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Andresen

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[54] POWER SUPPLY

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[58] Field of Search 317/16, 33 SC; 219/412, 425, 509; 321/14

[56] References Cited

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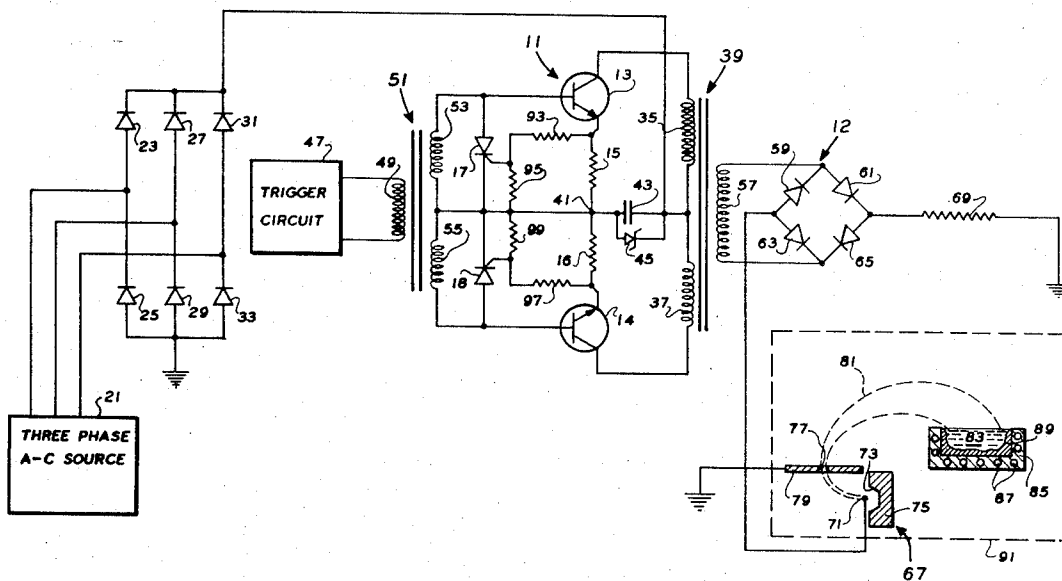
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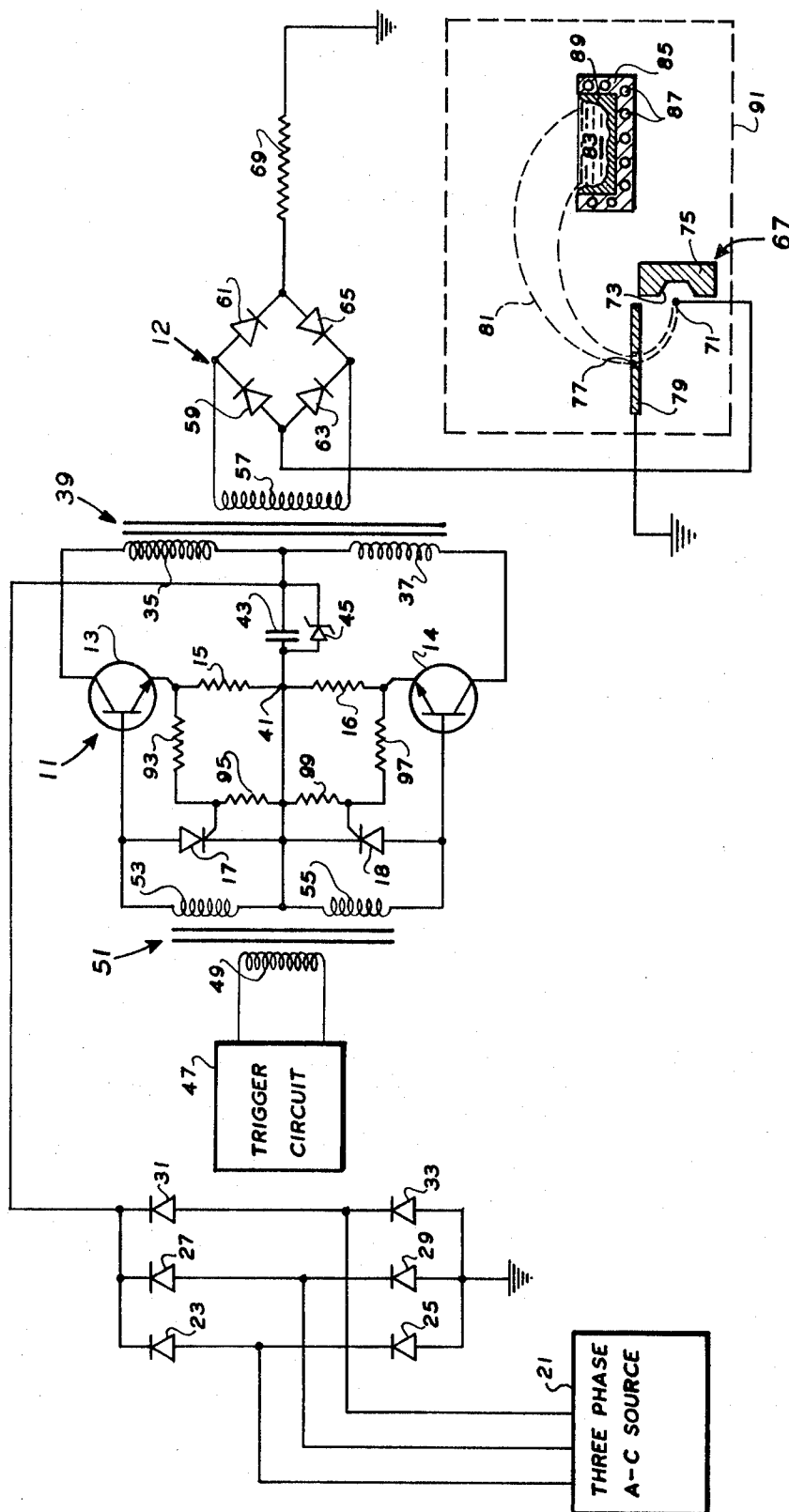
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ABSTRACT

A power supply is described for an electron gun employed in an electron beam furnace system wherein the gun current is susceptible of rising upon the occurrence of an arc. Switching means including at least one transistor are coupled between the current source and the electron gun. The current through the transistor is sensed and control means operate to disable the transistor upon a rise in the current due to an arc.

6 Claims, 1 Drawing Figure





POWER SUPPLY

This invention relates generally to electrical power supplies and, more particularly, to a power supply for an electron gun employed in an electron beam furnace system.

The employment of electron beam furnace systems in various material treating processes such as melting, vapor plating, etc., has become increasingly prevalent. A typical electron beam furnace system includes an electron gun, which is appropriately energized to furnish a high intensity beam of electrons. The electron gun is generally disposed in an evacuated chamber separate from or in the same chamber as the material to be treated, and means are provided for directing the electron beam at the material.

The electron gun typically includes a source of electrons, such as a heated cathode or filament, and a grounded accelerating anode. The cathode is maintained at a high negative potential with respect to the anode to establish a high electrostatic field for accelerating the electrons. A suitable transverse magnetic field is also usually provided for directing the electrons onto the target material. As the beam of electrons impinges on the target material, the material is heated. The amount of heat developed is related to the electron beam current and the electron velocity effected by the accelerating electrostatic field through which the electrons are directed.

During bombardment of the target material by the electron beam, various vaporous materials are emitted and, in addition, various occluded gases may be released, particularly when the target material is in a relatively impure condition. The presence of such gaseous material often effects a substantial decrease in the resistance between various parts of the electron beam gun and leads and surrounding elements. This may result in electrical arcing between such parts and leads and elements, causing a substantial increase in the electron gun current and possibly resulting in harm to the electron gun structure and surrounding elements. To minimize the harmful effects of arcing, various voltage and current regulated electron gun power supplies have been developed.

Some previously known electron gun power supplies for electron beam furnace systems have limited the detrimental effects of arcing by limiting or cutting back the current to the electron gun. By limiting the current rise in the presence of an arc to a predetermined maximum value, the arc will often quickly terminate and normal operation may be resumed. For systems operating at relatively high power levels, (such as ten to twenty kilowatt systems operating with three or more amperes of beam current) electron gun current may be restored without coincident restoration of the arc only by cutting back the electron gun current sufficiently. In U. S. Pat. No. 328,267, issued Dec. 8, 1970, and assigned to the present assignee, a power supply is disclosed in which electron gun current is cut back very quickly upon sensing the incipency of an arc. This starves the arc in its incipency and thus enables restoration of electron gun current very quickly without coincident restoration of the arc.

Presently available power supplies have generally utilized vacuum tube devices. Although satisfactory for many applications, some circumstances may make it desirable that the heat generated and the power supply

size and weight be minimized. This naturally suggests the use of solid state devices.

Because of the relatively high voltages and currents utilized in an electron beam gun, the present state of the art does not permit mere substitution of solid state devices for the vacuum tube devices previously utilized in electron gun power supplies. This is due to the present high cost or unavailability of satisfactory solid state devices for accomplishing functions performed by vacuum tubes at high voltages and currents. Accordingly, design of a power supply incorporating all solid state components involves solving the high voltage problem.

Even though generated heat and some weight and size may be significantly reduced through the use of solid state devices in a power supply, magnetic components such as transformers may still contribute excessive size and weight. Thus, it is desirable that means be found minimizing the size and weight of magnetic elements in the power supply.

Further complication is added to the design of a satisfactory power supply for electron beam guns where it is desired to produce current cut back very quickly. As previously mentioned, such rapid cut back enables rapid restoration of beam current without concurrent restoration of arcs.

It is therefore an object of this invention to provide a power supply for an electron beam gun employed in an electron beam furnace system, such power supply being compact and light in weight.

Another object of the invention is to provide a power supply for an electron beam gun employed in an electron beam furnace system, such power supply utilizing solid state devices.

A further object of the invention is to provide a power supply of the type described which is low in cost and reliable of operation.

It is another object of the invention to provide a power supply of the type described and which operates to cut back electron beam current to a level which starves incipient arcs, thereby permitting rapid restoration of beam current without concurrent restoration of arcs.

Other objects of the invention will become apparent to those skilled in the art from the following description taken in connection with the accompanying drawing wherein:

FIG. 1 is a schematic diagram illustrating an electron beam furnace system and illustrating a power supply, for the electron beam gun of the system, constructed in accordance with the invention.

Very generally, the power supply of the invention includes switching means 11 adapted for connection to a source of alternating current. Means 12 are coupled to the switching means for producing a direct current and for coupling the direct current to the electron gun of the furnace system. The switching means include at least one transistor 13 or 14 and means 15 or 16 for sensing the emitter-collector current of the transistor. Control means 17 or 18 are connected to the sensing means for disabling the transistor upon a rise in the emitter-collector current due to an arc in the furnace system.

Referring now to FIG. 1, the illustrated power supply operates to convert a conventional three-phase a-c current into a higher frequency a-c current by means of a transistor inverter. The higher frequency a-c current is then stepped up in voltage in a transformer and is recti-

fied for application to the electron beam gun in the furnace system. A power supply of this general type employing silicon controlled rectifiers in an inverter circuit is shown and described in U. S. Pat. No. 3,544,913 issued Dec. 1, 1970.

he invention however, is applicable to a power supply in which any type of transistorized network is used between the conventional power source and the electron beam gun. Thus, in a system such as shown in U. S. Pat. No. 3,609,200 issued Sept. 28, 1971, a switching circuit employing silicon controlled rectifiers is shown for supplying power to an electron gun employed in an electron beam furnace system. In the event transistors, rather than silicon controlled rectifiers are used for the switching networks shown in the aforesaid patents, the present invention may be applicable.

The invention, as illustrated in the embodiment of FIG. 1, derives its original power from a suitable three-phase supply 21, which may be a conventional three-phase 212 volt 60 cycle line source. A three-phase full-wave rectifier comprised of solid state diodes 23, 25, 27, 29, 31 and 33, suitably polarized and connected, produces a low-ripple direct current from the alternating current in the source 21. Suitable filtering, not shown, may be provided for the output of the rectifier and this output is applied to the switching means 11 which, in the illustrated embodiment, comprise a transistor inverter.

The transistor inverter 11 comprises a pair of NPN transistors 13 and 14. Positive direct current potential is applied to the collectors of the transistors 13 and 14 through the primary winding 35 and 37, respectively, of a transformer 39. The emitters of the transistors 13 and 14 are connected to a junction 41 through the series emitter resistors 15 and 16, respectively. A capacitor 43 joins the junction 41 to the d-c supply line from the three-phase full-wave rectifier, and a reverse polarized zener diode 45 is provided for protective purposes across the capacitor 43.

In order to drive the transistors 13 and 14 in a switching mode at a selected frequency, a trigger circuit 47 is provided. The trigger circuit 47 may be of any suitable design to provide output pulses at a desired frequency to the primary winding 49 of a step-up driving transformer 51. For example, the trigger circuit 47 may consist of an oscillator, an amplifier to amplify the pulses provided by the oscillator, and suitable voltage regulation and control circuitry to provide trigger pulses of the desired magnitude and of the desired shape.

The step-up driving transformer 51 includes a pair of series connected secondary windings 53 and 55. These windings, respectively, are connected at one end to the bases of the respective transistors 13 and 14, and have their junction connected to the junction 41. Current pulses in the driving transformer 51 result in positive pulses being applied alternately to the bases of the transistors 13 and 14 at the desired frequency. These pulses switch the transistors on alternately, thereby providing an alternating current in the secondary winding 57 of the step-up transformer 39.

The alternating current in the secondary winding 57, at a substantially increased voltage, for example 10 KV or more, is rectified by a full-wave bridge rectifier 12 comprised of four suitably polarized and connected diodes 59, 61, 63 and 65. Two corners of the bridge are connected across the secondary winding 57 and two

corners of the bridge are connected across the cathode of an electron beam gun 67 through a series resistor 69. The electron beam gun 67 is connected to the bridge rectifier 12 such that the cathode 71 thereof is at a high negative potential with respect to ground.

The cathode 71, which may be a linear filament, is suitably supported by means not shown in a trough 73 defined in a backing electrode 75. The backing electrode 75 is also maintained at a negative potential. When the cathode is heated, by suitable means, not shown, electrons are emitted. These are accelerated through an opening 77 in an anode plate 79, maintained at ground potential, thereby being at a positive or accelerating voltage with respect to the cathode 71. After passing through the opening 77, the electrons, now in the form of a beam 81, are accelerated through a suitable magnetic field established by means, not shown, to pass through an arcuate path and impinge upon the surface of a melt 83. The melt 83 is contained within a crucible 85 cooled by a plurality of coolant passages 87 such that part of the melt solidifies and forms a skull 89. The crucible and electron beam gun are disposed inside a high vacuum enclosure 91. Depending on the particular system application, the material contained within the crucible 85 may be processed for purification purposes, or may be evaporated for deposition on a substrate, not shown, also within the enclosure 91.

During normal operation of a high vacuum electron beam furnace system, arcing between various elements of the electron beam gun and leads and various elements of the furnace may periodically occur. Although the precise conditions which produce arcing are not entirely understood, it is believed that local hot spots producing an increase in the level of thermionic emission, and the presence of significant quantities of positive ions in a particular region, may contribute to the occurrence of an arc.

An arc may be described generally as having two stages; an incipient stage which is manifested by a rapid rise in current to the electron gun, and a steady state stage in which the current stabilizes at a point where the arc passes the maximum power. By merely limiting current to a level below the higher current steady state stage, damage to gun and furnace parts may often be prevented. In some cases, however, the arc may continue at the lower current level and may rise to the higher current level steady state stage when current limiting is removed.

Accordingly, rather than current limiting, it is often necessary to substantially reduce the power supplied to the electron beam gun and maintain it at the reduced level for a period of about four-tenths of a second or more before power can be restored without coincident restoration of the arc. It is believed that this delay allows the large number of ions in the arcing region to dissipate throughout the vacuum furnace and allows the regions which have been heated to a high temperature and which may have a high level of thermionic emission, to cool down. A delay of four-tenths of a second or more is significant and may contribute to a relatively high level of inefficiency in furnace operation and fluctuation in energy delivered to the material being heated. The latter phenomenon can have a particularly deleterious effect in the case of vapor deposition operations, since it may produce an intolerable variation in the vapor deposition rate.

If, as taught in the aforementioned U. S. Pat. N. 3,546,606 the arc is starved in its incipient stage, by cutting back the electron gun current sufficiently before current can rise to the higher steady state level, full operating current may be restored very quickly without coincident restoration of the arc. Although not entirely understood, it is believed that fast restoration is possible because extensive ionization of vapor particles in the region of the arc is avoided, or because extensive local superheating of electron emissive surfaces does not occur, or both.

In order to gain the benefit of fast turn-on, as has been previously mentioned, electron gun current is cut back while the arc is in its incipency. Just how far ahead of the steady state condition, in time, the cut back of current should occur depends upon the particular circuit characteristics and component values, the degree of vacuum in the electron beam furnace, the amount and kinds of vapors present around the electron gun, and the particular geometry of the electron gun itself and the surrounding furnace structure. With furnaces of relatively low power levels, if the electron gun current is cut back less than about 15 milliseconds after the beginning of an arc, it is often possible to restore electron gun current within 200 milliseconds without coincident restoration of the arc.

Experience indicates that, for most furnace system configurations, the electron gun current should be cut back to a minimum current level in order to starve the arc. The level required for satisfactory operation is typically less than 2 amperes, and for high reliability it is often preferable that it be cut back to less than 1 ampere.

A further advantage accrues from rapid cutoff of electron gun current at the incipency of an arc. This advantage stems from the fact that the presence of an arc is usually accompanied by a high-level of radio-frequency (RF) transients. The power supply circuitry may be sensitive to such transients and complications may develop during their presence. RF traps may be included in the circuitry at suitable locations to cut down the effect of the RF transients, but this naturally leads to an increase in the cost of the circuit. Because of the reduction in RF transients, flowing from the fact that the arcs are starved in their incipency, circuit design is simplified in this respect.

In order to disable the resistors 13 and 14 in the event of an arcing condition within the furnace enclosure 91, the silicon controlled rectifiers 17 and 18 are provided, connected as previously described. The gate of the silicon controlled rectifier 17 is connected through a resistor 93 to the emitter of the transistor 13, and is connected to the junction 41 through a resistor 95. Similarly, the gate of the silicon controlled rectifier 18 is connected through a resistor 97 to the emitter of the transistor 14 and is connected to the junction 41 through a resistor 99.

The values of the resistors 15 and 16 are selected such that during normal operation of the transistor inverter 11, the voltage developed across the resistors 15 and 16 is insufficient to trigger the SCR's 17 and 18, respectively, into conduction. Accordingly, the transistors 13 and 14 are switched on alternately to provide the alternating current to the primary windings 35 and 37 of the step-up transformer 39.

In the event of an arcing condition within the furnace enclosure 91, the current drawn by the system in-

creases substantially due to the lowered impedance. In the event that the arcing occurs while the transistor 13 is on, the voltage developed across the resistor 15 becomes sufficiently high so as to trigger the gate of the silicon controlled rectifier 17 and turn the silicon controlled rectifier on. This shunts current from the base of the transistor 11, effectively disabling the transistor and cutting off current to the electron beam gun 67. As the pulse in the secondary winding 53 drops to zero, the voltage across the silicon controlled rectifier also drops to zero, thus turning the silicon controlled rectifier off and enabling the transistor 13 to turn on upon receipt of the next positive going pulse to its base. The resistors 93 and 95 enable adjustment of the voltage at the gate of the silicon controlled rectifier 17.

The operation of the silicon controlled rectifier 18 with respect to the transistor 14 is similar to that described in connection with the silicon controlled rectifier 17 and the transistor 13. Thus, depending upon which particular cycle the arcing occurs in, the transistor inverter 11 may be disabled immediately, allowing for a very rapid cut back in gun current. As previously described, advantages accrue from such rapid cut back.

The time period during which gun current is cut back depends upon the frequency of pulses provided to the transistor inverter by the trigger circuit 47. For example, if the trigger circuit 47 provides output pulses at 10 KHz, a transistor will be disabled for 50 microseconds cutting off gun current for that time. If the arc has not dissipated in that time, the other transistor will be disabled and thus cut off gun current for another 50 microseconds. The process continues until the arc has dissipated.

It may therefore be seen that the invention provides a power supply for an electron beam gun employed in an electron beam furnace system wherein the gun current is susceptible of rising upon the occurrence of an arc. The power supply provides for rapid cut back of gun current by means of solid state components. In particular, transistors are utilized along with shunting silicon controlled rectifiers, thereby providing a low cost, lightweight, compact and reliable power supply. Heat produced is minimized and by operating at relatively high a-c frequencies, the size of transformers may be minimized.

Various modifications of the invention in addition to those shown and described herein will become apparent to those skilled in the art from the foregoing description and accompanying drawings. Such modifications are intended to fall within the scope of the appended claims.

What is claimed is:

1. A power supply for an electron gun employed in an electron beam furnace system wherein the gun current is susceptible of rising upon the occurrence of an arc, comprising, switching means adapted for connection to a source of alternating current, means coupled to said switching means for producing a direct current and for coupling same to the electron gun, said switching means including a pair of transistors and driving means for alternately rendering said transistors conductive, means for sensing the emitter-collector current of said transistors, and control means connected to said sensing means for shunting base current from said transistors upon a rise in the emitter-collector current of said transistors due to an arc, to thereby cut said transistors off.

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- 2. A power supply according to claim 1 wherein said switching means comprise frequency increasing means.
- 3. A power supply according to claim 1 wherein said control means comprise a pair of silicon controlled rectifiers, each connected to the base of a respective one of said transistors.
- 4. A power supply according to claim 1 wherein said sensing means comprise a pair of emitter resistors, each connected in series with the emitter of one of said transistors.
- 5. A power supply according to claim 4 wherein said control means comprise a pair of silicon controlled rectifiers, each connected between the base and emitter of a respective one of said transistors, each of said silicon controlled rectifiers being connected with its gate and

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- cathode across one of said emitter resistors.
- 6. A power supply for an electron gun employed in an electron beam furnace system wherein the gun current is susceptible of rising upon the occurrence of an arc, comprising, switching means adapted for connection to a source of alternating current, means coupled to said switching means for producing a direct current and for coupling same to the electron gun, said switching means including at least one transistor, means for sensing the emitter-collector current of said transistor, and control means connected to said sensing means for disabling said transistor upon a rise in the emitter current of said transistor due to an arc.

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