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(54) **Eljárás és berendezés munkadarab gradiens indukciós melegítésére**

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(54) **Gradient induction heating of a workpiece**

Gradientinduktionsheizung für ein Bauteil

Chauffage par induction par gradient de piéces

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WO-A1-00/28787
DE-A1- 3 710 085
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Description

Field of the Invention

[0001] The present invention relates to controlled gradient induction heating of a workpiece.

Background of the Invention

[0002] It is advantageous to heat certain workpieces to a temperature gradient along a dimension of the workpiece. For example a cylindrical aluminum workpiece, or billet, that undergoes an extrusion process is generally heated to a higher temperature throughout its cross section at the end of the billet that is first drawn through the extruder than the cross section at the opposing end of the billet. This is done since the extrusion process itself is exothermic and heats the billet as it passes through the extruder. If the billet was uniformly heated through its cross section along its entire longitudinal axis, the opposing end of the billet would be overheated prior to extrusion and experience sufficient heat deformation to make extrusion impossible.

[0003] One method of achieving gradient induction heating of an electrically conductive billet, such as an aluminum alloy billet along its longitudinal axis, is to surround the billet with discrete sequential solenoidal induction coils. Each coil is connected to an current source at supply line frequency (i.e. 50 or 60 Hertz). Current flowing through each solenoidal coil establishes a longitudinal flux field around the coil that penetrates the billet and inductively heats it. In order to achieve gradient heating along the billet's longitudinal axis, each coil in sequence from one end of the billet to the other generally supplies a smaller magnitude of current (power) to the coil. Silicon controlled rectifiers may be used in series with the induction coil to achieve adjustable currents in the sequence of coils.

[0004] Use of supply line frequency makes for a simple current source but limits the range of billet sizes that can be commercially heated in such an arrangement. Penetration depth (in meters) of the induction current is defined by the equation, $503(p/\mu F)^{1/2}$, where ρ is the electrical resistively of the billet in $\Omega{\cdot}$m.; μ is the relative (dimensionless) magnetic permeability of the billet; and F is the frequency of the applied field. The magnetic permeability of a non-magnetic billet, such as aluminum, is 1. Aluminum at 500°C has an electrical resistivity of 0.087 $\mu\Omega{\cdot}$meter. Therefore from the equation, with F equal to 60 Hertz, the penetration depth can be calculated as approximately 19.2 mm, or approximately 0.8-inch. Induction heating of a billet is practically accomplished by a "soaking" process rather than attempting to inductively heat the entire cross section of the billet at once. That is the induced field penetrates a portion of the cross section of the billet, and the induced heat is allowed to radiate (soak) into the center of the billet. Typically an induced field penetration depth of one-fifth of the cross sectional radius of the billet is recognized as an efficient penetration depth. Therefore an aluminum billet with a radius of 4 inches (102 mm) results in the optimal penetration depth of 0.8-inch (19.2 mm) with 60 Hertz current. Consequently the range of billet sizes that can be efficiently heated by induction with a single frequency is limited.

[0005] DE-A-3710085 (Asea Brown Boveri) discloses an apparatus for inductively heating workpieces in which an inverter for each of a number of inductors is connected by a respective smoothing choke to the output of a rectifier and each inverter is controlled independently of the others by an associated load oscillating circuit.

[0006] WO-A-00/28787 (Inductotherm) discloses a multi-section induction coil surrounding a susceptor. Power is provided to each of the sections of the coil from a single power source via a switching circuit.

[0007] One objective of the present invention is to provide an apparatus and a method of gradient inductive heating of a billet with a frequency of current that can easily be changed for varying sizes of workpieces.

Brief Summary of the Invention

[0008] The present invention provides an apparatus as set out in claim 1 and a method as set out in claim 7.

[0009] Other aspects of the invention are set forth in the dependent claims.

Brief Description of the Drawings

[0010] The figures, in conjunction with the specification and claims, illustrate one or more non-limiting modes of practising the invention. The invention is not limited to the illustrated layout and content of the drawings.

[0011] **FIG. 1** is a simplified schematic illustrating one example of the gradient induction heating or melting apparatus of the present invention.

[0012] **FIG. 2** is a simplified schematic illustrating one of the plurality of power supplies used in the gradient induction heating or melting apparatus of the present invention.

[0013] **FIG. 3** is a graph illustrating typical results in load coil currents for variations in inverter output voltages for one example of the gradient induction heating or melting apparatus of the present invention.

Detailed Description of the Invention

[0014] There is shown in **FIG. 1** one example of the gradient induction heating apparatus **10** of the present invention. The workpiece in this particular non-limiting example, is billet **12.** The dimensions of the billet in **FIG. 1** are exaggerated to show sequential induction coils **14a** to **14f** around the workpiece. The workpiece may be any type of electrically conductive workpiece that requires gradient heating along one of its dimensions, but for convenience, in this specific example, the workpiece will be referred to as a billet and gradient heating will be achieved along the longitudinal axis of the billet. In other examples of the invention, the workpiece may be an electrically conductive material placed within a crucible, or a susceptor that is heated to transfer heat to another material. In these examples of the invention, the induction coils are disposed around the crucible or susceptor to provide gradient heating of the material placed in the crucible or the susceptor.

[0015] Induction coils **14a** to **14f** are shown diagrammatically in **FIG. 1.** Practically the coils will be tightly wound solenoidal coils and adjacent to each other with separation as required to prevent shorting between coils, which may be accomplished by placing a dielectric material between the coils. Other coil configurations are contemplated within the scope of the invention.

[0016] Pulse width modulated (PWM) power supplies **16a** to **16f** can supply different rms value currents (power) to induction coils **14a** to **14f,** respectively. Each power supply may include a rectifier/inverter power supply with a low pass filter capacitor **(C_F)** connected across the output of rectifier **60** and a tuning capacitor **(C_{TF})** connected across the input of inverter **62** as shown in **FIG. 2,** and as disclosed in U.S. Patent No. 6,696,770 titled *Induction Heating or Melting Power Supply Utilizing a Tuning Capacitor.* In **FIG. 2, L_{fc}** is an optional line filter and **L_{clr}** is a current limiting reactor. The output of each power supply is a pulse width modulated voltage to each of the induction coils.

[0017] **FIG. 2** further illustrates the details of a typical power supply wherein the non-limiting power source (designated lines **A, B** and **C)** to each power supply is 400 volts, 30 Hertz. Inverter **62** comprises a full bridge inverter utilizing IGBT switching devices. In other examples of the invention the inverter may be otherwise configured such as a resonant inverter or an inverter utilizing other types of switching devices. Microcontroller **MC** provides a means for control and indication functions for the power supply. Most relevant to the present invention, the microcontroller controls the gating circuits for the four IGBT switching devices in the bridge circuit. In this non-limiting example of the invention the gating circuits are represented by a field programmable gate array (FPGA), and gating signals can be supplied to the gates **G1** through **G4** by a fiber optic link (indicated by dashed lines **61** in **FIG. 2).** The induction coil connected to the output of power supply shown in **FIG. 2** is represented as load coil **L_{load}**. Coil **L_{load}** represents one of the induction coils **14a** through **14f** in **FIG. 1.** The resistive element, **R,** in **FIG. 2** represents the resistive impedance of heated billet 12 that is inserted in the billet, as shown in **FIG. 1.**

[0018] In operation the inverter's pulse width modulated output of each power supply **16a** through **16f** can be varied in duration, phase and/or magnitude to achieve the required degree of gradient induction heating of the billet. **FIG. 3** is a typical graphical illustration of variations in the voltage outputs **(V_1, V_2** and **V_3)** from the power supplies for three adjacent induction coils that result in load coil currents **I_1, I_2** and **I_3,** respectively. Desired heating profiles can be incorporated into one or more computer programs that are executed by a master computer communicating with the microcontroller in each of the power supplies. The induction coils have mutual inductance; to prevent low frequency beat oscillations all coils should operate at substantially the same frequency. In utilizing the flexibility provided by the use of inverters with pulse width modulated outputs, all inverters are synchronized. That is, the output frequency and phase of all inverters are, in general, synchronized.

[0019] While energy flows from the output of each inverter to its associated induction coil two diagonally disposed switching devices (e.g., **S_1** and **S_3,** or **S_2** and **S_4** in **FIG. 2)** are conducting and voltage is applied across the load coil. At other times the coil is shorted and current is flowing via one switching device and an antiparallel diode (e.g., **S_1** and **D_2; S_2** and **D_1; S_3** and **D_4;** or **S_4** and **D_3** in **FIG. 2.** This minimizes pickup of energy from adjacent coils.

[0020] Referring back to **FIG. 1,** synchronous control of the power outputs of the plurality of power supplies is used to minimize circuit interference between adjacent coils. Serial control loop **40** represents a non-limiting means for synchronous control of the power outputs of the plurality of power supplies. In this non-limiting example of the invention serial control loop **40** may comprise a fiber optic cable link (FOL) that serially connects all of the power supplies. Control input (CONTROL INPUT in **FIG. 1)** of the control link to each power supply may be a fiber optic receiver (FOR) and control output (CONTROL OUTPUT in **FIG. 1)** of the control link from each power supply may be a fiber optic transmitter (FOT). One of the controllers of the plurality of power supplies, for example the controls of power supply **16a** is programmably selected as the master controller. The CONTROL OUTPUT of the master controller of power supply **16a** outputs a normal synchronization pulse **20** to the CONTROL INPUT of the slave controller of power supply **16f.** If slave controller of power supply **16f** is in a normal operating state, it passes the normal synchronization pulse to the slave controller of power supply **16e,** and so on, until the normal synchronization pulse is returned to the CONTROL INPUT of the master controller of power supply **16a.** In addition each controller generates an independent pulse width modulated ac output power for each inverter in the plurality of power supplies. In the event of an abnormal condition in any one of the power supplies, the effected controller can output an abnormal operating pulse to the controller of the next power supply. For example while a normal synchronization pulse may be on the order of 2 microseconds, an abnormal operating pulse may be on the order of 50 microseconds. Abnormal operating pulses are processed by the upstream controllers of power supplies to shutdown or modify the induction heating process. Generally the time delay in the round trip transmission of the synchronization pulse from and to the master controller is negligible. In the event of failure of one of the controllers, a synchronizing signal will not return to the master controller, which will result in the execution of an abnormal condition routine, such as stopping subsequent normal synchronization pulse generation.

[0021] In the above non-limiting example of the invention six power supplies and induction coils are used. In other examples of the invention other quantities of power supplies and coils may be used without deviating from the scope of the invention.

[0022] The examples of the invention include reference to specific electrical components. One skilled in the art may practise the invention by substituting components that are not necessarily of the same type but will create the desired conditions or accomplish the desired results of the invention. For example, single components may be substituted for multiple components or vice versa.

[0023] The foregoing examples do not limit the scope of the invention. The scope of the invention is set forth in the appended claims.

Claims

1. Apparatus for gradient induction heating or melting of a workpiece (12), the apparatus comprising:

a plurality of induction coils (14a-14f) for sequential disposition around the workpiece; and
a power supply (16a-16f) for each of the plurality of induction coils, each of the power supplies including an inverter (INV) having an ac output connected to a respective one of the plurality of induction coils;
characterised in that:

a control line (40) is connected between the power supplies;
the ac output of the inverter of each of the power supplies has pulse width modulation control; and
the control line synchronously controls the pulse width modulated ac output of the inverter of each, of the power supplies.

2. An apparatus according to claim 1, wherein the inverter of each of the power supplies comprises at least four solid state switching devices (S_1, S_2, S_3, S_4) and a controlled (MC) associated with each inverter controls the inverters's solid state switching devices.

3. An apparatus according to claim 1 or 2, wherein at least one of the inverters has a tuning capacitor (C_{TF}) across the input of the inverter.

4. An apparatus according to any preceding claim, wherein the plurality of induction coils are tightly wound solenoid induction coils disposed adjacent to each other with dielectric separation to prevent shorting between adjacent coils.

5. An apparatus according to any preceding claim, wherein the workpiece comprises electrically conductive material placed within a crucible.

6. An apparatus according to any of claims 1 to 4, wherein the workpiece comprises a susceptor.

7. A method of gradiently heating or melting a workpiece (12) by induction, comprising the steps of:

supplying ac power from a respective inverter (INV) to each one of a plurality of induction coils (14a-14f) disposed around and along the length of the workpiece;
inducing a separate magnetic field around each one of the plurality of induction coils;
characterised by:

pulse width modulating the ac power from each of the separate inverters to each of the plurality of induction coils; and
varying the pulse width modulation of the ac power from each of the separate inverters.

8. A method according to claim 7, including the step of inserting a tuning capacitor (C_{TF}) across the input of at least one of the separate inverters.

9. A method according to claim 7 or 8, including the step of synchronizing the pulse width modulation of the ac power from each of the inverters.

10. A method according to claim 9, including the step of transmitting a control signal serially between the inverters to synchronize the pulse width modulation of the ac power from each of the separate inverters.

11. A method according to claim 10, wherein the control signal comprises a master control signal generated in one of the inverters for serial transmission to the remaining plurality of inverters.

12. A method according to claim 11, wherein one of the inverters generates an abnormal control signal serially to the one of the inverters in which the master control signal is generated.

Patentansprüche

1. Vorrichtung zum schrittweisen Induktionserhitzen oder -schmelzen eines Werkstückes (12), wobei die Vorrichtung Folgendes umfasst:

eine Vielzahl von Induktionsspulen (14a-14f) zur sequentiellen Anordnung um das Werkstück; und
eine Stromversorgung (16a-16f) für jede der Vielzahl von Induktionsspulen, wobei jede der Stromversorgungen einen Wechselrichter (INV) umfasst, der einen Wechselstromausgang aufweist, der mit einer jeweiligen einen der Vielzahl von Induktionsspulen verbunden ist;
dadurch gekennzeichnet, dass:

eine Steuerleitung (40) zwischen den Stromversorgungen angeschlossen ist;
der Wechselstromausgang des Wechselrichters von jeder der Stromversorgungen eine Pulsbreitenmodulationssteuerung aufweist; und
die Steuerleitung den pulsbreitenmodulierten Wechselstromausgang des Wechselrichters von jeder der Stromversorgungen synchron steuert.

2. Vorrichtung nach Anspruch 1, wobei der Wechselrichter von jeder der Stromversorgungen mindestens vier Festkörperschaltvorrichtungen (S_1, S_2, S_3, S_4) umfasst und wobei eine Steuerung (MC), die jedem Wechselrichter zugeordnet ist, die Festkörperschaltvorrichtungen des Wechselrichters steuert.

3. Vorrichtung nach Anspruch 1 oder 2, wobei mindestens einer der Wechselrichter einen Abstimmkondensator (C_{TF}) am Eingang des Wechselrichters aufweist.

4. Vorrichtung nach einem der vorhergehenden Ansprüche, wobei die Vielzahl von Induktionsspulen eng gewickelte Magnetinduktionsspulen sind, die benachbart zueinander mit einer dielektrischen Trennung angeordnet sind, um einen Kurzschluss zwischen benachbarten Spulen zu verhindern.

5. Vorrichtung nach einem der vorhergehenden Ansprüche, wobei das Werkstück elektrisch leitfähiges Material umfasst, das in einem Tiegel angeordnet wird.

6. Vorrichtung nach einem der Ansprüche 1 bis 4, wobei das Werkstück einen Suszeptor umfasst.

7. Verfahren zum schrittweisen Erhitzen oder Schmelzen eines Werkstückes (12) durch Induktion, wobei das Verfahren folgende Schritte umfasst:

Anlegen eines Wechselstroms von einem jeweiligen Wechselrichter (INV) an jede von einer Vielzahl von Induktionsspulen (14a-14f), die um und entlang der Länge des Werkstücks angeordnet sind;
Induzieren eines separaten Magnetfelds um jede der Vielzahl von Induktionsspulen;
gekennzeichnet durch:

Pulsbreitenmodulation des Wechselstroms von jedem der separaten Wechselrichter zu jeder der Vielzahl von Induktionsspulen; und
Variieren der Pulsbreitenmodulation des Wechselstroms von jedem der separaten Wechselrichter.

8. Verfahren nach Anspruch 7, das den Schritt des Einfügens eines Abstimmkondensators (C_{TF}) am Eingang von mindestens einem der separaten Wechselrichter umfasst.

9. Verfahren nach Anspruch 7 oder 8, das den Schritt des Synchronisierens der Pulsbreitenmodulation des Wechselstroms von jedem der separaten Wechselrichter umfasst.

10. Verfahren nach Anspruch 9, das den Schritt des seriellen Übertragens eines Steuersignals zwischen den Wechselrichtern umfasst, um die Pulsbreitenmodulation des Wechselstroms von jedem der separaten Wechselrichter zu synchronisieren.

11. Verfahren nach Anspruch 10, wobei das Steuersignal ein Hauptsteuersignal umfasst, das in einem der Wechselrichter für die serielle Übertragung zu der verbleibenden Vielzahl von Wechselrichtern erzeugt wird.

12. Verfahren nach Anspruch 11, wobei einer der Wechselrichter ein abnormales Steuersignal für denjenigen Wechselrichter seriell erzeugt, in dem das Hauptsteuersignal erzeugt wird.

Revendications

1. Un appareil destiné au chauffage ou à la fusion par induction à gradient d'une pièce à usiner (12), l'appareil comprenant :

une pluralité de bobines d'induction (14a-14f) destinées à une disposition séquentielle autour de la pièce à usiner, et
une alimentation électrique (16a-16f) destinée à chaque bobine de la pluralité de bobines d'induction, chacune des alimentations électriques comprenant un inverseur (INV) possédant une sortie c.a. raccordée à une bobine respective de la pluralité de bobines d'induction,
caractérisé en ce que :

une ligne de commande (40) est raccordée

entre les alimentations électriques,
la sortie c.a. de l'inverseur de chacune des alimentations électriques possède une commande à modulation de largeur d'impulsions, et
la ligne de commande commande de manière synchronisée la sortie c.a. à modulation de largeur d'impulsions de l'inverseur de chacune des alimentations électriques.

2. Un appareil selon la Revendication 1, où l'inverseur de chacune des alimentations électriques comprend au moins quatre dispositifs de commutation à semiconducteur (S_1, S_2, S_3, S_4) et un dispositif de commande (MC) associé à chaque inverseur commande les dispositifs de commutation à semiconducteur de l'inverseur.

3. Un appareil selon la Revendication 1 ou 2, où au moins un des inverseurs possède une capacité d'accord (C_{TF}) sur l'entrée de l'inverseur.

4. Un appareil selon l'une quelconque des Revendications précédentes, où la pluralité de bobines d'induction sont des bobines d'induction à solénoïde étroitement enroulées disposées adjacentes les unes aux autres avec une séparation diélectrique destinée à empêcher un court-circuit entre des bobines adjacentes.

5. Un appareil selon l'une quelconque des Revendications précédentes où la pièce à usiner comprend un matériau électriquement conducteur placé à l'intérieur d'un creuset.

6. Un appareil selon l'une quelconque des Revendications 1 à 4, où la pièce à usiner comprend un suscepteur.

7. Un procédé de chauffage ou de fusion à gradient d'une pièce à usiner (12) par induction comprenant les opérations suivantes :

la fourniture d'une alimentation c.a. à partir d'un inverseur respectif (INV) à chaque bobine d'une pluralité de bobines d'induction (14a-14f) disposées autour et le long de la longueur de la pièce à usiner,
l'induction d'un champ magnétique distinct autour de chaque bobine de la pluralité de bobines d'induction,
caractérisé par :

la modulation en largeur d'impulsions de l'alimentation c.a. à partir de chacun des inverseurs distincts vers chaque bobine de la pluralité de bobines d'induction,
et
la variation de la modulation en largeur d'impulsions de l'alimentation c.a. à partir de chacun des inverseurs distincts.

8. Un procédé selon la Revendication 7, comprenant l'opération d'insertion d'une capacité d'accord (C_{TF}) sur l'entrée d'au moins l'un des inverseurs distincts.

9. Un procédé selon la Revendication 7 ou 8, comprenant l'opération de synchronisation de la modulation en largeur d'impulsions de l'alimentation c.a. à partir de chacun des inverseurs.

10. Un procédé selon la Revendication 9, comprenant l'opération de transmission d'un signal de commande en série entre les inverseurs de façon à synchroniser la modulation en largeur d'impulsions de l'alimentation c.a. à partir de chacun des inverseurs distincts.

11. Un procédé selon la Revendication 10, où le signal de commande comprend un signal de commande maître généré dans l'un des inverseurs pour une transmission en série vers la pluralité restante d'inverseurs.

12. Un procédé selon la Revendication 11, où l'un des inverseurs génère un signal de commande anormal en série vers l'un des inverseurs dans lequel le signal de commande maître est généré.

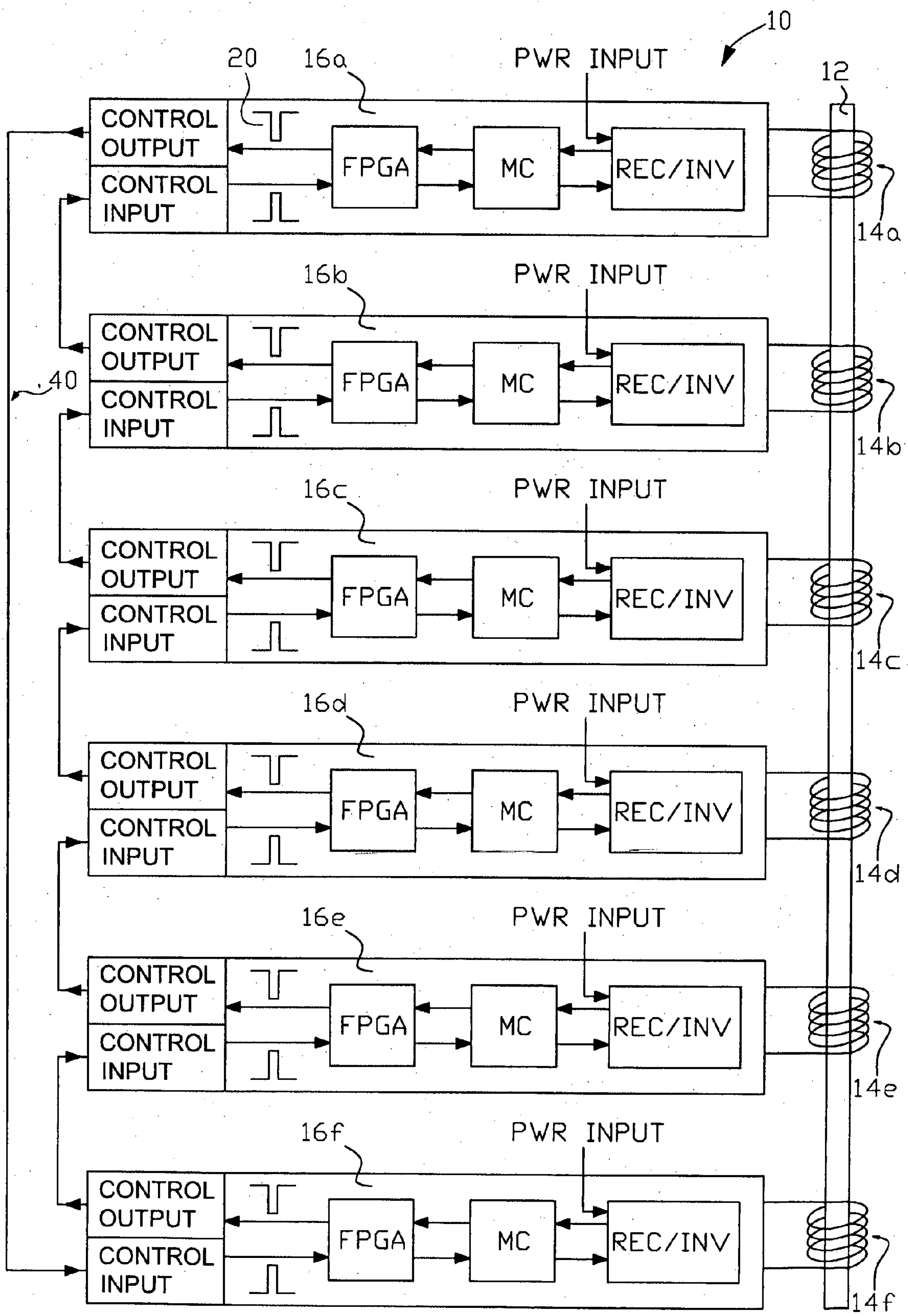
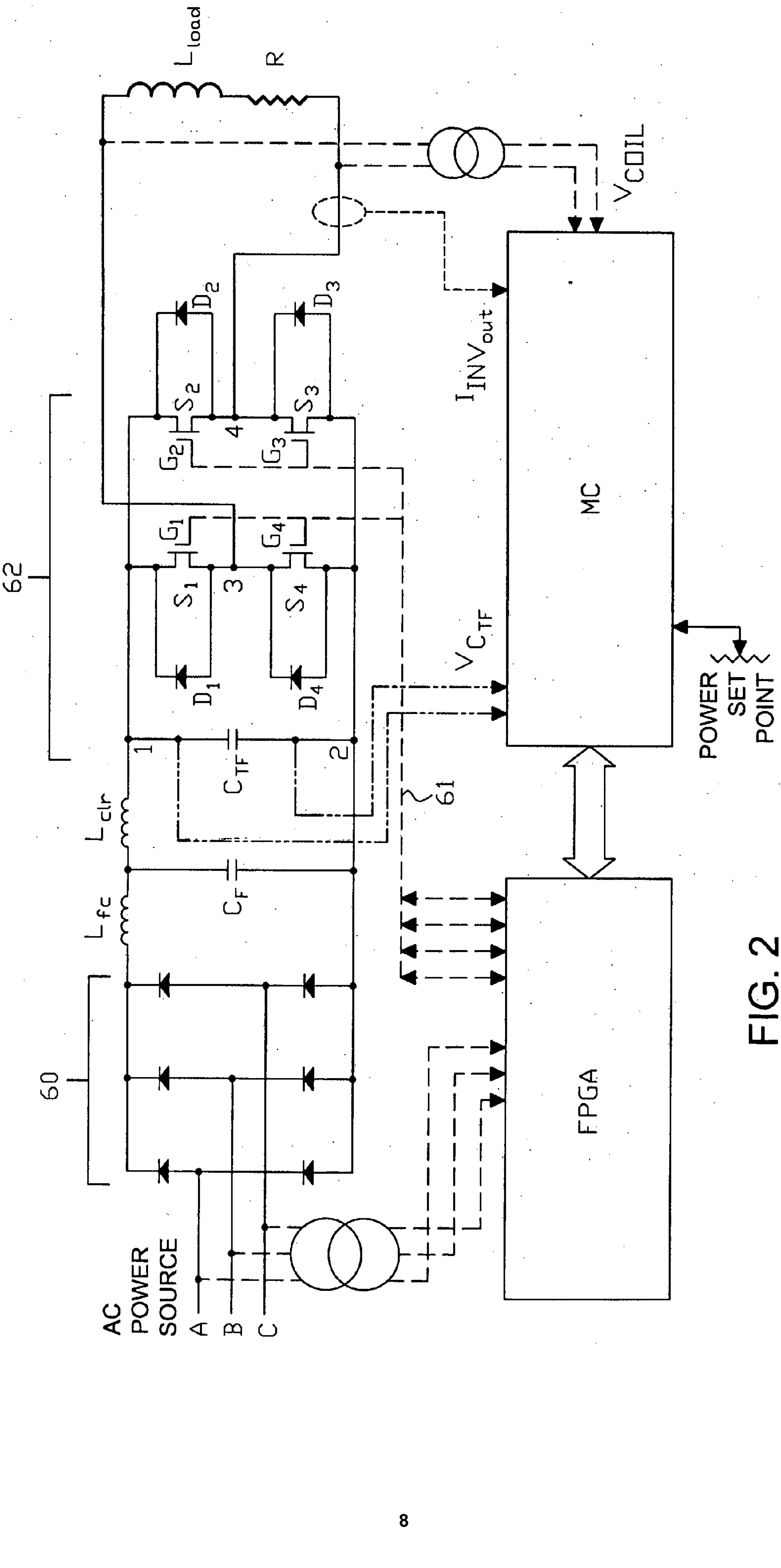
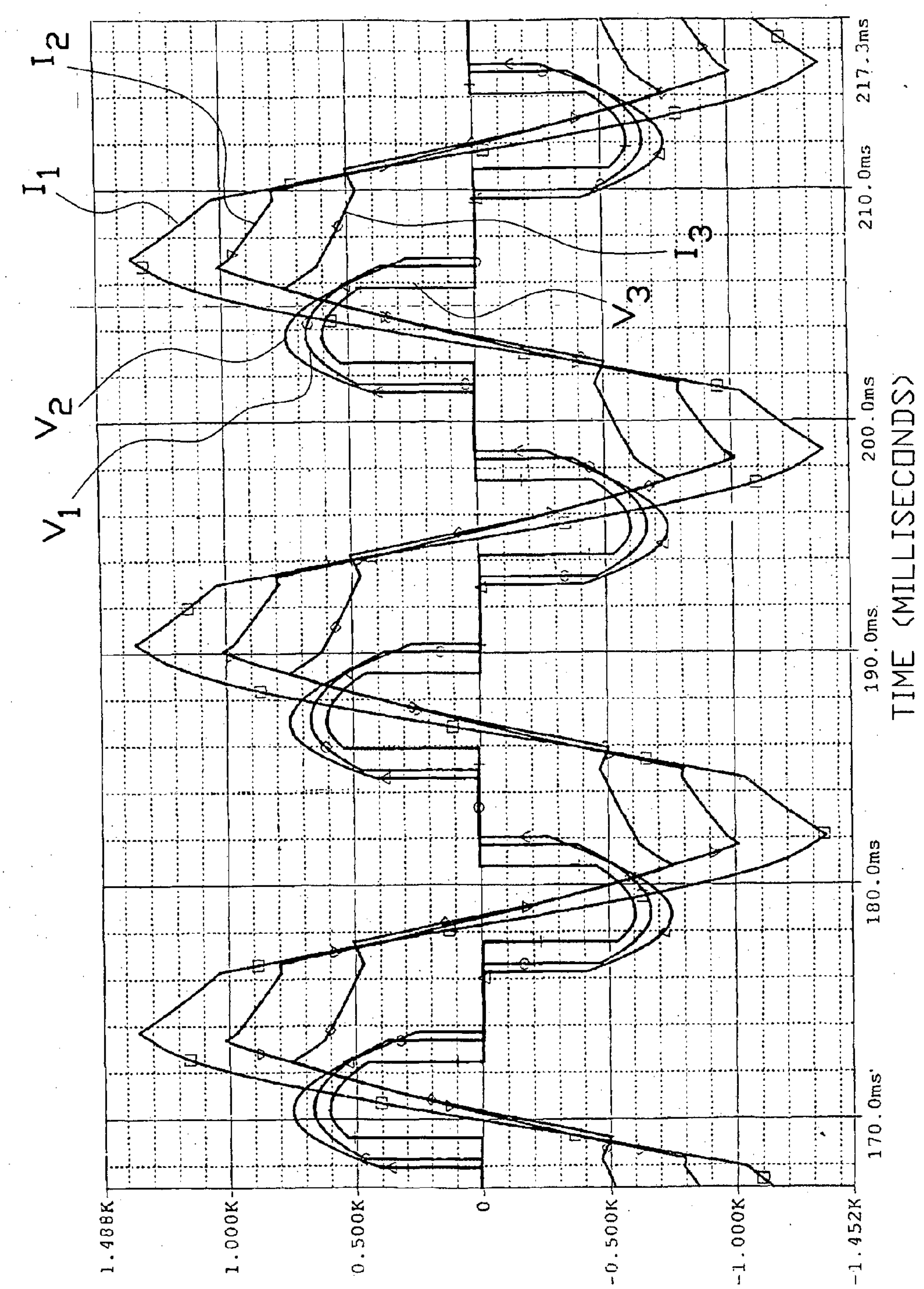

10
12
20
16a
PWR INPUT
CONTROL OUTPUT
CONTROL INPUT
FPGA
MC
REC/INV
14a
16b
PWR INPUT
CONTROL OUTPUT
CONTROL INPUT
FPGA
MC
REC/INV
14b
40
16c
PWR INPUT
CONTROL OUTPUT
CONTROL INPUT
FPGA
MC
REC/INV
14c
16d
PWR INPUT
CONTROL OUTPUT
CONTROL INPUT
FPGA
MC
REC/INV
14d
16e
PWR INPUT
CONTROL OUTPUT
CONTROL INPUT
FPGA
MC
REC/INV
14e
16f
PWR INPUT
CONTROL OUTPUT
CONTROL INPUT
FPGA
MC
REC/INV
14f

FIG. 1



L load
R
V COIL
I INV out
MC
V C TF
POWER
SET
POINT
62
S2
D2
S3
D3
G2
4
G3
G1
G4
S1
3
S4
D1
D4
1
2
C TF
61
L clr
C F
L fc
60
FPGA
AC
POWER
SOURCE
A
B
C

FIG. 2



I_2
I_1
I_3
V_1
V_2
V_3
1.488K
1.000K
0.500K
0
-0.500K
-1.000K
-1.452K
170.0ms
180.0ms
190.0ms
200.0ms
210.0ms
217.3ms
TIME (MILLISECONDS)
VOLTAGE (KILOVOLTS) / CURRENT (KILOAMPERES) MAGNITUDE

FIG. 3

REFERENCES CITED IN THE DESCRIPTION

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- WO 0028787 A **[0006]**
- US 6696770 B **[0016]**

713295/MK (EP1729542)

Szabadalmi igénypontok

1. Berendezés munkadarabok (12) gradiens indukciós melegítésére vagy megolvasztására, amely tartalmaz:
a munkadarab körül sorban elrendezett indukciós tekercseket (14a-14f); és energiaforrást (16a-16f) az egyes indukciós tekercsekhez, ahol az egyes energiaforrások az indukciós tekercsekhez kapcsolódó ac kimenettel rendelkező inverterrel (INV) vannak ellátva; azzal jellemezve, hogy
az energiaforrások között vezérlővezeték (40) van beiktatva;
az egyes energiaforrások inverterének ac kimenete impulzusszélesség-moduláció vezérléssel van ellátva; és
a vezérlővezeték szinkron módon vezérli az egyes energiaforrások inverterének impulzusszélesség-modulált ac kimenetét.

2. Az 1. igénypont szerinti berendezés, amelynél az egyes energiaforrások inverterei tartalmaznak legalább négy szilárdtest kapcsolóeszközt (S_1, S_2, S_3, S_4) és egy-egy vezérlőt (MC), amelyek az egyes inverterekhez kapcsolódva vezérlik az inverterek szilárdtest kapcsolóeszközét.

3. Az 1. vagy 2. igénypont szerinti berendezés, amelynél az inverterek legalább egyike hangoló kondenzátorral (C_{TF}) rendelkezik az inverter bemeneténél.

4. Az előző igénypontok bármelyike szerinti berendezés, amelynél az indukciós tekercsek szorosan tekercselt szolenoid indukciós tekercsek, amelyek egymás mellett helyezkednek el dielektromosan elválasztva a szomszédos tekercsek közötti rövidzárlat megakadályozásához.

5. Az előző igénypontok bármelyike szerinti berendezés, amelynél a munkadarab villamosan vezető anyagot tartalmaz, amely egy tégelyben van elhelyezve.

6. Az 1 - 4. igénypontok bármelyike szerinti berendezés, amelynél a munkadarab tartalmaz egy szuszceptort.

7. Eljárás munkadarabok (12) gradiens melegítésére vagy megolvasztására, amely a következő lépéseket tartalmazza:
megfelelő inverterből (INV) energiát vezetünk több indukciós tekercs (14a-14f) mindegyikébe, amelyek a munkadarab hossza mentén vannak elrendezve;
az indukciós tekercsek mindegyike körül különálló mágneses teret indukálunk;
azzal jellemezve, hogy
az egyes inverterek indukciós tekercsekhez vezetett ac teljesítményét impulzusszélesség-moduláljuk; és
az egyes inverterek ac teljesítmény impulzusszélesség-modulálását változtatjuk.

8. A 7. igénypont szerinti eljárás, amelynél a különálló inverterek legalább egyikénél hangoló kondenzátort (C_{TF}) helyezünk el a bemeneten.

9. A 7. vagy 8. igénypont szerinti eljárás, amelynél az egyes inverterek ac teljesítményénél alkalmazott impulzusszélesség-modulációt szinkronizáljuk.

10. A 9. igénypont szerinti eljárás, amelynél vezérlőjelet viszünk át sorosan az inverterek között az egyes inverterek ac teljesítményénél alkalmazott impulzusszélesség-moduláció szinkronizálásához.

11. A 10. igénypont szerinti eljárás, amelynél a vezérlőjel tartalmaz egy mester vezérlőjelet, amelyet az egyik inverter állít elő, és amely sorosan vihető át a többi inverterhez.

12. A 11. igénypont szerinti eljárás, amelynél az inverterek egyike előállít egy rendellenes vezérlőjelet sorosan az egyik inverterhez, amelyikben a mester vezérlőjel elő lett állítva.