance frequency Fs0 of the salve-side circuit changes continuously by controlling the voltage applied to the slave frequency synchronizing reactor 35.

[0085] According to Embodiment 5 described above, it is possible to control the voltage applied to the slave frequency synchronizing reactor 35 through the use of the slave voltage phase control device 34. For this reason, it is possible to ensure synchronizing the phase of an output voltage of the slave inverter 19b with the phase of the output voltage from the master inverter 19a.

Industrial Applicability

[0086] As described so far, the control device for induction heating units of the present invention can be applied in individually controlling amounts of temperature rise in one side portion and the other side portion of a material to be heated.

Description of symbols

[0087] 1 material to be heated, 2 entry conveyor roller, 3 delivery conveyor roller, 4 ground, 5 master C-shaped heating unit, 5a master entry C-shaped inductor, 5b master delivery C-shaped inductor, 6 slave C-shaped heating unit, 6a slave entry C-shaped inductor, 6b slave delivery C-shaped inductor, 7a-7d material current, 8a-8d ground current, 9 arc, 10 first material loop circuit, 11 second material loop circuit, 12 ground loop circuit, 13,14 material current, 15 ground current, 16 voltage-fed inverter power source, 17 rectifier, 18 smoothing capacitor, 19a master inverter, 19b slave inverter, 20 AC power source, 21 voltage-fed matching device, 22a master matching transformer, 22b slave matching transformer, 23a master series resonance capacitor, 23b slave series resonance capacitor, 24a master current detector, 24b slave current detector, 25a master voltage detector, 25b slave voltage detector, 26 master frequency control circuit, 27 slave frequency control circuit, 28 slave current phase control circuit, 29 master voltage control circuit, 30 slave voltage control circuit, 31 frequency synchronizing capacitor, 32 disconnecting switch, 33 slave voltage phase control circuit, 34 slave voltage phase control device, 35 slave frequency synchronizing reactor

Claims

1. A control device for induction heating units, comprising:

a master frequency control part that sets an operation frequency of a master inverter, which drives a master C-shaped induction heating unit provided on one side of a material to be heated, so that a phase of an output voltage and a phase of an output current from the master inverter are synchronized;

a slave frequency control part that synchronizes an operation frequency of a slave inverter, which drives a slave C-shaped induction heating unit provided on the other side of the material to be heated, with the operation frequency of the master inverter;

a slave current phase control part that synchronizes a phase of an output current from the slave inverter with the phase of the output current from the master inverter;

a master voltage control part that sets a pulse

width of the output voltage from the master inverter; and
a slave voltage control part that sets a pulse width of an output voltage from the slave inverter.

2. The control device for induction heating units according to claim 1, further comprising:

a slave voltage phase control part that synchronizes a phase of the output voltage from the slave inverter with the phase of the output voltage from the master inverter.

3. The control device for induction heating units according to claim 2, further comprising:

a slave series resonance capacitor connected between the slave C-shaped heating unit and the slave inverter;
a slave frequency synchronizing capacitor connected in parallel to the slave series resonance capacitor; and
a disconnecting switch connected in parallel to the slave series resonance capacitor and connected in series to the slave frequency synchronizing capacitor,
wherein the slave voltage phase control part synchronizes the phase of the output voltage from the slave inverter with the phase of the output voltage from the master inverter by opening and closing the disconnecting switch.

4. The control device for induction heating units according to claim 2, further comprising:

a slave series resonance capacitor connected between the slave C-shaped heating unit and the slave inverter;
a slave frequency synchronizing capacitor connected in parallel to the slave series resonance capacitor; and
a slave voltage phase control device connected in parallel to the slave series resonance capacitor and connected in series to the slave frequency synchronizing capacitor,
wherein the slave voltage phase control part synchronizes the phase of the output voltage from the slave inverter with the phase of the output voltage from the master inverter by controlling a voltage applied to the slave frequency synchronizing capacitor through the use of the slave voltage phase control device.

5. The control device for induction heating units according to claim 2, further comprising:

a slave series resonance capacitor connected between the slave C-shaped heating unit and the slave inverter;
a slave frequency synchronizing reactor connected in series to the slave series resonance capacitor and connected in parallel to the slave C-shaped heating unit; and
a disconnecting switch connected in series to the slave series resonance capacitor and the slave frequency synchronizing reactor and connected in parallel to the slave C-shaped heating unit,
wherein the slave voltage phase control part synchronizes the phase of the output voltage from the slave inverter with the phase of the output voltage from the master inverter by opening and closing the disconnecting switch.

6. The control device for induction heating units according to claim 2, further comprising:

a slave series resonance capacitor connected between the slave C-shaped heating unit and the slave inverter;
a slave frequency synchronizing reactor connected in series to the slave series resonance capacitor and connected in parallel to the slave C-shaped heating unit; and
a slave voltage phase control device connected in series to the slave series resonance capacitor and the slave frequency synchronizing reactor and connected in parallel to the slave C-shaped heating unit,
wherein the slave voltage phase control part synchronizes the phase of the output voltage from the slave inverter with the phase of the output voltage from the master inverter by controlling a voltage applied to the slave frequency synchronizing reactor through use of the slave voltage phase control device.

FIG. 1

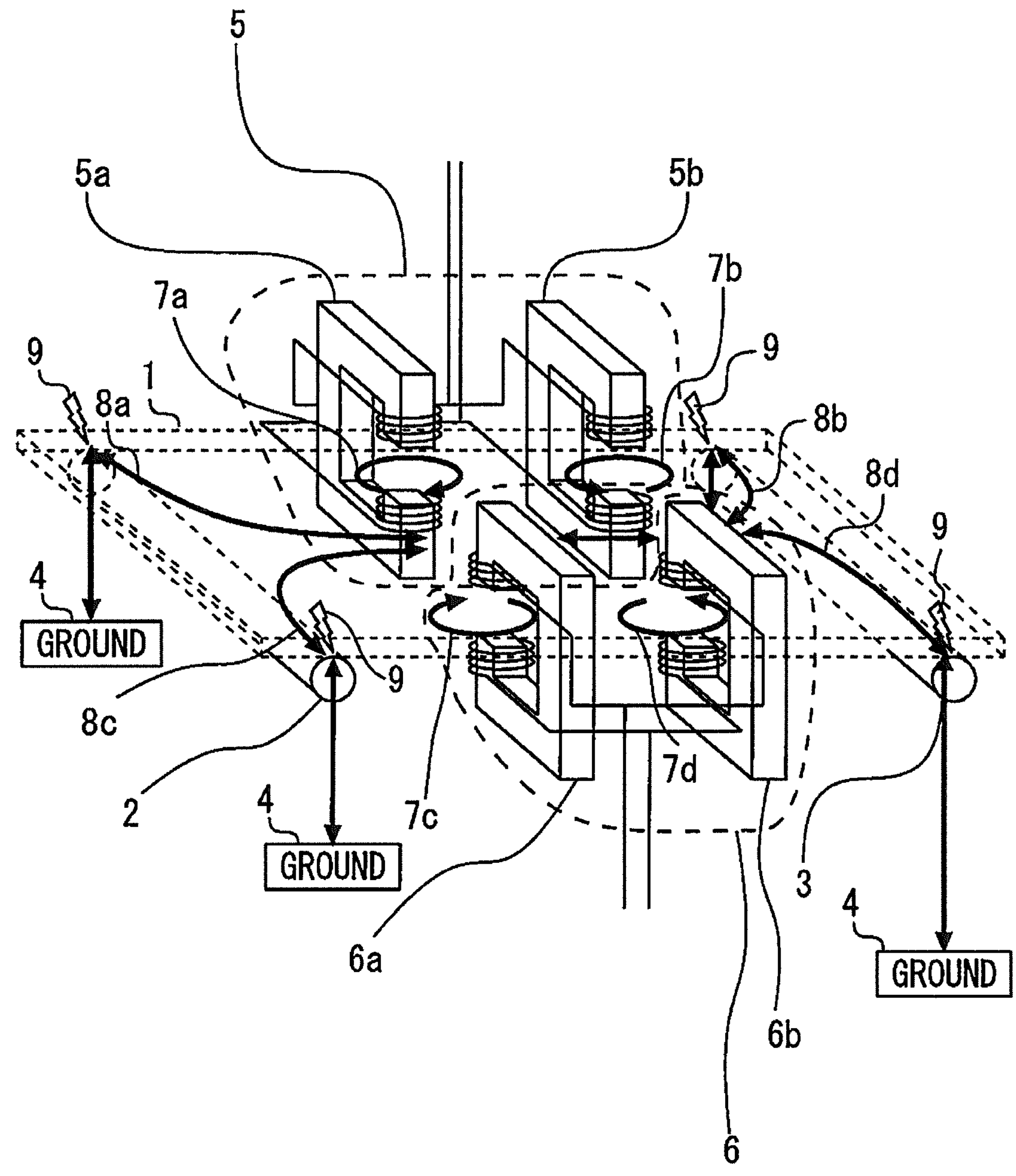

5
5a
5b
7a
7b
9
9
1
8a
8b
8d
9
4
GROUND
8c
9
2
4
GROUND
7c
7d
6a
3
4
GROUND
6b
6

FIG. 2

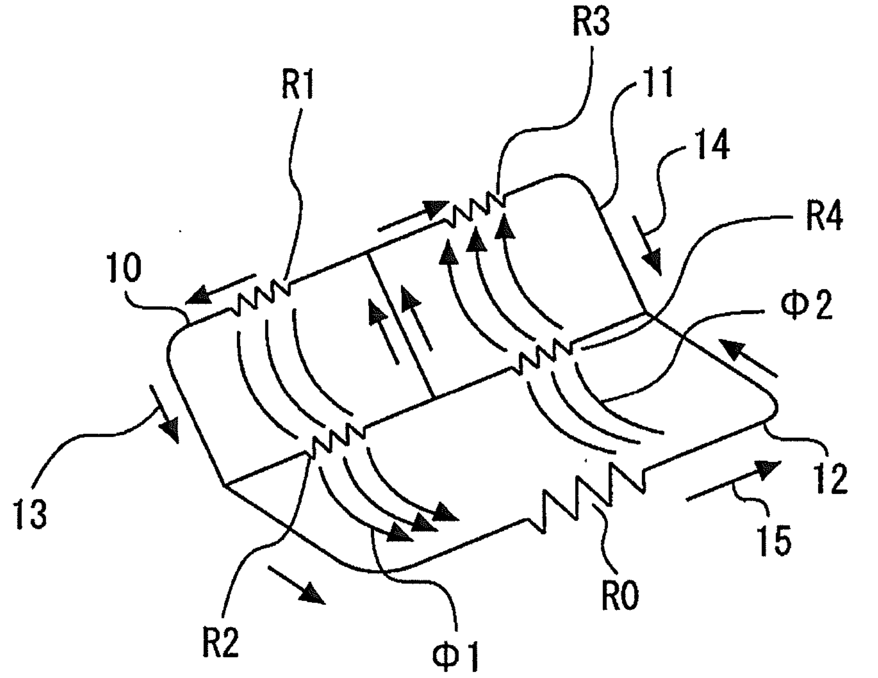


FIG. 3

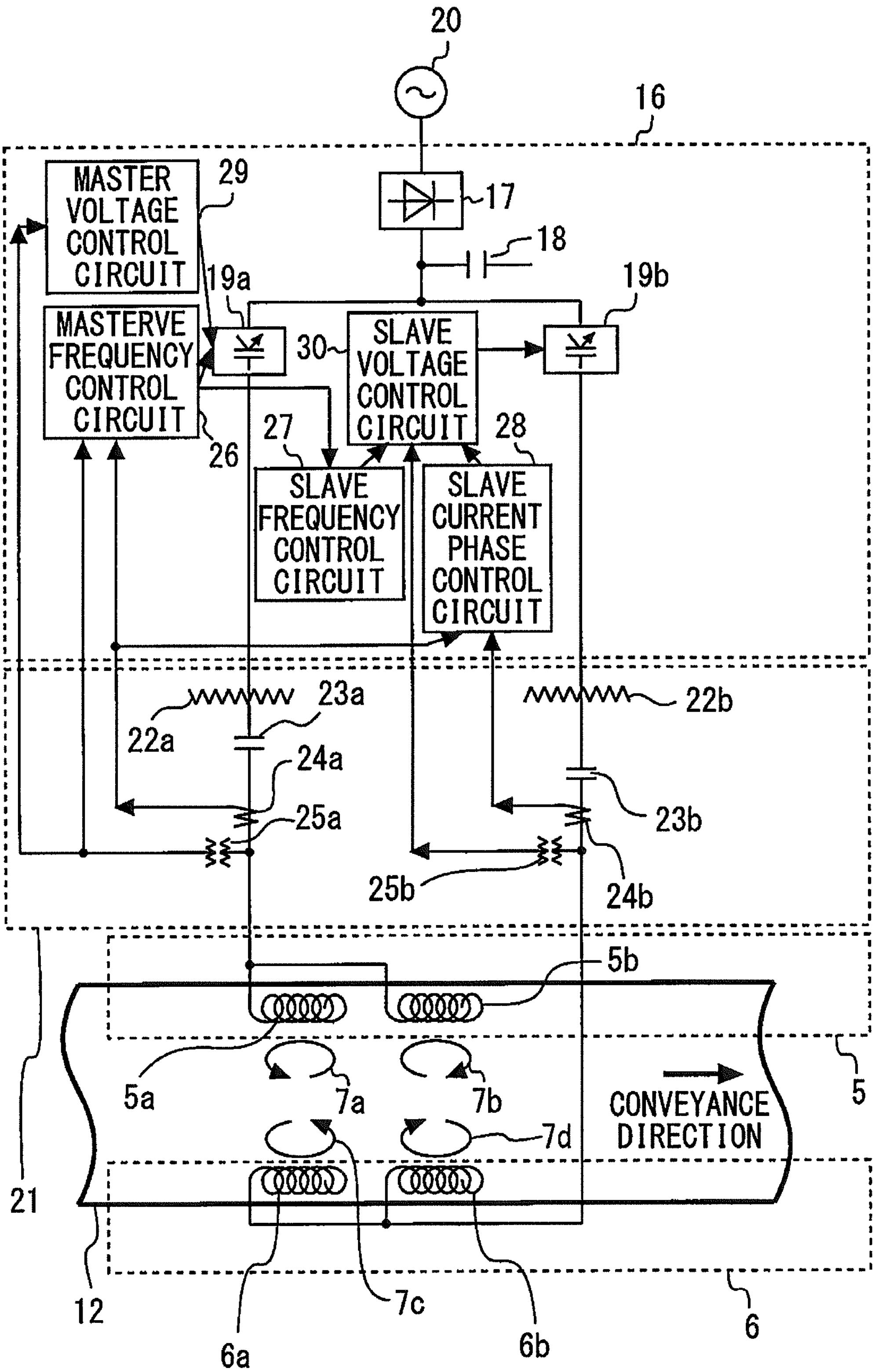

20
16
MASTER VOLTAGE CONTROL CIRCUIT
29
17
18
19a
19b
MASTERVE FREQUENCY CONTROL CIRCUIT
30
SLAVE VOLTAGE CONTROL CIRCUIT
27
28
26
SLAVE FREQUENCY CONTROL CIRCUIT
SLAVE CURRENT PHASE CONTROL CIRCUIT
23a
22b
22a
24a
23b
25a
25b
24b
5b
5a
7a
7b
CONVEYANCE DIRECTION
5
7d
21
12
7c
6a
6b
6

FIG. 4

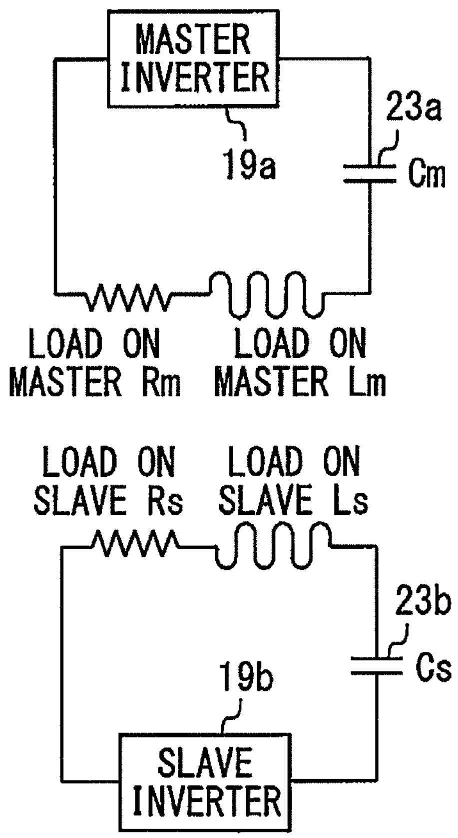

MASTER INVERTER
19a
23a
Cm
LOAD ON MASTER Rm
LOAD ON MASTER Lm
LOAD ON SLAVE Rs
LOAD ON SLAVE Ls
23b
Cs
19b
SLAVE INVERTER

FIG. 5

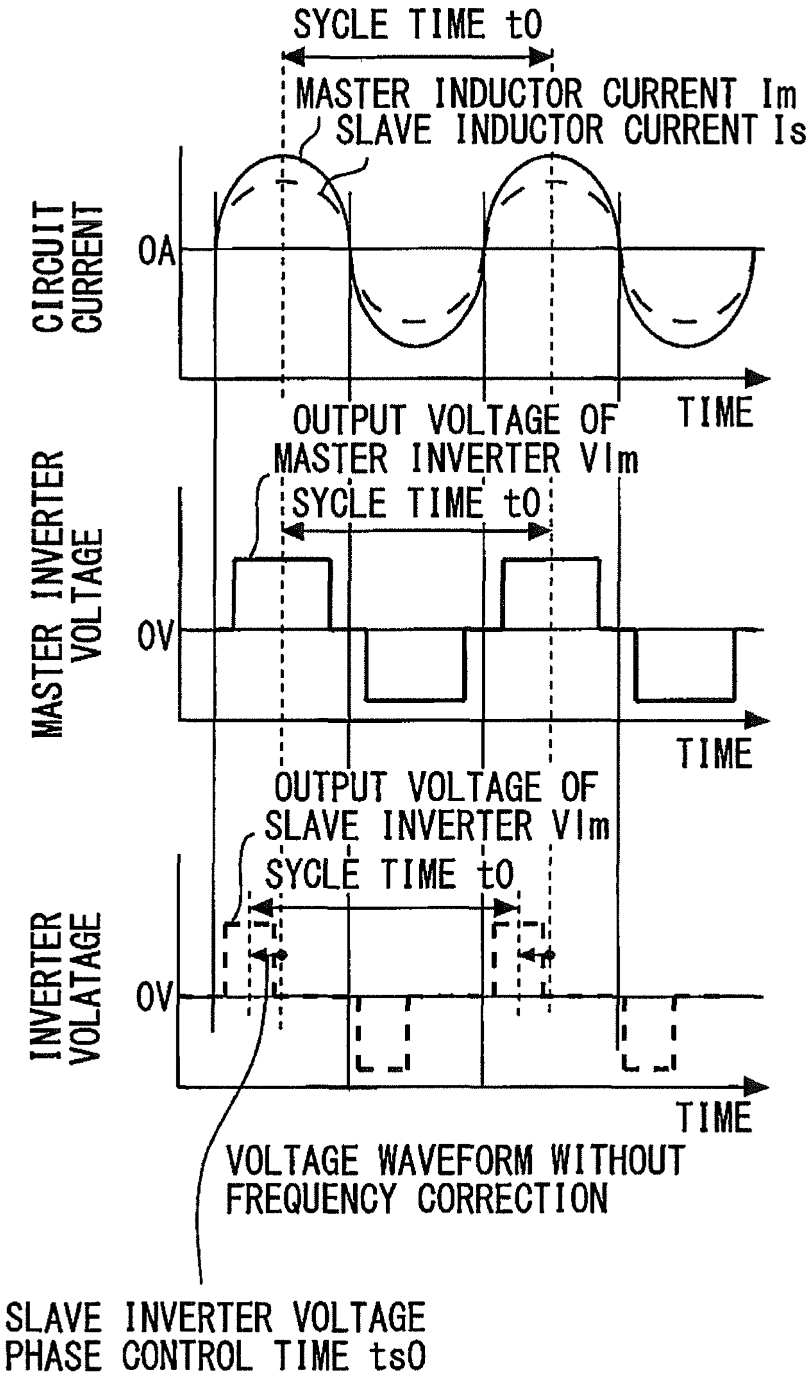
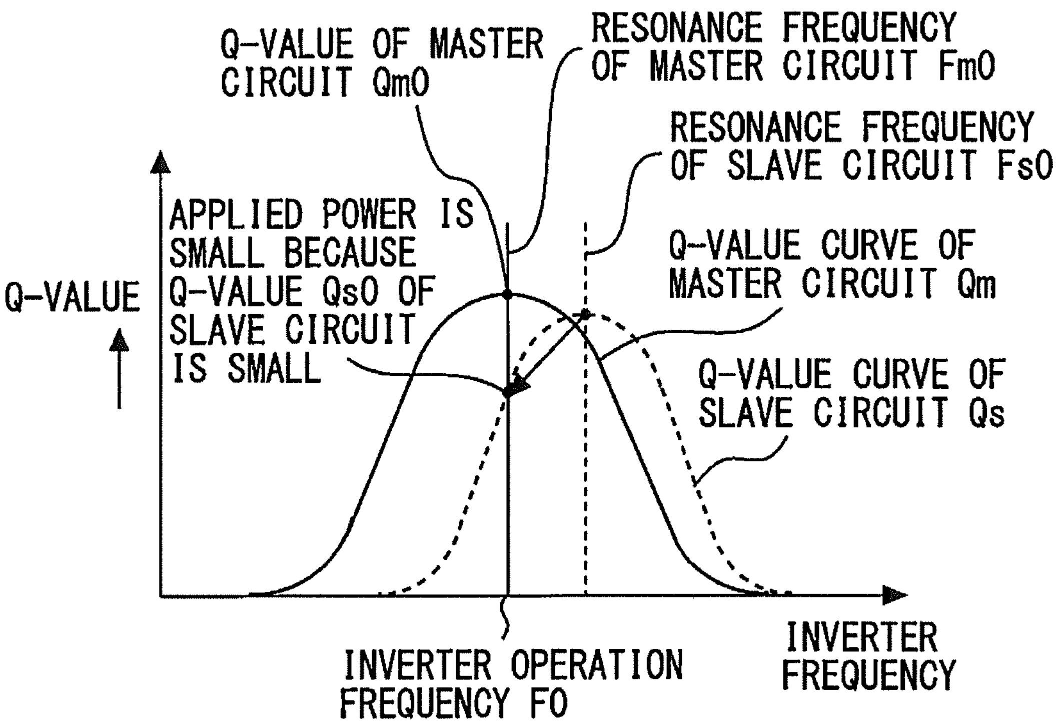

SYCLE TIME t0
MASTER INDUCTOR CURRENT Im
SLAVE INDUCTOR CURRENT Is
CIRCUIT CURRENT
0A
TIME
OUTPUT VOLTAGE OF MASTER INVERTER VIm
SYCLE TIME t0
MASTER INVERTER VOLTAGE
0V
TIME
OUTPUT VOLTAGE OF SLAVE INVERTER VIm
SYCLE TIME t0
INVERTER VOLATAGE
0V
TIME
VOLTAGE WAVEFORM WITHOUT FREQUENCY CORRECTION
SLAVE INVERTER VOLTAGE PHASE CONTROL TIME ts0

FIG. 6



SLAVE FREQUENCY ASYNCHRONOUS Q-VALUE CURVE

FIG. 7

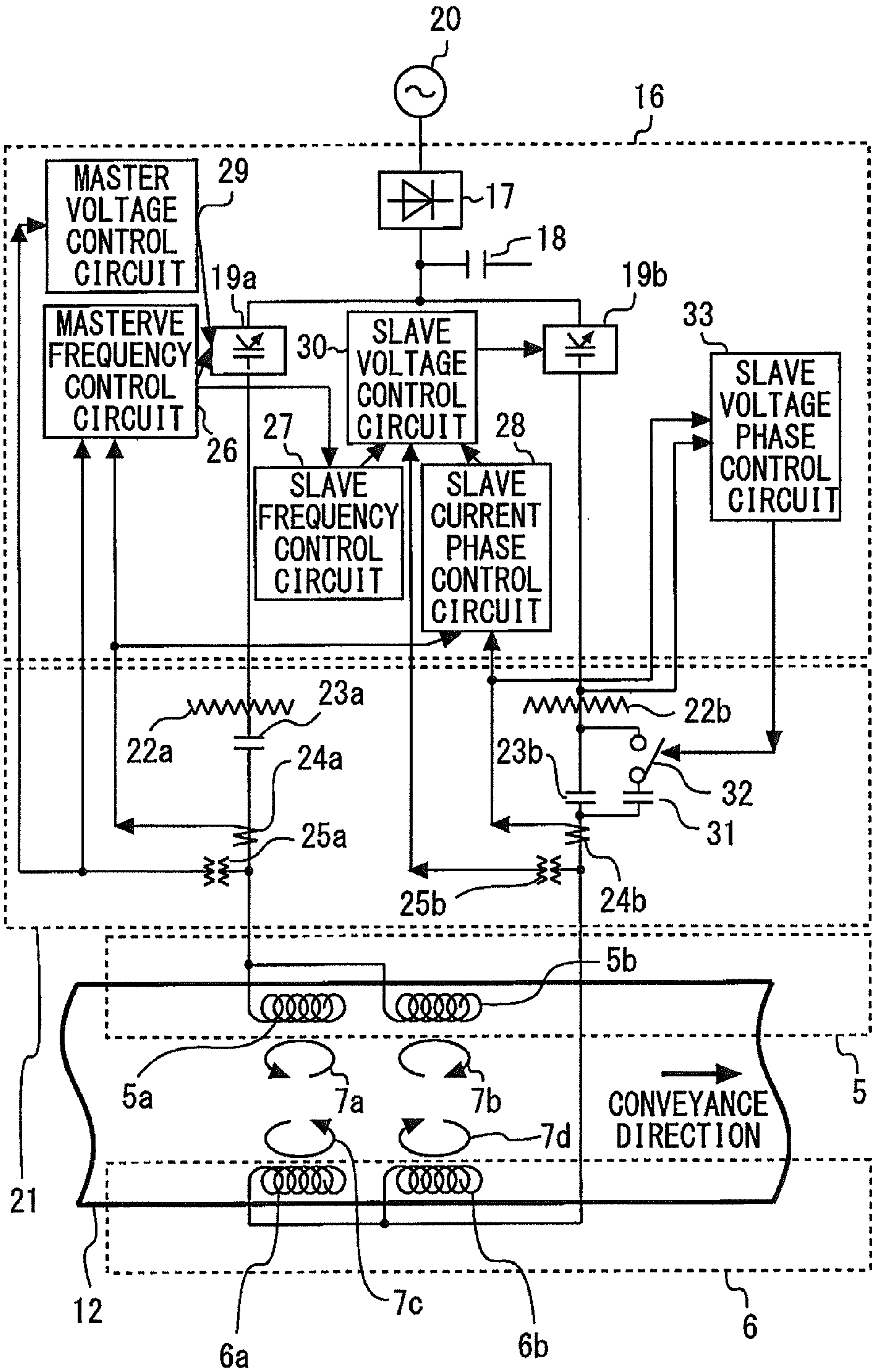

20
16
MASTER VOLTAGE CONTROL CIRCUIT
29
17
18
19a
19b
MASTERVE FREQUENCY CONTROL CIRCUIT
30
SLAVE VOLTAGE CONTROL CIRCUIT
33
SLAVE VOLTAGE PHASE CONTROL CIRCUIT
26
27
28
SLAVE FREQUENCY CONTROL CIRCUIT
SLAVE CURRENT PHASE CONTROL CIRCUIT
23a
22a
24a
22b
23b
32
25a
31
25b
24b
5b
5a
7a
7b
CONVEYANCE DIRECTION
5
7d
21
12
7c
6a
6b
6

FIG. 8

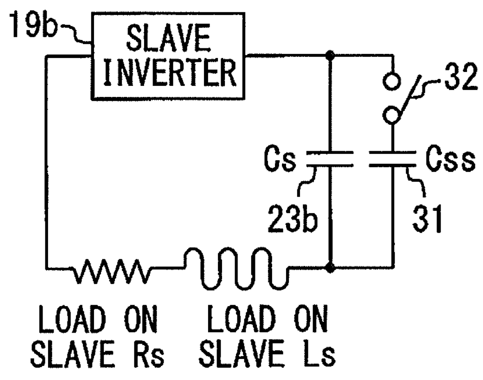

19b
SLAVE INVERTER
32
Cs
Css
23b
31
LOAD ON SLAVE Rs
LOAD ON SLAVE Ls

FIG. 9

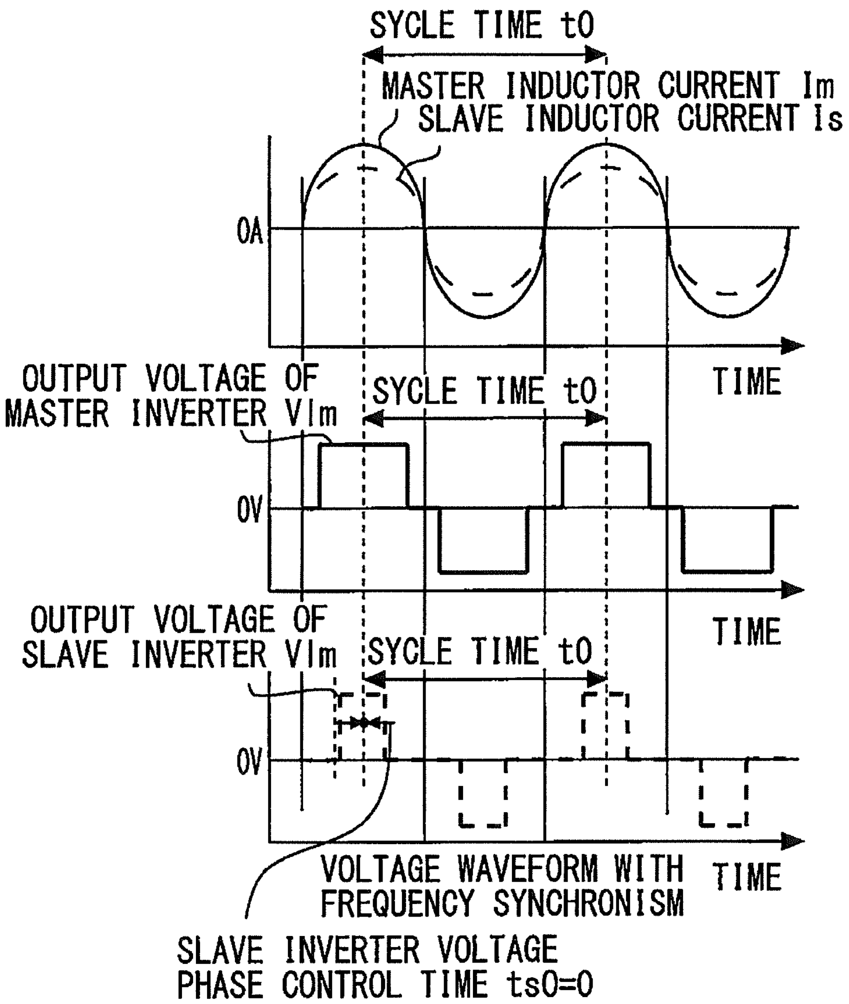
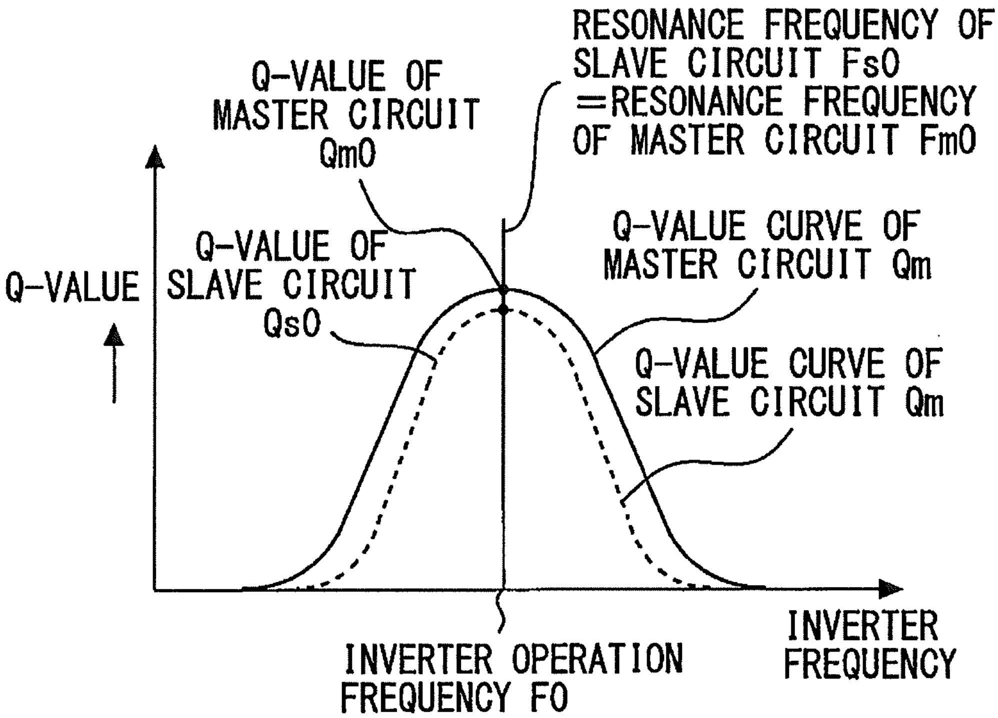

SYCLE TIME t0
MASTER INDUCTOR CURRENT Im
SLAVE INDUCTOR CURRENT Is
0A
TIME
OUTPUT VOLTAGE OF MASTER INVERTER VIm
SYCLE TIME t0
0V
TIME
OUTPUT VOLTAGE OF SLAVE INVERTER VIm
SYCLE TIME t0
0V
VOLTAGE WAVEFORM WITH FREQUENCY SYNCHRONISM
TIME
SLAVE INVERTER VOLTAGE PHASE CONTROL TIME ts0=0

FIG. 10



SLAVE RESONANCE FREQUENCY SYNCHRONOUS Q-VALUE CURVE

FIG. 11

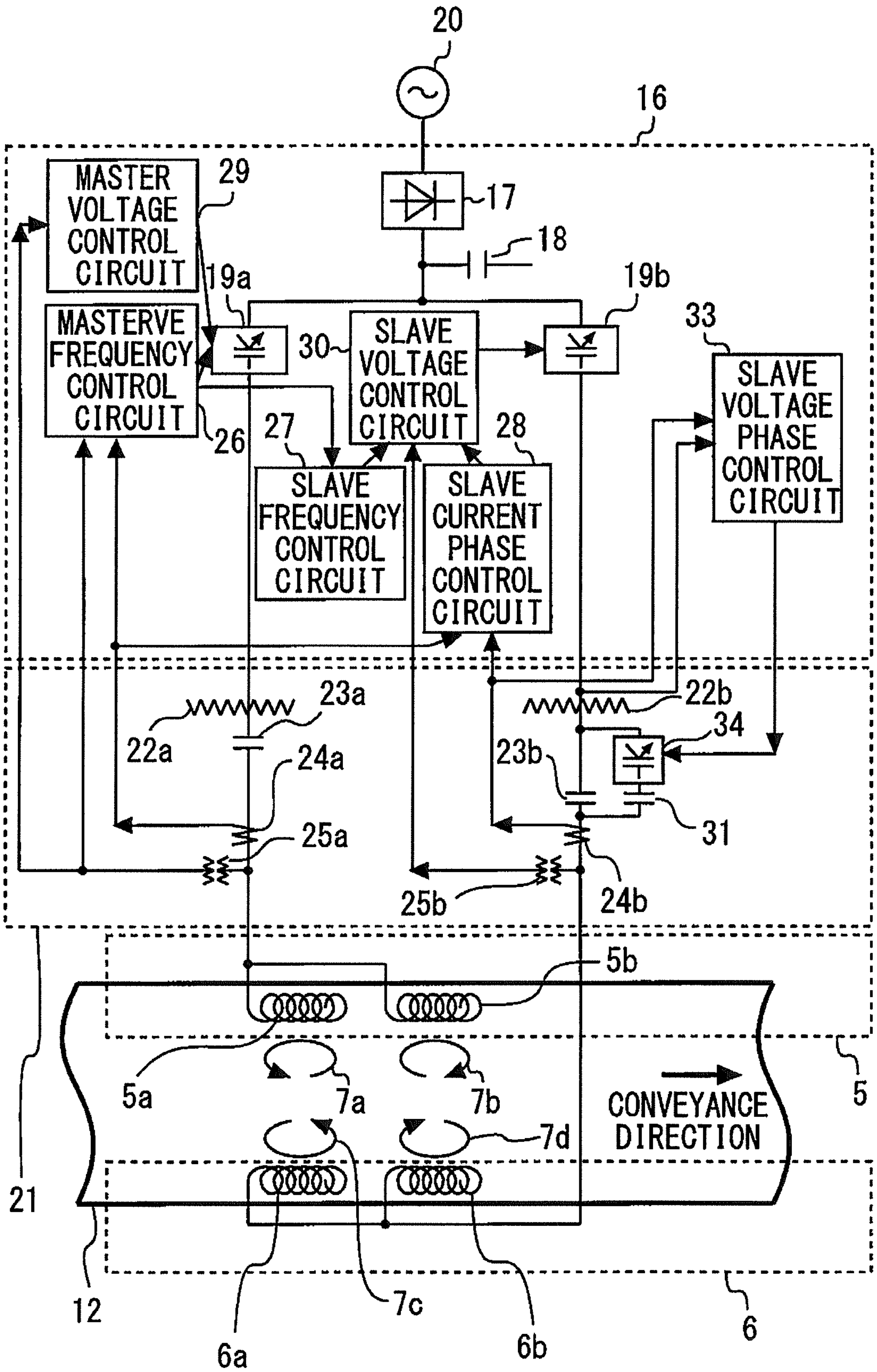

20
16
MASTER VOLTAGE CONTROL CIRCUIT
29
17
18
19a
19b
33
MASTERVE FREQUENCY CONTROL CIRCUIT
30
SLAVE VOLTAGE CONTROL CIRCUIT
SLAVE VOLTAGE PHASE CONTROL CIRCUIT
26
27
28
SLAVE FREQUENCY CONTROL CIRCUIT
SLAVE CURRENT PHASE CONTROL CIRCUIT
23a
22b
22a
34
24a
23b
25a
31
25b
24b
5b
5a
7a
7b
CONVEYANCE DIRECTION
5
7d
21
12
7c
6
6a
6b

FIG. 12

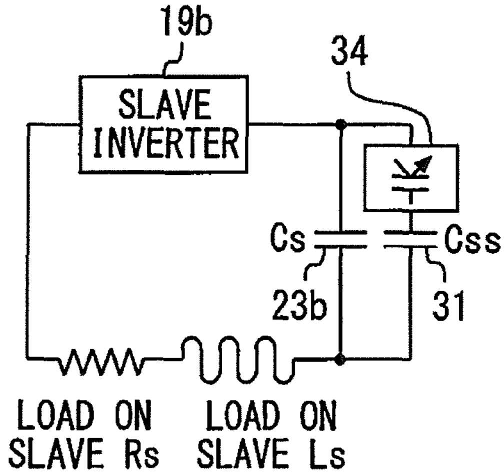

19b
SLAVE
INVERTER
34
Cs
Css
23b
31
LOAD ON
SLAVE Rs
LOAD ON
SLAVE Ls

FIG. 13

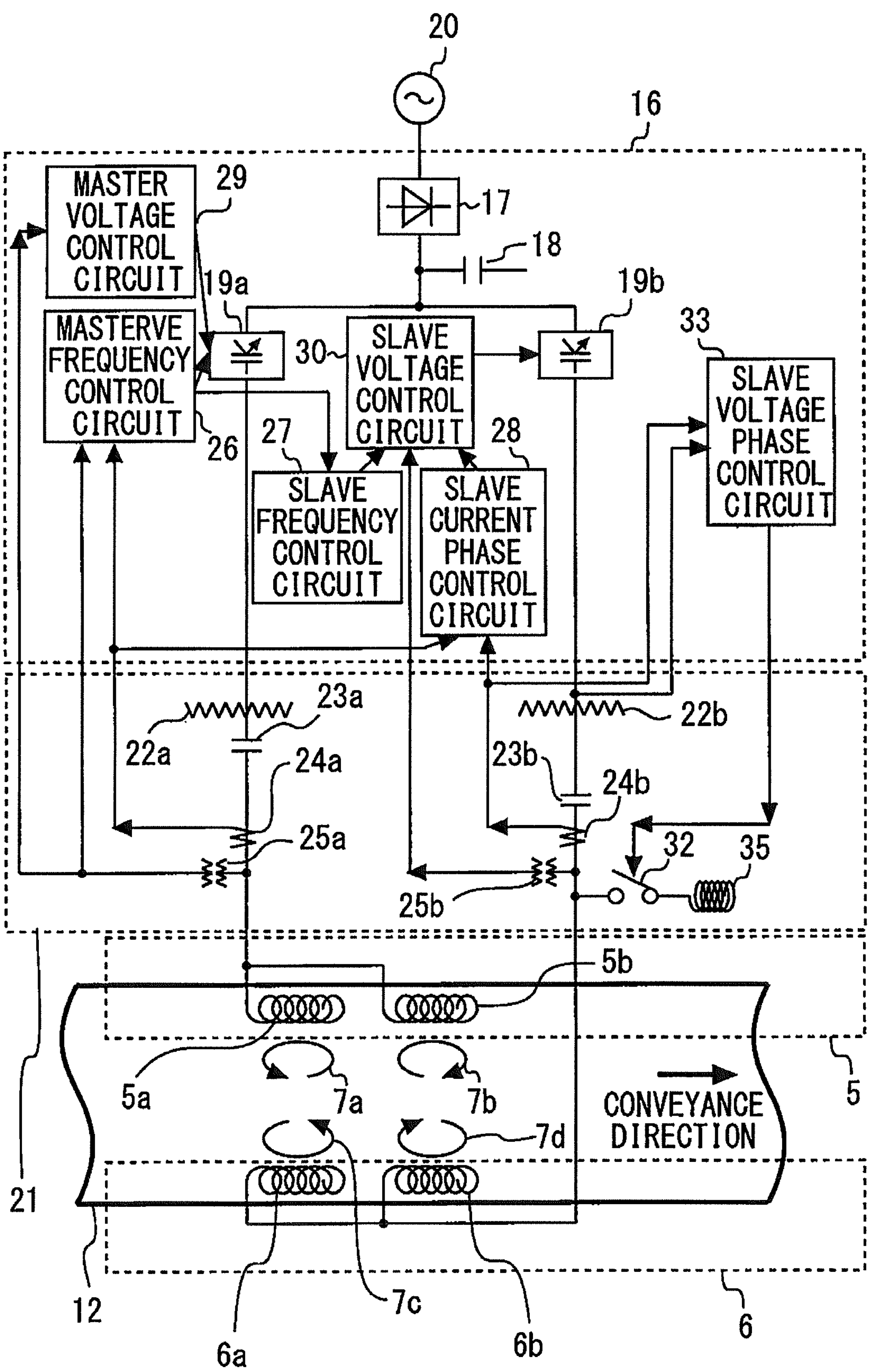

20
16
MASTER VOLTAGE CONTROL CIRCUIT
29
17
18
19a
19b
MASTERVE FREQUENCY CONTROL CIRCUIT
30
SLAVE VOLTAGE CONTROL CIRCUIT
33
SLAVE VOLTAGE PHASE CONTROL CIRCUIT
26
27
28
SLAVE FREQUENCY CONTROL CIRCUIT
SLAVE CURRENT PHASE CONTROL CIRCUIT
23a
22a
22b
24a
23b
24b
25a
32
35
25b
5b
5a
7a
7b
5
CONVEYANCE DIRECTION
7d
21
12
7c
6a
6b
6

FIG. 14

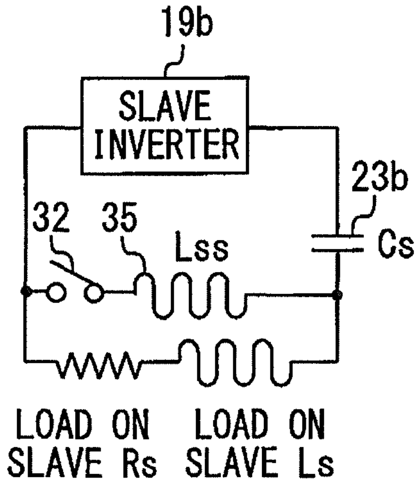

19b
SLAVE
INVERTER
23b
Cs
32
35
Lss
LOAD ON
SLAVE Rs
LOAD ON
SLAVE Ls

FIG. 15

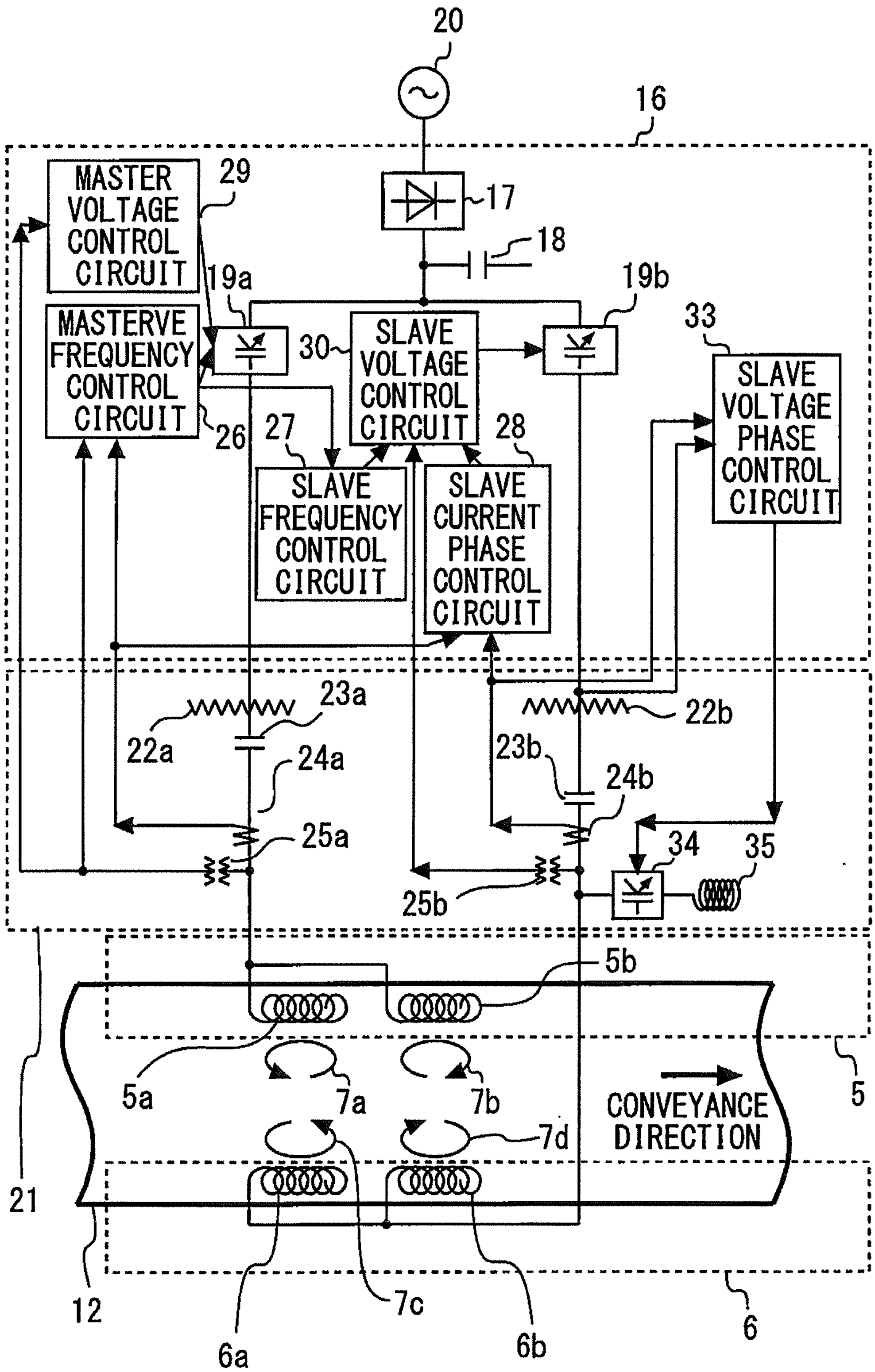
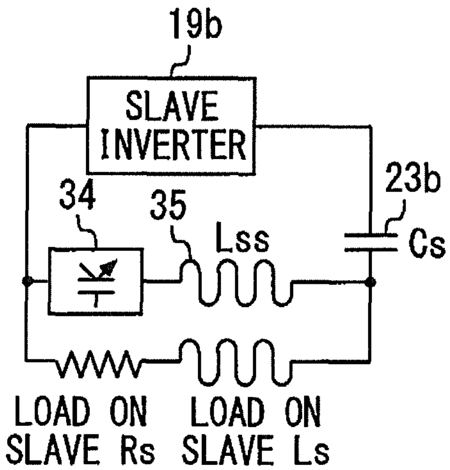

20
16
MASTER VOLTAGE CONTROL CIRCUIT
29
17
18
19a
19b
MASTERVE FREQUENCY CONTROL CIRCUIT
30
SLAVE VOLTAGE CONTROL CIRCUIT
33
SLAVE VOLTAGE PHASE CONTROL CIRCUIT
26
27
28
SLAVE FREQUENCY CONTROL CIRCUIT
SLAVE CURRENT PHASE CONTROL CIRCUIT
23a
22a
24a
22b
23b
24b
25a
25b
34
35
5b
5a
7a
7b
5
CONVEYANCE DIRECTION
7d
21
12
7c
6
6a
6b

FIG. 16


19b
SLAVE
INVERTER
23b
34
35
Lss
Cs
LOAD ON
SLAVE Rs
LOAD ON
SLAVE Ls

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2012/071565

A. CLASSIFICATION OF SUBJECT MATTER
H05B6/06(2006.01)i, *H05B6/10*(2006.01)i

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)
H05B6/06, H05B6/10

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2012
Kokai Jitsuyo Shinan Koho	1971-2012	Toroku Jitsuyo Shinan Koho	1994-2012

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 5-299162 A (Sumitomo Metal Industries, Ltd.), 12 November 1993 (12.11.1993), paragraph [0003]; fig. 6 (Family: none)	1-6
Y	JP 2011-65818 A (Toshiba Mitsubishi-Electric Industrial Systems Corp.), 31 March 2011 (31.03.2011), fig. 1 & CN 102026432 A & KR 10-2011-0030243 A	1-6
Y	JP 5-315064 A (Nippon Kinzoku Co., Ltd.), 26 November 1993 (26.11.1993), paragraph [0016] (Family: none)	1-6

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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Date of the actual completion of the international search	Date of mailing of the international search report
05 September, 2012 (05.09.12)	18 September, 2012 (18.09.12)

Name and mailing address of the ISA/	Authorized officer
Japanese Patent Office	
Facsimile No.	Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2012/071565

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2002-313547 A (Mitsui Engineering & Shipbuilding Co., Ltd.), 25 October 2002 (25.10.2002), paragraphs [0008], [0019] to [0031]; fig. 6 (Family: none)	1-6
Y	Microfilm of the specification and drawings annexed to the request of Japanese Utility Model Application No. 99097/1982(Laid-open No. 3498/1984) (Fuji Denki Seizo Kabushiki Kaisha), 10 January 1984 (10.01.1984), fig. 2 (Family: none)	3-6
Y	JP 2010-245002 A (Mitsui Engineering & Shipbuilding Co., Ltd.), 28 October 2010 (28.10.2010), paragraphs [0069], [0070]; fig. 5 (Family: none)	3-6
A	JP 2011-14331 A (SPC Electronics Corp.), 20 January 2011 (20.01.2011), paragraphs [0051] to [0062]; fig. 1 (Family: none)	1-6
A	JP 2002-260833 A (Mitsui Engineering & Shipbuilding Co., Ltd.), 13 September 2002 (13.09.2002), paragraphs [0017] to [0019] & US 2006/0237449 A1 & US 2006/0237450 A1	1-6
A	JP 5-192775 A (Mitsubishi Electric Corp.), 03 August 1993 (03.08.1993), fig. 2 (Family: none)	1-6

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REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 3156746 B **[0003]**