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POWER SUPPLY

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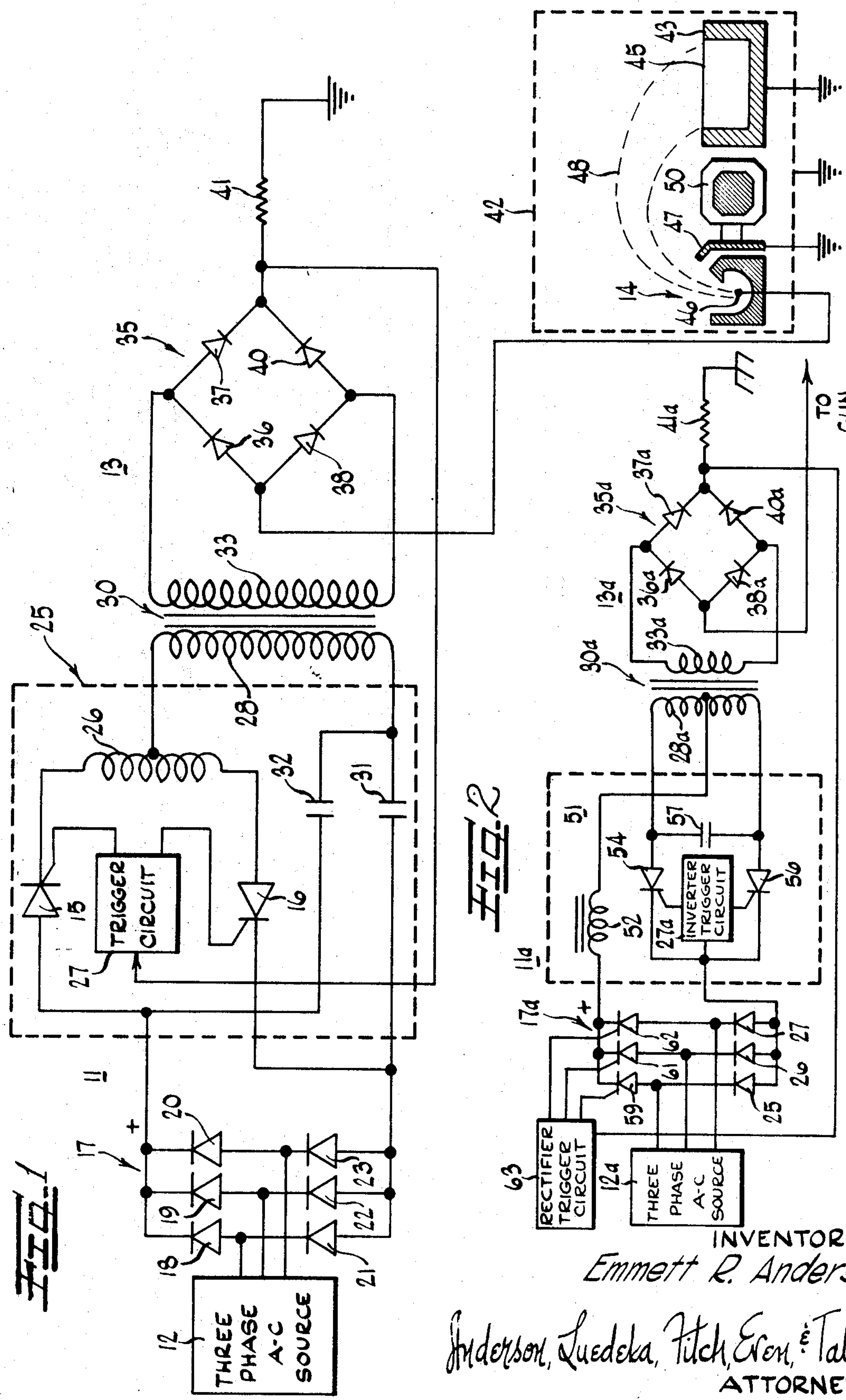

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POWER SUPPLY

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ABSTRACT OF THE DISCLOSURE

A power supply is described for use with an electron gun employed in an electron beam furnace system. The power supply includes means for increasing the frequency of an a-c source and for deriving a direct current from the increased frequency signal and applying such direct current to the electron gun. The frequency increasing means operate to a non-conductive condition in the presence of an arc in the electron gun.

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 together with the material to be treated, 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 filament, 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 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 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, particularly when the target material is in a relatively impure condition. The presence of such gaseous materials 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 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 with-

out coincident restoration of the arc only by cutting back the electron gun current sufficiently. In co-pending application, Ser. No. 642,626, filed May 3, 1967, and 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 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 a 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 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 another embodiment of the invention.

Very generally, the power supply of the invention comprises frequency increasing means **11** adapted for connection to an A-C source **12** and providing an A-C output of a predetermined frequency which is substantially higher than the frequency of the source. Means **13** convert the output of the frequency increasing means to a direct current and supply the direct current to an electron gun **14**. The frequency increasing means include current control means **15** and **16** which are operable to render the frequency increasing means non-conductive upon a rise in current to the electron gun due to an arc.

Referring now to FIG. 1, power is derived from the A-C source **12** which preferably provides three phase power. The source may be a commercial power line providing a 220 volt, 60 cycle, three phase voltage. This output is coupled to the frequency increasing means **11**.

The illustrated frequency increasing means **11** operates on the output from the source **12** to produce a single phase alternating current of substantially higher frequency. The frequency increasing means **11** includes a three phase full wave rectifier **17** having suitably polarized and connected solid state diodes **18, 19, 20, 21, 22** and **23**.

The frequency increasing means **11** also include a series type inverter **25** to which the output of the three phase rectifier **17** is coupled. The inverter includes the two current control devices **15** and **16** which are connected respectively between the positive output of the rectifier and one end connection of an inductor **26** and between the negative output and the other end connection of the inductor **26**. In the embodiment illustrated in FIG. 1, the current control devices **15** and **16** are silicon controlled rectifiers (SCR's). Each of the SCR's has a gate electrode connected to a trigger circuit **27**. The trigger circuit **27** operates to alternately fire the SCR's **15** and **16** so that the output of the inverter **25** is of a predetermined frequency, described in greater detail below. Trigger circuits suitable for this purpose are known in the art and some types of trigger circuits which may be satisfactorily utilized in this connection are described in detail in chapter 5 of Semiconductor Controlled Rectifiers, by Gentry, Gutzwiller, Holonyak and Von Zastrow; Prentiss Hall, 1964.

The output of the inverter **25** is applied across the primary winding **28** of a step up transformer **30**. One end of the primary winding **28** is connected to a center tap on the inductor **26**. The other end of the primary winding **28** is connected through a capacitor **31** to the negative side of the three phase rectifier **17** and through a capacitor **32** to the positive side of the rectifier **17**.

The output from the transformer **30**, which is derived across the secondary winding **33** thereof, is applied across a bridge rectifier **35**. The bridge rectifier consists of four suitably polarized diodes **36, 37, 38** and **40**. The juncture between the diodes **36** and **38** is connected to the electron beam gun **14** to supply the accelerating voltage thereto. The juncture between the diodes **37** and **40** is coupled to ground through a resistor **41**, the purpose of which is explained below.

The electron beam gun **14** is disposed in a suitably grounded electron beam furnace, schematically indicated by the dotted lines **42**. The interior of the furnace is evacuated and contains a crucible **43** in which target material **45** is disposed for heating by an electron beam.

The electron gun **14** may be of any conventional type. In the embodiment illustrated in FIG. 1, the electron gun **14** is disposed in the furnace **42** and includes a cathode **46** and a grounded accelerating anode **47**. The electrons emitted by the cathode **46** are accelerated and formed into a beam **48** by the accelerating potential established between the cathode **46** and the grounded anode **47**. The beam is deflected by a transverse magnetic field, produced by an appropriately positioned electromagnet **50**, onto the surface of the target **45**. The cathode **46** may be heated either directly or indirectly by suitable means not illustrated.

During operation of the foregoing described power supply, the voltage which is developed across the electron gun **14** may 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.

During normal operation, the three phase rectifier **17** supplies a direct current to the inverter **25**. This direct current is converted to an alternating current by the alternating conduction of the SCR's **15** and **16**. With the SCR **15** conductive, current will flow through the SCR **15** and the upper half of the inductor **26**, through the primary winding **28** and the capacitor **31**. The decay time of this current will depend upon the time constant in the series LC circuit comprised of the inductor **26**, the primary winding **28** and the capacitor **31**. When the current in the SCR **15** falls to zero, the SCR **15** becomes non-conductive and the trigger circuit **27** operates to turn the SCR **16** on.

With the SCR **16** conductive, current will flow through the capacitor **32**, the primary winding **28**, the lower half of the inductor **26** and the SCR **16**. The decay time of this current will depend upon the time constant of the LC series circuit comprised of the capacitor **32**, the primary winding **28** and the lower portion of the inductor **26**.

The result of the operation of the invertor **25** is an alternating current in the primary winding **28**. This is stepped up in the transformer **30** so that an alternating current output of substantially higher voltage is derived across the secondary winding **33**. This output is then rectified in the bridge rectifier **35** to a high voltage DC which is supplied to the electron beam gun **14**.

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 limiting current to a level below the higher current steady state stage, damage to gun and furnace parts may often be prevented. In some systems, however, especially those exceeding about 10 kw. of beam power and 2 or 3 amperes normal operating current, 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.

In such higher power systems it is usually necessary to substantially reduce the power supplied to the electron beam gun and maintain it at the reduced level for a period of about $\frac{4}{10}$ 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 $\frac{4}{10}$ 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 inteolerable variation in the vapor deposition rate.

If, as taught in the aforementioned application Ser. No. 642,626, 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 power levels exceeding 10 kw., if the electron gun current is cut back less than about 15 milliseconds after the beginning of an arc, it is usually possible to restore electron gun current within 200 milliseconds without coincident restoration of the arc. For many operations, a 200 millisecond delay is too long, but shorter delay may be achieved by using cut back times shorter than 15 milliseconds, as pointed out below.

Experience indicates that, for most furnace system configurations operating in excess of 10 kw. beam power and 3 amperes beam current, 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 usually less than 2 amperes, and for high reliability it is preferable that it be cut back to less than 1 ampere. Highly satisfactory results are obtained with an operating current of 5 amperes when the current is cut back to less than 5 percent of the operating current—about 0.1 ampere. In the latter case, and with a cut back time of 10 microseconds, it is usually possible to restore electron gun current very quickly, in some cases as quickly as 100 microseconds from cut back, without coincident restoration of an arc.

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 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 incipiency, circuit design is simplified in this respect.

In order to sense the incipiency of an arc, the resistor **41** is utilized. The voltage appearing across the resistor **41** corresponds to the electron beam current, and this voltage is applied to the trigger circuit **27**. Suitable means, not illustrated, are incorporated in the trigger circuit in order to temporarily interrupt operation thereof when the voltage across the resistor exceeds a preselected level. Such means are readily designed by those skilled in the art, and may for example, be similar to the circuits shown on pages 319 and 320 of the aforementioned Gentry book. This being the case, neither of the SCR's **15** or **16** will be placed in the conductive condition and hence the output of the inverter **25** falls to zero.

The trigger circuit may be temporarily disabled, upon sensing a rise in current due to an arc, in any convenient way, depending upon the type of trigger circuit used. For example, bias for diode or transistor operation may be removed when the voltage across the resistor **41** exceeds a preselected level. Another example is the use of a diode or transistor shunt for the output of the trigger circuit.

Because the current cutback time is dependent upon the time of cutback of the current output of the inverter **25**, the time constants in the inverter circuitry are selected to be such that the cutback time will be of satisfactory shortness. It has been found that, for many purposes, the inverter may be designed to operate at an output frequency exceeding 400 cycles per second without undue design complexity. It may, however, be preferable to operate at frequencies of 1 kc. or higher in order to provide cut back times of less than one millisecond. It should be mentioned at this point that the cut back times referred to herein are the total time from the very beginning of a gun current rise due to arcing until that time at which the current is cut back to the minimum level. As a practical matter, the time prior to the current passing above the preselected trigger level may be ignored, since this is normally less than a microsecond.

Referring now to FIG. 2, another embodiment of the invention is shown. Components of the circuit diagram in FIG. 2 which are identical in type and function to those in the diagram of FIG. 1 have been given identical numbers with the subscript *a*. In the embodiment of FIG. 2, a parallel type inverter **51** is utilized rather than the series type inverter of FIG. 1.

In FIG. 2, an inductor **52** is connected to the output of the three phase rectifier **17*a*** and to a center tap on the primary winding **28*a*** of the transformer **30*a***. The respective ends of the primary winding **28*a*** are connected through SCR's **54** and **56** to the negative side of the bridge rectifier **17*a***. Conduction of the SCR's **54** and **56** is controlled by the inverter trigger circuit **27*a***. A capacitor **57** is connected between the anodes of the SCR's to render the conducting SCR non-conductive when the other SCR is rendered conductive. Thus, when the SCR **54** is rendered conductive by the trigger circuit **27*a***, current flows through the inductor **52** and the upper half of the primary winding **28*a***. The rise time of the current thus conducted is determined by the inductance of the inductor **52** and the upper half of the primary winding **28*a***.

Upon the firing of the SCR **56**, the SCR **54** shuts off. Current now flows through the inductor **52**, the lower half of the primary winding **28*a*** and the SCR **56**. The rise time of this current is determined by the inductance of the inductor **52** and the lower half of the primary winding **28*a***. The conduction of the SCR **56** is halted upon the firing, once again, of the SCR **54**.

The inverter **51** cannot interrupt power when triggering is removed from the inverter trigger circuit **58**. This is due to the fact, mentioned above, that the firing of one SCR in the inverter is required to shut off its parallel SCR. Accordingly, 3 SCR's **59**, **61** and **62** are utilized in the rectifier **17*a*** to control current to the electron gun **16**. A further rectifier trigger circuit **63** is connected to the gates of the SCR's **59**, **61** and **62** and operates, as is known in the art (see the previously mentioned Gentry book), to fire the SCR's for appropriate three phase conduction. Trigger circuits capable of such function are described in the previously cited Gentry et al. article. Upon the sensing of a current rise due to an arcing condition, by sensing the voltage across the resistor **41*a***, the triggering circuit **63** is turned off so that power is no longer applied to the inverter **51**. Accordingly, power is removed from the electron beam gun.

Although current cut back may not be as quickly attainable in the circuit of FIG. 2 compared with that of FIG. 1, some decrease in cut back time occurs by utilizing three SCR's rather than one. Moreover, the advantages accruing from the use of solid state devices are still present, and the higher frequency output of the inverter enables reduction in size and weight of magnetic components, as was the case in the embodiment of FIG. 1.

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 and such cutting back may be accomplished in a sufficiently short period of time as to enable rapid restoration of beam current without coincident restoration of the arcs.

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 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, frequency increasing means adapted for connection to a source of alternating current, said frequency increasing means, when thus connected, providing an alternating current output of a predetermined frequency which is substantially higher than the frequency of the source, said frequency increasing means including current control means operable to render the frequency increasing means non-conductive upon a rise in current to the electron gun due to an arc, and means coupled to said frequency increasing means for producing a direct current and for coupling same to the electron gun.

2. A power supply according to claim **1** wherein said current control means include a plurality of controlled rectifiers, a trigger circuit coupled to said controlled rectifiers for alternately rendering said controlled rectifiers conductive, and means coupled to said trigger circuit for temporarily preventing operation thereof.

3. A power supply according to claim **1** wherein said frequency increasing means comprise alternating current to direct current converting means adapted to be coupled to the alternating current source, and further comprise inverter means coupled to said converting means for providing an alternating current output at the pre-determined frequency.

4. A power supply according to claim **3** wherei nsaid converting means include at least one controlled rectifier, a trigger circuit coupled to said controlled rectifier for periodically rendering same conductive in accordance with the frequency of the alternating current source, and means coupled to said trigger circuit for temporarily preventing operation thereof.

5. A power supply according to claim **3** wherein said inverter means include at least one controlled rectifier, a trigger circuit coupled to said controlled rectifier for periodically rendering same conductive in accordance with the pre-determined frequency, and means coupled to said trigger circuit for temporarily preventing operation thereof.

6. A power supply for an electron gun employed in an electron beam furnace system wherein the gun current is susceptible of rising from an operating level to a substantially higher steady state level upon the occurrence of an arc, comprising, frequency increasing means adapted for connection to a source of alternating current, said frequency increasing means, when thus connected, providing an alternating current output of a predetermined frequency which is substantially higher than the frequency of the source, means for coupling said frequency increasing means to the electron gun and for producing a direct current for the electron gun, said frequency increasing means including current control means having at least one element operable from a periodically conductive condition to a non-conductive condition upon the removal of voltage thereacross, said current control means including means for temporarily preventing periodic conduction of said one element upon a rise in current to the electron gun due to an arc, said predetermined frequency being selected to cause electron gun current to be cut back to a level sufficient to starve the arc before the gun current can rise to the higher steady state level.

7. A power supply according to claim **6** wherein said one element is operable to a conductive condition from a non-conductive condition in response to a trigger signal applied thereto, and wherein said current control means include trigger means for periodically applying trigger signals to said one element in accordance with the predetermined frequency, said conduction preventing means operating to suspend operation of said trigger means.

8. A power supply according to claim **6** wherein said coupling and direct current producing means comprise transformer means coupled to the output of said frequency increasing means for providing an alternating current output of substantially higher voltage than the output of said frequency increasing means, and further comprise rectifier means coupled to the output of said transformer means.

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