July 9, 1968 E. R. ANDERSON 3,392,304

POWER SUPPLY FOR AN ELECTRON BEAM FURNACE GUN

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Fig 1

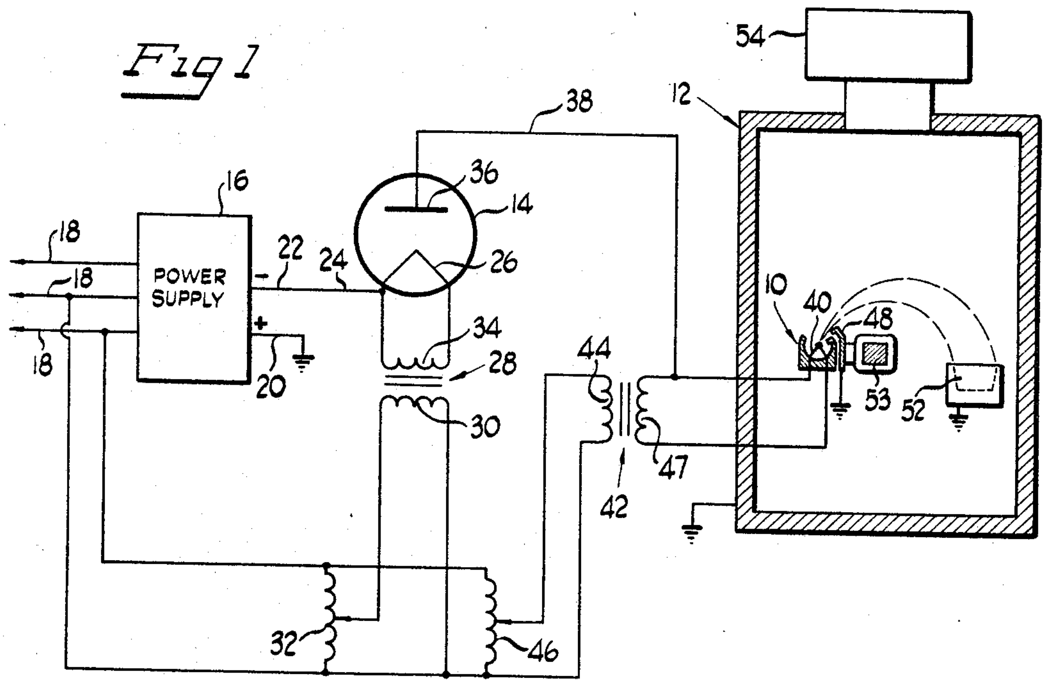
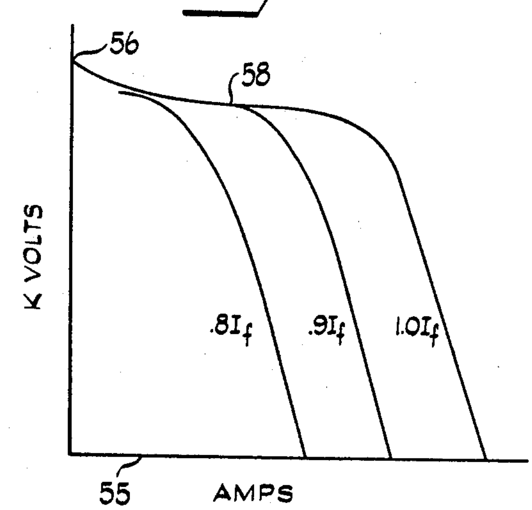


Fig 2



INVENTOR
EMMETT R. ANDERSON

BY Anderson, Luedeka, Fitch, Even & Tabin
ATTORNEYS

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POWER SUPPLY FOR AN ELECTRON BEAM FURNACE GUN

Emmett Raymond Anderson, Berkeley, Calif., assignor, by mesne assignments, to Air Reduction Company, Incorporated, a corporation of New York

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4 Claims. (Cl. 315—14)

The present invention relates generally to power supplies and more particularly to a power supply which is adaptable for supplying several kilowatts of power to an electron beam gun employed in a high vacuum electron beam furnace.

Electron beam furnaces may be utilized in numerous situations particularly where material treating operations are to be conducted. Typical examples of such operations which are now quite well known include high temperature melting and purification of various materials, vapor plating, cleaning, etc. Usually the electron beam furnace employed in such operations comprises an electron gun disposed in an evacuated enclosure together with the material to be treated. The electron gun typically is provided with an electron emitting cathode or filament and an accelerating anode, which is maintained at a high positive potential with respect to the cathode so as to establish the high electrostatic field for accelerating the electrons. When the cathode is sufficiently energized and the requisite electrostatic field is established a high intensity beam of electrons is emitted from the electron gun and may be directed to bombard the material, thereby heating the same. Obviously the amount of heating effected is related to the intensity of the electron beam current together with the accelerating voltage applied by the field through which the electrons travel.

As the electrons bombard the target material various occluded gases and vaporous materials are released from the material. The presence of such substances in the path of the electrons may result in a substantial decrease in resistance in the path of the electrons, leading to a corresponding marked increase in the electron beam current. This often causes arcing in the electrostatic field between the cathode and the anode in the electron gun chamber. Such effects are generally undesirable since they tend to shorten the life of the electron gun as well as damaging the target material.

Apparatus has been developed for alleviating the aforementioned effects as well as regulating the power supplied to the electron gun. Certain of such apparatus, during normal operation, maintains the voltage at a generally constant level, and when arcing occurs limits the current supplied to a preselected level. Such apparatus has been relatively complex.

Other apparatus has been developed which controls or maintains constant the current supplied to an electron gun. Such apparatus normally employ monocyclic power supplies which usually include inductors and capacitors connected so as to provide resonant circuits which resonate at the frequency of the input circuit. But, extensive means are ordinarily provided in such circuits for protecting the various elements against overstress. In addition, reactive elements of uneconomically large size are often required.

It is an object of the present invention to provide an improved and simplified power supply adaptable for supplying several kilowatts of power to an electron beam gun employed in a high vacuum electron beam furnace while maintaining the electron beam current emitted by the gun below preselected levels.

Another object of the invention is the provision of a power supply for an electron beam furnace which limits the effects of arcing in the electron beam.

Still another object is the provision of a power supply for an electron beam gun which limits the maximum current supplied to the gun under arc discharge conditions.

A further object is the provision of an electron beam gun power supply which is relatively economical to manufacture, durable in use and which aids in prolonging the useful life of the electron gun structure.

Other objects and advantages will become readily apparent from the following detailed description and accompanying drawings wherein:

FIGURE 1 is a schematic circuit diagram of one embodiment of a power supply in accordance with the present invention, and

FIGURE 2 is a graph showing typical characteristic curves of a power diode suitable for use in the circuit illustrated in FIGURE 1.

Generally, in the illustrated power supply the current supplied by an electron gun **10** in an electron furnace **12** is limited to a preselected level by employing a diode **14** connected in series with the output of a D-C power supply **16** and the electron beam of the gun **10**. By limiting the beam current to a preselected level, the effects of abrupt increases in the electron beam current, such as may occur during arcing are avoided, thus preventing damage to the electron gun structure as well as to the target material.

More specifically, the high voltage D-C power supply **16** may be a conventional three phase, full wave rectifier which is connected through suitable leads **18** to a source of three phase A-C power (not shown). The positive output terminal **20** of the power supply **16** is grounded and the negative terminal **22** of the power supply **16** is coupled through a conductor **24** to the filament **26** of the diode **14**.

In the illustrated embodiment, the diode has a directly heated filament which is heated by a filament transformer **28**. In this connection a primary winding **30** of the filament transformer **28** is connected to a first variable autotransformer **32**, which is connected to a single phase of the A-C power supply. A secondary winding **34** of the filament transformer **28** is coupled to the filament **26** of the diode **14**. The filament transformer **28** is preferably provided with high voltage insulation on its windings since there is generally a substantial difference between the voltage on the windings.

The anode **36** of the diode **14** is coupled through a conductor **38** to the cathode **40** of the electron gun **10** which may be of the conventional type. In the illustrated embodiment, the cathode **40** of the electron gun **10** is energized by a filament transformer **42**. The filament transformer **42** includes a primary winding **44** connected to a second variable autotransformer **46** which is connected to the single phase of the A-C power supply. The filament transformer **42** further includes a secondary winding **47** coupled to the cathode **40**. The windings of the filament transformer **42** are also preferably provided with high voltage insulation.

The accelerating anode **48** of the electron gun **10** is suitably grounded so that the requisite high voltage or accelerating potential is applied between the cathode **40** and the accelerating anode **48** of the gun **10**. The electron gun **10** is suitably disposed within the appropriately grounded electron beam furnace **12** so that the electron beam is directed upwardly and is deflected onto the suitably grounded target material **52** by a transverse magnetic field established by a suitable magnet **53** disposed within the furnace **12** together with the electron gun **10** and the target material **52**. In addition, the furnace includes a suitable vacuum pump **54** for maintaining the necessary vacuum.

As may be seen a complete series circuit is defined extending from the grounded positive terminal of the power supply **16** through the negative terminal **22**, through the diode **14**, and through the electron beam emitted by the cathode **40** to the grounded accelerating anode **48**. Thus, the diode **14** is electrically in series relationship with the electron beam and accordingly may be appropriately adjusted to limit the electron beam current, as is hereinafter explained in detail.

During normal operation of the electron gun, the beam current is adjusted by adjusting the voltage applied across the primary winding **44**. This is achieved by appropriate adjustment of the second variable autotransformer **46**. The maximum beam current which can flow through the electron gun is set by selecting the level of operation of the diode. The desired maximum level of the control diode **14** is selected by means of the first variable autotransformer **32**, which controls the filament current of the diode **14**. The particular power diode **14** is selected to supply the required maximum current to the electron gun. In this connection, a power diode of the type having a substantially pure tungsten filament is generally employed. The characteristic curves at several levels of filament current of a typical power diode suitable for use in a power supply in accordance with the present invention are illustrated in FIGURE 2.

Observation of these curves reveals that the maximum diode current as measured along the horizontal axis, increases as the filament current (I_f) increases, but reaches a maximum value for each particular value of I_f as shown by the intersection of each curve with the base line **55**. At a selected value of I_f, for example at 0.9 I_f, the current passing through the tube and correspondingly the electron beam current, may be conveniently adjusted by adjusting the second autotransformer **46** to cause the electron beam current to vary from zero amps, as shown by the point designated by the numeral **56**, to the point designated by the numeral **58**, at which the emission current of the particular tube at this level of filament current is approached. Accordingly, a desired current, which is less than the maximum diode current at the selected level of operation, may be drawn from the anode **36** of the diode **14** by adjusting the filament current, supplied to the cathode **40** of the electron gun.

As the diode current increases from zero amps to the amperage at the point **58**, the voltage drop across the diode, which is a relatively low proportion of the D-C supply voltage, increases at a relatively low rate remaining substantially constant with increasing diode current. The remainder of the supply voltage, thus, is developed across the electron gun **10**, providing a constant high accelerating potential for the electron beam as the electron beam current is varied. The voltage across the electron gun **10** is accordingly regulated or held substantially constant during normal operation as the electron beam current is varied.

However, if the electron beam current abruptly begins to increase, which may occur as a result of an abrupt decrease in resistance between the cathode **40** and the accelerating anode **48** of the electron gun **10**, caused by arcing in the electron beam, the voltage drop across the electron gun **10** will rapidly decrease and approach zero. Consequently, substantially all of the voltage supplied by the power supply **16** would appear across the diode **14**. But, arcing is minimized because the current passing through the diode **14**, which correspondingly passes through the electron gun is limited to a preselected level, as previously described.

It can be seen from the foregoing that the disclosed power supply is provided with a protective feature which limits the maximum current level which can be reached by the electron beam. This current level is generally dictated by the emission characteristics of a diode connected in series relationship with the electron gun. At the same time, the voltage developed across the electron gun is maintained substantially constant, or regulated, as the electron beam current is varied within the preselected limits determined by the diode characteristics.

If desired, a plurality of diodes may be connected to a common power supply and coupled to a plurality of electron guns. This may be conveniently achieved since there is a common ground return for the total emission current passing through each tube to the electron guns and thence to the grounded target material.

Thus, an improved and substantially simplified power supply has been provided in which, after selecting a particular maximum current level by adjusting the filament temperature of the diode, a single control is adjusted for varying the electron beam current over its preselected operating range. At the same time the voltage developed across the electron gun is regulated during normal operation while the beam current may vary, and an automatic protective feature is provided for limiting the maximum electron beam current to a preselected value regardless of abrupt decreases in the resistance of the electron beam path such as may result from arcing.

Various changes and modifications may be made in the above-described power supply without deviating from the spirit or scope of the present invention. Various features of the present invention are set forth in the appended claims.

What is claimed is:

1. Apparatus for controlling the electron beam current supplied by an electron gun and directed at a target material in an electron beam furnace comprising means for supplying a direct current voltage to said electron gun and a diode serially coupled between said direct current voltage supply means and said electron gun for limiting the current conducted therethrough.

2. Apparatus for controlling the electron beam current supplied by an electron gun and directed at a target material in an electron beam furnace comprising means for supplying a direct current voltage to said electron gun, a diode serially connected between said voltage supply means and said electron gun for limiting the current conducted therethrough, said diode having a heated filament, and means coupled to said heated filament for adjusting the current supplied thereto.

3. Apparatus for controlling the electron beam current supplied by an electron gun and directed at a target material in an electron beam furnace, said electron gun having a cathode, said apparatus comprising means for supplying a direct current voltage to said electron gun, a diode serially connected between said voltage supply means and said electron gun for limiting the current conducted therethrough, said diode having a heated filament, means coupled to said heated filament for adjusting the current supplied thereto, and means coupled to said cathode for adjusting the current supplied thereto.

4. Apparatus for controlling the electron beam current supplied by an electron gun and directed at a grounded target material disposed in a grounded electron beam furnace, said electron gun having a cathode and having a grounded accelerating anode, said apparatus comprising means for supplying a direct current voltage to said electron gun, said direct current voltage supply means having a positive output terminal connected to ground and having a negative output terminal, a diode serially connected between said negative output terminal of said voltage supply means and said electron gun for limiting the current conducted therethrough, said diode having a filament, means coupled to said filament for adjusting the current supplied thereto, and means coupled to said cathode for adjusting the current supplied thereto.

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RODNEY D. BENNETT, *Primary Examiner.*

M. F. HUBLER, *Assistant Examiner.*