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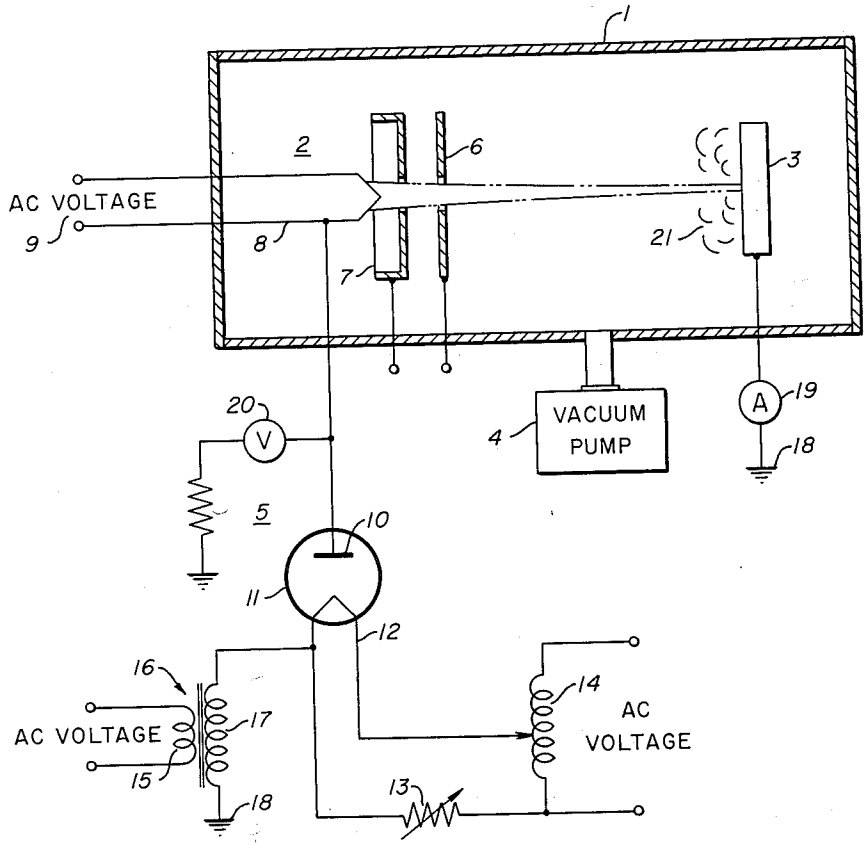
SEARCH ROOM

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APPARATUS FOR ELECTRON BEAM HEATING CONTROL

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APPARATUS FOR ELECTRON BEAM HEATING CONTROL

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This invention relates to electron beam, vacuum heating apparatus, such as for melting or welding high-melting point refractory materials and, more specifically, to the control of the electron current bombarding work piece. The electron beam in combination with new technique and apparatus has yielded improved quality in metals and insulating materials, including greater purity, high-temperature stability and strength. The precise and reliable control of the electron beam current and the reduction in arc discharges occurring in the apparatus are of paramount importance to achieving desired heating uniformity in welding or melting operations.

In general, the electron beam is produced from an electron gun and accelerated towards a work piece with such velocity that a very high heating takes place at the points where the beam strikes the work piece. The electron beam may be either of large or small cross sections, depending on whether the object is to melt or weld the work piece. The chamber in which the electron gun and work piece are located is maintained at a high vacuum by a suitable gas pump. The presence of gas in the chamber limits the effective operation of the device by causing arc discharges between the work piece and the electron gun and instabilities in the electron beam current. Even though the gas is continuously withdrawn from the chamber, the work piece itself emits gas due to the heating of the material and the precise control of the electron beam current is made difficult.

In the prior art systems, the electron beam current was controlled by varying the emission of the electron gun through current or voltage adjustment in its power supply. Increases in the quantity of gases in the chamber changed the electron beam current flow characteristics resulting in an increase in the electron beam current. Adjustment of the filament current had to be made to maintain a constant electron beam current. When an arc discharge occurred in the system, the electron current changed in an uncontrollable manner to a value exceeding the maximum permissible heating level for the work piece and, thereby, adversely affected the quality of the welded or melted work piece.

Another approach taken by the prior art was to use a current limiting device associated with the high voltage supply circuit to limit the D.C. current flow to the electron gun under all operation conditions. One example of such an arrangement is shown in U.S. Patent 2,554,902, issued May 29, 1951, wherein a constant current network is placed in the primary circuit of the high voltage and electron gun filament transformers to reduce the operating voltages in the system when an arc discharge occurs. The net effect of part of the added current control network is to increase the internal impedance of the high voltage supply source and make it relatively high, as compared to the impedance of the gun discharge, so that variations in the electron gun impedance due to changes in vapor pressure will not significantly affect the heating current. In this manner, the welding current flow is determined in part by the high voltage supply source impedance, in series with the gun discharge impedance, and the electron gun emission.

The present invention has for its object the improved

control of the electron beam current in an electron beam heater.

A further object of the invention is to control within limits the bombarding current in the system of an electron beam heater when an arc discharge occurs, to prevent damage to the work piece.

Another object of the invention is to achieve uniform and improved control of the electron beam current for the heating of a work piece.

A further objective of the invention is to provide a more rapid response in the control of the electron beam current where the beam current level is varied.

A still further objective of the invention is to maintain a high-quality, uniform heating character at the work piece by maintaining a substantially constant accelerating voltage for the electron beam.

The above objectives are accomplished in accordance with the present invention by controlling the internal impedance of the high voltage supply source. As opposed to the prior art approach where the emissivity of the electron gun was used to control the beam current or a current limiting network was added, the present invention controls the impedance of the high voltage supply source by control of the cathode supply to the vacuum tube rectifiers. More specifically, the power supply which furnishes the high voltage potential utilizes a vacuum tube rectifier, or rectifiers, and the power supply output is connected between the work piece and the electron gun to establish the accelerating potential difference. The electron beam current passes through the discharge path to the work piece and through the rectifiers of the high voltage power supply. The current through the rectifiers depends on the electron emission of the cathodes and the voltage applied between the cathode and anode of the rectifiers. By controlling the power supplied to the cathode the current through the rectifier and, accordingly, the electron beam current can be limited. The rectifier tubes are connected in series with the electron beam gun. The filament heating current for the gun filament is preset to a value high enough to maintain adequate thermionic emission to freely pass the current which has passed through the rectifier tubes thereby reflecting in the heating operation the current control maintained by the rectifier tubes. By using this system of controlling the electron beam current, gas pressure variations in the chamber have very little effect on the electron beam current stability.

As generally described above, and referring to the schematic shown in FIGURE 1 of an electron beam heater and the control apparatus according to the present invention, an electron beam heating device, includes a chamber **1**, an electron gun **2**, and a work piece **3**. The chamber **1** is continuously evacuated to a substantial vacuum by a pump **4**. The high voltage power supply **5** supplies the accelerating potential between the electron gun **2** and the work piece **3**. The electron gun **2** comprises an accelerating electrode **6**, modulating electrode **7** and filament **8** and an A.C. voltage is applied to the filament input **9**.

The high voltage power supply is shown as a half-wave rectifier, although other types of vacuum tube rectifier systems would serve equally as well when adapted to the teaching of the present invention. The anode **10** of the rectifier **11** is connected to the filament **8** of the electron gun **2** and the power for filament-cathode **12** is controlled by resistor **13** and auto-transformer **14** for fine and coarse adjustment respectively. An A.C. voltage is supplied to the primary winding **15** of high voltage transformer **16** and the secondary winding **17** is connected at one end to the cathode **12** and at the other end to the ground **18**. The work piece **3** is also at the ground potential to complete the circuit for the electron beam

heating current. The electron beam current is monitored by an ammeter 19 connected between the work piece and the ground 18, while the accelerating potential between the work piece and the electron gun is monitored by the voltmeter 20.

In operation, the filament heating current for the electron gun 2 is pre-set to a flow high enough to maintain adequate thermionic emission to freely pass the current which has passed through the rectifier 11. An accelerating potential difference is applied between the electron gun 2 and the work piece 3 from the rectifier 5, accelerating the electron beam towards the work piece 3. The electron beam heats the work piece to either weld or melt, depending on the purpose of the device. Gas 21 is evolved from the work piece and is continuously withdrawn by pump 4. The accelerating electrode 6 is disposed between the work piece 3 and the electron gun 2 to focus the beam and a modulating electrode 7 can be pulse modulated with a high negative potential to permit pulse operation of the electron beam.

The electron beam current is controlled by the adjustment of the power to cathode 12 in rectifier tube 11. As the power is increased by adjusting auto-transformer 14, the cathode 12 emits electrons which pass to the anode 10. The electron flow to the anode 10 is proportional to electron emission of cathode 12 and reaches a maximum for any given cathode power when all the electrons from cathode 12 are drawn to the anode 10. The electron flow to the anode 10 is determined by the cathode power and the cathode-to-anode voltage. In a particular range of cathode power for a given cathode-to-anode voltage all electrons will flow to the anode, usually termed the voltage saturation or current emission-limited region. As the cathode power is increased further for a given cathode-to-anode voltage a point is reached beyond which no further increase in anode current will take place, commonly called the temperature saturation region. For a more elaborate description of these terms reference is made to "Fundamentals of Electron Devices," by Karl R. Spangenberg, McGraw-Hill Book Co., Inc., New York, 1957, Chapter 9.

In a conventional power supply the rectifier tubes are operated in the temperature saturation region so that as much current as possible or needed by the circuit can be drawn through the rectifier. In contrast, the present invention controls the electron beam heating current through operation of the vacuum-tube rectifier, or rectifiers, below the temperature saturation region for substantially all the range of cathode-to-anode voltage limiting the maximum amount of current that can pass through the rectifier. Generally, in operation all or almost all of the electrons emitted from the cathode reach the anode, corresponding to near voltage saturation operation. Instabilities in the electron beam heating current are substantially eliminated as the limiting action of the vacuum-tube rectifier prevents excessive electron beam current increases. It is desirable to operate the vacuum-tube rectifier in the region adjacent general voltage saturation between the voltage and temperature saturation regions, to reduce the voltage drop across the rectifier tube. An improved and more rapid response is obtained for adjustment of the electron beam current when the vacuum-tube rectifier has either a tungsten or thoriated tungsten filament cathode, as these materials respond quickly to power input changes.

The electron beam heating device has a potential difference between the work piece 3 and electron gun 2 that does not draw all electrons emitted from the electron gun 2 to the work piece 3. Consequently, all the current that passes through the vacuum-tube rectifier 11 will also pass to the work piece 3.

It must be recognized that the present invention has utility for a number of devices that employ an electron beam for heating a work piece. The work piece may be one or more elements that are to be welded together or a specimen that is to be melted to improve the purity of the material. In the case of welding with a device according to the present invention, the operation of the rectifier 5 has the further advantage of more precise control of the welding current and a substantial elimination of changes in the accelerating potential when the beam current intensity is varied. Also, the fast response provided by the use of tungsten or thoriated-tungsten filament cathodes is of decided importance in welding operations.

It should be understood that this invention in its broader aspects is not limited to specific examples herein illustrated and described, and that the following claims are intended to cover all changes and modifications within the true spirit of the invention.

What is claimed is:

1. An apparatus for controlling the power of an electron beam heater comprising a chamber, means coupled to said chamber for producing a substantial vacuum, a work piece disposed within said chamber, an electron gun disposed in said chamber spaced from said work piece, means energizing said electron gun to produce a beam of electrons bombarding said work piece, a D.C. power supply having a vacuum-tube rectifier, the output of said power supply being connected between said work piece and said electron gun to place said work piece at a positive potential with respect to said electron gun, and means for adjusting the cathode power of said vacuum-tube rectifier to control the electron beam current heating said work piece, said cathode power being adjusted such that the rectifier operates below its temperature saturation region.

2. An apparatus as described in claim 1, wherein said vacuum-tube rectifier has a filament-cathode made from a substance selected from the group consisting of tungsten and thoriated tungsten.

3. An apparatus for controlling the power of an electron beam welder comprising a chamber, means coupled to said chamber for producing a substantial vacuum, a work piece disposed within said chamber for welding, an electron gun disposed in said chamber spaced from said work piece, means energizing said electron gun to provide a narrow beam of electrons bombarding said work piece for controlled welding, a D.C. power supply having a vacuum-tube rectifier, the output of said power supply being connected between said work piece and said electron gun to place said work piece at a positive potential with respect to said electron gun, and means for adjusting the cathode power of said vacuum-tube rectifier to control the welding current, said cathode power being adjusted such that the rectifier operates below the rectifier's temperature saturation region over substantially all the range of cathode to anode voltages received by the rectifier.

4. An apparatus as described in claim 3, wherein said vacuum-tube rectifier has a filament-cathode made from a substance selected from the group consisting of tungsten and thoriated tungsten.

5. An apparatus for controlling the power of an electron beam heater, comprising a chamber, means coupled to said chamber for producing a substantial vacuum, a work piece disposed within said chamber, an electron emitter disposed in said chamber spaced from said work piece, means energizing said electron emitter to produce a beam of electrons bombarding said work piece, a source of high voltage A.C., a vacuum-tube rectifier comprising an anode and cathode, the anode of said vacuum-tube rectifier being connected to said electron emitter and the A.C. source being coupled between said work piece and the cathode to form a closed circuit for the electron beam current through the electron emitter work piece path and said vacuum tube, and means energizing said cathode and adapted to vary the electron emission

for controlling the electron beam current bombarding said work piece, said last named means being adjusted for operating said vacuum-tube rectifier below its temperature saturation region over substantially all the range of cathode to anode voltage received by said rectifier.

6. An apparatus as described in claim 5, wherein said cathode is of the filament type and made from a substance selected from the group consisting of tungsten and thoriated tungsten.

7. The method of heating a specimen that comprises introducing said specimen into a high-vacuum chamber containing thermionically electron-emissive cathode means, evacuating said chamber to a high vacuum for maintaining an essentially electronic current to said specimen, establishing a potential difference between said

cathode and specimen from a D.C. power supply having a vacuum-tube rectifier to accelerate electrons emitted by said cathode means to bombard and heat said specimen, and adjusting the cathode power of said vacuum-tube rectifier below the temperature saturation region of said rectifier for a given range of anode voltage to limit the maximum electron current passing through said rectifier, whereby the maximum electron beam current is controlled.

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