United States Patent

[11] 3,609,200

[72] Inventor **Emmett R. Anderson**
Berkeley, Calif.

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[73] Assignee **Air Reduction Company, Incorporated**
New York, N.Y.
Continuation-in-part of application Ser. No. 675,902, Oct. 17, 1967, now Patent No. 3,544,913.

[54] **POWER SUPPLY**
5 Claims, 2 Drawing Figs.

[52] **U.S. Cl.** **13/31**
[51] **Int. Cl.** **H05b 7/00**
[50] **Field of Search** ..... 13/12, 31; 307/252.73, 252.53; 315/106; 219/121 EB

[56] **References Cited**

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Primary Examiner—Bernard A. Gilheany
Assistant Examiner—R. N. Envall, Jr.
Attorney—Fitch, Even, Tabin & Luedeka

ABSTRACT: A power supply is described for use with an electron gun employed in an electron beam furnace system. The power supply includes a transformer and a rectifier connecting the secondary of the transformer to the electron beam gun for supplying current thereto. The power supply also includes a semiconductor-switching circuit connected to the primary of the transformer for supplying current to the primary. The switching circuit is controlled by a pulsing circuit, and a trigger circuit is controlled by a pulsing circuit, and a trigger circuit is connected to the pulsing circuit and to means for sensing a rise in current to the electron gun in the presence of an arc. Upon the sensing of such rise in current, the trigger circuit disables the pulsing circuit to thereby render the switching circuit inoperative and cut off current to the electron beam gun.

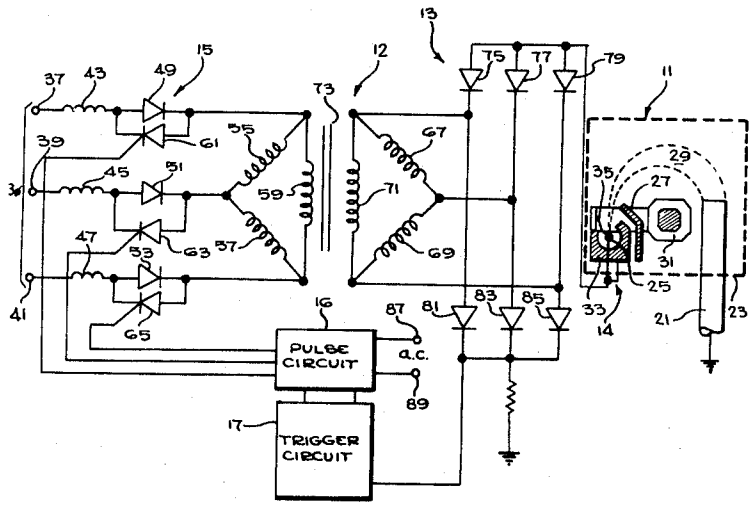


Fig. 1

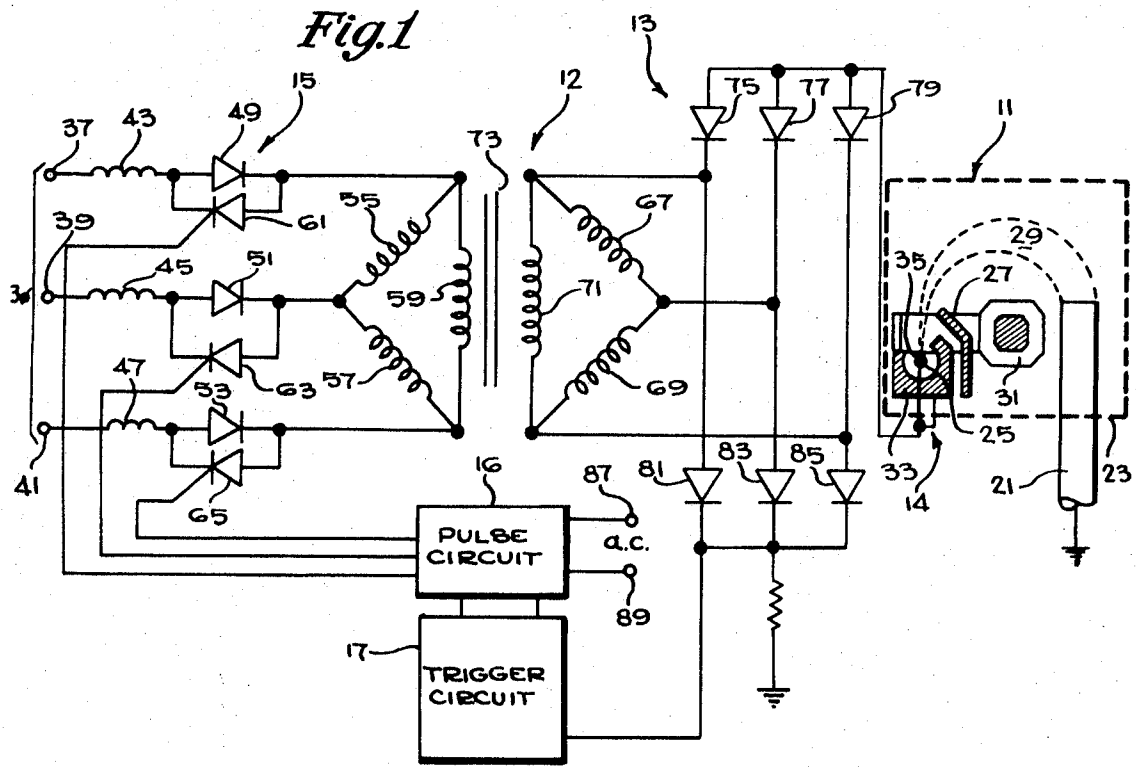
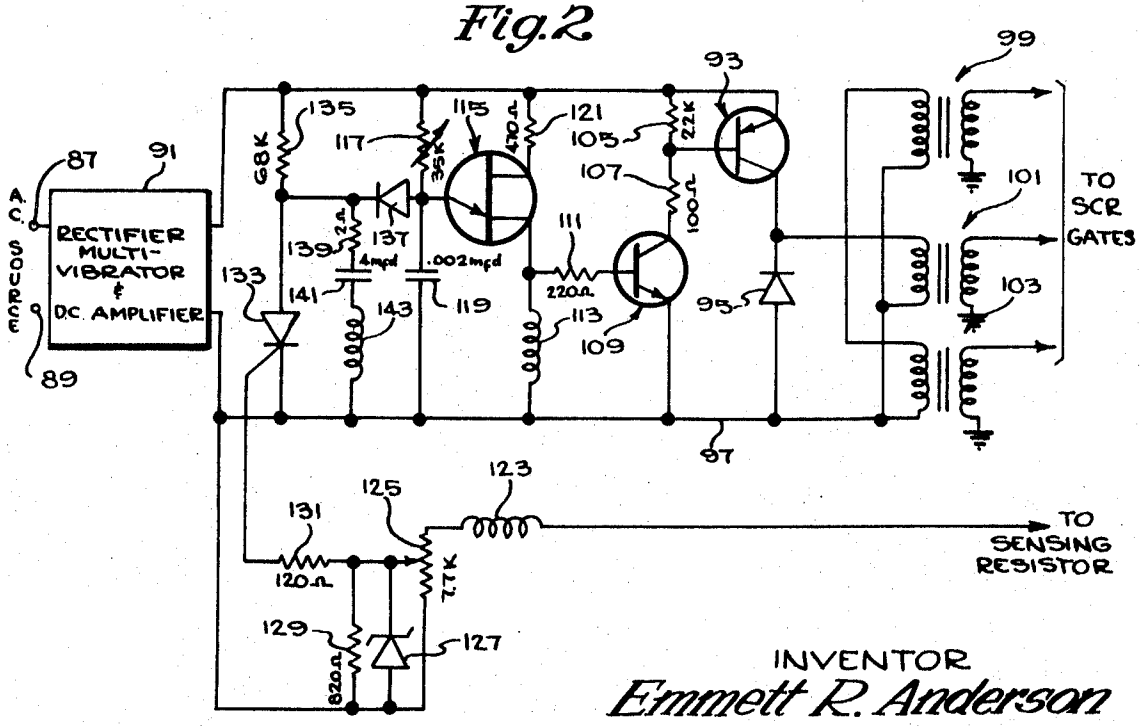


Fig. 2



INVENTOR
Emmett R. Anderson

Anderson, Luedeka, Fitch, Even & Tabin
ATTYS

POWER SUPPLY

This application is a continuation-in-part of copending application Ser. No. 675,902 filed Oct. 17, 1967 now U.S. Pat. No. 3,544,913. This invention relates 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. In addition, an electron beam furnace system may in some cases be employed as a pump, such as in the case of a titanium sublimation pump in which titanium is sublimited and condensed within a chamber to getter molecules of gas within the chamber and thereby reduce the pressure within the chamber.

A typical electron beam furnace system including those used for pumping as above described 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 together with the material to be heated, and means are provided for directing the electron beam at the material. The electron gun usually includes a source of electrons, such as a heated cathode or element, and a grounded accelerating anode, the cathode being maintained at a high negative potential with respect to the anode so as to establish a high electrostatic field for accelerating the electrons. A suitable transverse magnetic field may also be 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 being 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. The presence of such gaseous materials often effects a decrease in the resistance between various parts of the electron beam gun and leads and surrounding elements. This may result in 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-regulating 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 valve, the arc will often quickly terminate and normal operation may be resumed. For systems operating at relatively high-power levels, (such as 10 to 20 kilowatt systems operating with three or more amperes of beam current) electron gun current may be restored without coincident restoration of the arc merely by cutting back the electron gun current sufficiently. In copending application Ser. No. 868,284, assigned to the present assignee, a power supply is disclosed in which electron gun current is cut back very quickly upon sensing the incipiency of an arc. This starves the arc in its incipiency 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 are 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 and current problems.

As previously mentioned, it is desirable to provide for rapid cut back of the electron beam current in the presence of arcing to thereby starve arcs in their incipiency and enable rapid restoration of beam current without concurrent restoration of arcs. Some highly successful systems have been designed to accomplish this in the case of relatively large furnaces. In the case of a small furnace system, however, such as is typical in the case of a titanium sublimation pump, it is desirable to design a simple, low cost and reliable power supply.

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 in 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 drawings, 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; and

FIG. 2 is a schematic diagram of one type of pulsing and trigger circuit arrangement which may be utilized in the power supply of FIG. 1. Very generally, the power supply of the invention is employed with an electron beam furnace system **11** and includes a transformer **12** and rectifiers **13** connecting the secondary of the transformer to the electron beam gun **14** of the furnace system. A switching circuit **15** is connected to the primary of the transformer **12** and is adapted for connection to a source of alternating current. A pulsing circuit **16** is connected to the switching circuit **15** for providing firing pulses to the switching circuit for operating same. A trigger circuit **17** is connected to the pulsing circuit **16** and is also connected to a sensing device **18**. The sensing device senses a rise in current to the gun **14** due to an arc. Upon the occurrence of such a current rise, the trigger circuit **17** operates to disable the pulsing circuit **16**, thereby rendering the switching circuit **15** nonconductive and cutting off current to the electron gun **14**.

Referring now more specifically to FIG. **1**, the invention is shown utilized in connection with an electron beam furnace system **11** constituting a titanium sublimation pump. As is the case in other electron beam furnace systems, the titanium sublimation pump incorporates an electron beam gun and a system for directing the beam to heat a target, in this case a feed rod **21** of titanium. The titanium at the end of the rod which is heated sublimates and condenses on suitable collection means, not shown, to getter any molecules in the chamber, resulting in a pumping action. The operation of a titanium pump is well known to those skilled in the art and will not be discussed in further detail herein.

The furnace system or titanium pump **11** includes the electron beam gun **14** which is disposed within a vacuum-tight enclosure **23**. The electron gun **14** may be of any conventional type. In the illustrated embodiment, the electron gun **14** includes a cathode **25** and a grounded accelerating anode **27**. The electrons emitted by the cathode **25** are accelerated and formed into a beam **29** by the accelerating potential established between the cathode **25** and the grounded anode **27**. The beam is deflected by a transverse magnetic field, produced by an appropriately positioned electromagnet **31**, onto the upper end of the titanium rod **21**. The cathode **25** may be heated directly or indirectly by suitable means, not illustrated. A shaping or backing electrode **33** is provided having a trough **35** in which the cathode **25** is disposed. Because

the shaping electrode **33**, like the cathode **25**, is at a highly negative potential, the electrons are urged out of the open side of the trough **35** to be deflected towards the target.

During operation of the foregoing described power supply, the voltage which is developed across the electron gun **14** may, if desired, be generally held constant by a suitable voltage sensing and regulating network, not illustrated. Such voltage-regulating circuitry may include suitable provision for preventing the occurrence of high current surges resulting from switching transients generated during cut back of gun current, described below.

Power for operating the electron beam gun is obtained from a suitable three-phase supply, not shown, the output terminals of which are indicated at **37, 39** and **41**. The terminals **37, 39** and **41** are connected through chokes **43, 54** and **47**, respectively, to the anodes of semiconductor diodes **49, 51** and **53**, respectively. The cathodes of the diodes **49, 51** and **53** are connected to terminals at the junction points of the delta connected primary windings **55, 57** and **59** of the transformer **12**. Semiconductor controlled rectifiers **61, 63** and **65** are connected across the diodes **49, 51** and **53**, respectively, in reverse polarity. With the semiconductor-controlled rectifiers switching periodically into conductive condition, the controlled rectifiers together with the diodes **49, 51** and **53** constitute a switching circuit which transmits the three-phase alternating current from the source to the primary windings of the transformer **12**. The chokes **43, 45** and **47** aid in the suppression of switching transients.

The secondary of the transformer **12** consists of the secondary windings **67, 69** and **71**, connected in delta and inductively coupled to the primary of the transformer through a suitable core **73**. The secondary of the transformer **12** is connected to the electron gun **14** through the three-phase rectifier circuit **13**. The three-phase rectifier circuit consists of six diodes **75, 77, 79, 81, 83** and **85** connected to provide a direct current output to the cathode **25** of the electron gun. The junctions or terminals of the delta connected secondary winding of the transformer **12** are connected to the junctures between the respective pairs of diodes **75, 81; 77, 83**; and **79, 85**.

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 application Ser. No. 868,284, 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 incipiency. 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 incipiency of an arc. This advantage stems from the fact that the presence of an arc is usually accompanied by a high-level of radiofrequency (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 incipiency, circuit design is simplified in this respect. In order to sense the incipiency of an arc, the resistor **18** is utilized. The voltage appearing across the resistor **18** is related to and indicative of the electron beam current, and the voltage is applied to the SCR trigger circuit **17**. Suitable means, not illustrated, are incorporated in the trigger circuit in order to temporarily interrupt the operation of the pulse circuit **16** when the voltage across the resistor exceeds a preselected level corresponding to the incipient stage of an arc. Such means are readily designed by those skilled in the art and may, for example, be similar to the circuits shown in chapter eight of *Semiconductor Controlled Rectifiers*, by Gentry, Gutzwiller, Holonyak and von Zastrow; Prentiss Hall, 1964. The SCR pulsing circuit **16** operates similarly to circuits taught in chapter five of the aforementioned publication to apply firing pulses to the gates of the SCR's **61, 63** and **65**.

When operation of the circuit **16** is temporarily interrupted, the semiconductor controlled rectifiers **61, 63** and **65** become nonconductive, cutting off alternating current to the primary of the transformer **12**. This cuts off direct current supplied through the rectifiers **13** to the electron gun **14**, thereby cutting off beam current and starving any arcs. Using a **5** KC frequency for the output of the switching SCR's, as will be explained below more fully, it is typically possible to cut back current to the electron gun within about 8 milliseconds from the time gun current begins to rise. Gun current may then be restored in about 140 milliseconds.

The SCR pulsing circuit **16** may be temporarily disabled, upon the sensing of a rise in current due to an arc, in any convenient way depending upon the type of pulsing means used. For example, the trigger circuit may operate to remove bias for diode or transistor operation when the voltage across the resistor **18** exceeds a preselected level. Another example is the use of a diode or transistor shunt for the output of the pulsing circuit. Operating current for the SCR pulsing circuit is

derived from a single-phase AC source, the terminals of which are indicated at **87** and **89**.

Referring now to FIG. **2**, one suitable arrangement of the pulsing circuit **16** and trigger circuit **17** which may be utilized in the power supply of FIG. **1**, is illustrated. Alternating current from the AC source terminals **87** and **89** is applied to a rectifier, DC amplifier and multivibrator circuit **91** of suitable design. The circuit **91** is designed in accordance with known practice to produce an output AC current superimposed on a DC bias current. Such an output may be achieved by using a regulated DC amplifier for amplifying the output of a bridge rectifier, and a multivibrator connected to shunt a part of the output of the DC amplifier to produce pulses at the frequency of the multivibrator. Output pulses of the circuit **91**, which are superimposed on the regulated DC and which are at the frequency desired for properly timing the SCR's **61**, **63** and **65** in the circuit of FIG. **1** (e.g. 5 kc.), are passed to the emitter of an NPN transistor **93**. Preferably, such frequency is about 4 kc. to 10 kc. During normal operation, the transistor **93** is conductive and the output pulses of the multivibrator **91** are therefore developed across a diode **95** connected from the collector of the transistor **93** to a reference line **97**, which is at some suitable potential above ground. These pulses are then passed through three pulse transformers **99**, **101** and **103** to the gates of the SCR's **61**, **63** and **65** in FIG. **1**.

With the circuitry illustrated in FIG. **2**, there is no intentional coordination of the switching frequency of SCR's **61**, **63** and **65** with the frequency of the AC source, nor is there any differential phase relation between the switching timing of the SCR's. Nevertheless, the SCR switching frequency is high enough that a crude high-frequency AC signal is applied to the transformer for step-up and subsequent rectification. Alternatively, more sophisticated circuitry may be used including provision for a phase shift to trigger the SCR's **61**, **63** and **65** at different times, e.g. 120° out of phase. This may result in less ripple in the output of the rectifiers **13**.

Biasing for the base of the transistor **93** is provided by a pair of series connected resistors **105** and **107** connected in series with the collector emitter circuit of an NPN transistor **109** across the output of the circuit **91**. A resistor **111** and a choke **113** are connected across the base emitter circuit of the transistor **109**. The junction between the choke **113** and the resistor **111** is connected in the emitter base two circuit of a unijunction transistor **115**. The emitter of the unijunction transistor **115** is connected through a variable resistor **117** to the output of the circuit **91**. A capacitor **119** connects the emitter of the unijunction transistor **115** to the other side of the circuit **91**, and a resistor **121** connects the base one of the unijunction transistor **115** to the output of the circuit **91**.

During normal operation, the transistor **109** is maintained in the conductive state to maintain the transistor **93** in the conductive state through the biasing provided by the emitter to base two conduction of the unijunction transistor **115**. As will be explained, when a rise in current to the electron beam gun due to an arc is sensed across the resistor **17**, the unijunction transistor **115** is rendered nonconductive. The potential on the base of the transistor **109** then drops to a cutoff potential and the potential on the base of the transistor **93** rises to a cutoff potential. Pulses are then prevented from reaching the gates of the SCR's **61**, **63** and **65**, thereby cutting off current to the electron beam gun.

In order to provide for disabling of the pulsing circuit for the SCR gates, a trigger circuit is provided. The trigger circuit includes a choke **123**, a variable resistor **125** and a Zener diode **127** connected to the resistor **17**. A resistor **129** is connected across the Zener diode **127**. The tap of the variable resistor **125** is connected through a resistor **131** to the gate of a semiconductor controlled rectifier **133**. The SCR **133** is series connected with a resistor **135** across the output of the circuit **91**. A diode **137** connects the junction between the capacitor **119** and the variable resistor **117** to the junction between the resistor **135** and the SCR **133**. A resistor **139**, a capacitor **141**, and an inductor **143** are connected in series across the SCR **133**.

The voltage level setting on the variable resistor **125** determines the level of gun current at which the SCR **133** is rendered conductive. The trip level is selected to correspond to a rise in gun current just sufficient to indicate that an arc is occurring. The trip level may be, for example, **5** or **10** percent higher than the normal operating current. When the voltage across the resistor **17** rises above the trip level, and the SCR **133** becomes conductive, current is shunted from the emitter of the unijunction transistor **115**. The Zener diode protects the gate of the SCR **133** by breaking down if the voltage thereon becomes excessive. Once current is removed from the emitter of the transistor **115**, that transistor is turned off and thereby turns the other two transistors **109** and **93** off to disable the power supply. As this occurs, a current discharge from the capacitor **141** flows through the SCR **133** and the inductor **43**. When this is complete, the inductor produces a reverse spike in the discharge circuit which appears across the SCR and which is sufficient to turn the SCR off. Current from the circuit **91** then flows through the variable resistor **117**, the diode **137** and the resistor **139** to charge the capacitor **141**. Once the capacitor charges to a level sufficient to turn on the unijunction transistor **115**, normal operation of the circuit resumes and current to the electron gun **14** is restored. The timing of this process is adjusted by suitably adjusting the variable resistor **117**.

Although the circuits described herein refer to semiconductor controlled rectifiers, it will be apparent to those skilled in the art that suitable transistor switches or other solid-state semiconducting switching devices may be utilized in a manner within the teaching of the present invention.

It may therefore be seen that the invention provides a power supply, for an electron beam gun employed in an electron beam furnace system, which is compact and light in weight. The power supply utilizes solid-state components and is low in cost and reliable of operation. Provision is made for cutting back electron beam current in the presence of arcing.

Various modifications of the invention other than 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 appendant 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, a transformer, rectifier means for coupling the secondary of said transformer and adapted for connection to a source of alternating current, a pulsing circuit connected to said switching circuit for providing pulses thereto for operating said switching means, means for sensing a rise in current to the electron gun due to an arc, and a trigger circuit connecting said sensing means to said pulsing circuit, said trigger circuit being responsive to a sensing of a rise in current to the electron gun due to an arc by said sensing means to disable said pulsing circuit and thereby render said switching means inoperative, said trigger circuit including a time delay circuit for enabling said pulsing circuit after a predetermined time delay to reinitiate operation of said pulsing circuit and resume operation of said switching means.

2. A power supply according claim **1** wherein said semiconductor-switching means include a plurality of controlled rectifiers, and wherein said pulsing circuit is connected to the gates of said controlled rectifiers.

3. A power supply according to claim **1** wherein said trigger circuit includes means for shunting operating current from said pulsing circuit when said sensing means senses a rise in current due to an arc.

4. A power supply according to claim **1** wherein said trigger circuit includes a semiconductor controlled rectifier connected to shunt-operating current from said pulsing circuit when said semiconductor controlled rectifier is conductive.

5. A power supply according to claim **1** wherein the output frequency of said pulsing circuit is of the order of about 5 kc.

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,609,200 Dated September 28, 1971

Inventor(s) Emmett R. Anderson

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Abstract of Patent, lines 8-9, delete extra sentence "and a trigger circuit is controlled by a pulsing circuit,"

Column 1, line 48, "valve" should be --value--.
Column 1, line 67, change "are" to --art--.
Column 3, line 15, change "54" to --45--.
Column 6, line 47, after "transformer" insert --to the electron beam gun, semiconductor switching means connected to the primary of said transformer--.

Signed and sealed this 9th day of May 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents

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