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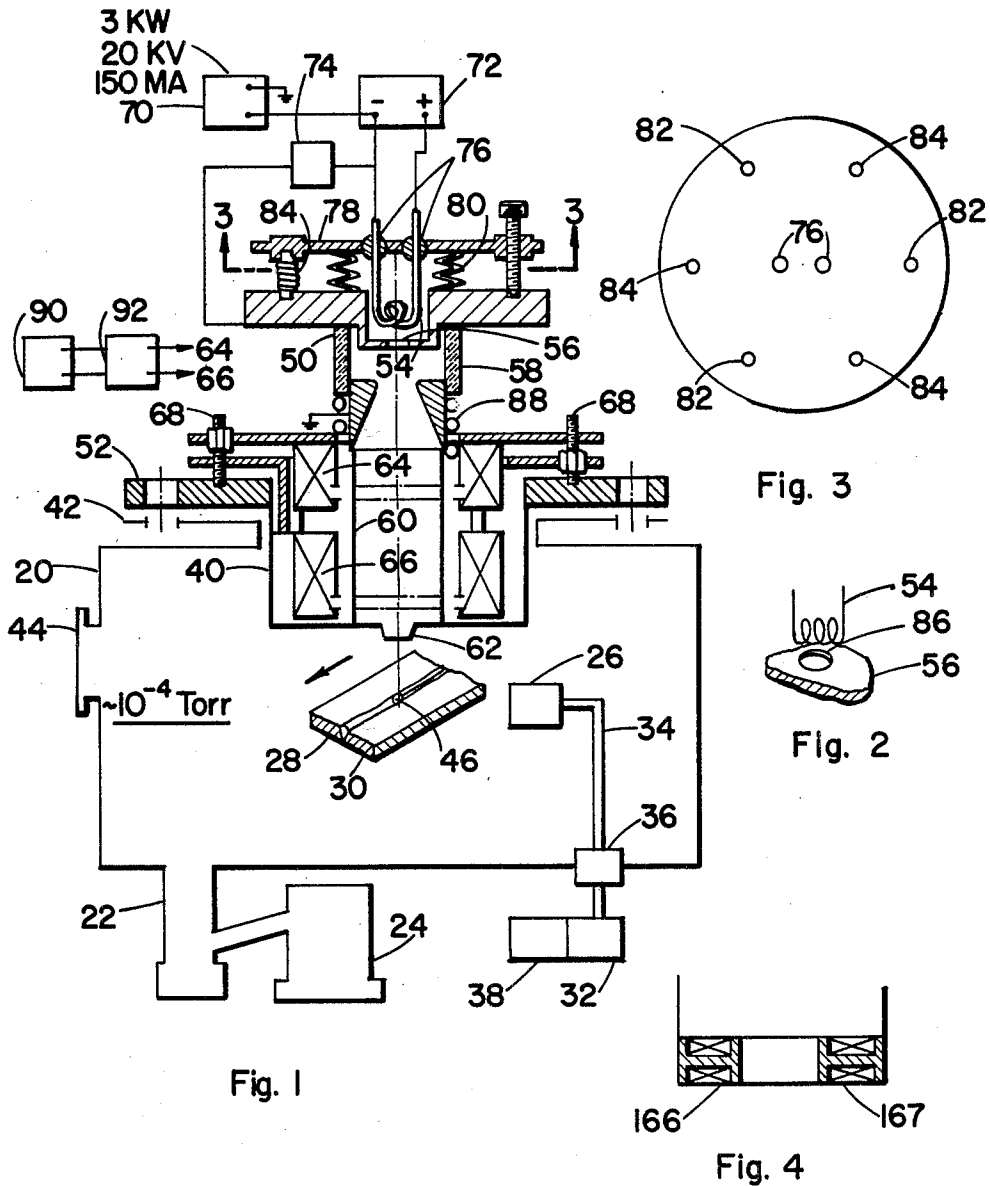
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C. B. SIBLEY

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ELECTRON BEAM HEATING DEVICE

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INVENTOR
CLIFTON B. SIBLEY

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ELECTRON BEAM HEATING DEVICE

Clifton B. Sibley, Needham, Mass., assignor, by mesne assignments, to National Research Corporation, a corporation of Massachusetts

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This invention relates to electron beam heating for welding, etching, annealing, refining, melting and like operations wherein a material is bombarded by a focused beam of electrons to produce intense local heating at the target point. Such heating operations are carried out in vacuum on the order of 10^{-4} torr. They offer the advantages of freedom from contamination, pinpoint location and high power densities compared to other methods of heating. Machines employing this heating comprise three essential elements—an electron beam gun, a work holder and a hermetic chamber. The gun and holder are oriented in the chamber so that the electron beam will sweep the work. Either or both of the gun and the work may be moved. Additionally, the beam may be bent by electrostatic or magnetic fields.

It is an object of this invention to provide an electron beam gun of the self-accelerated type for the above operations which will offer the advantages of high efficiency, reliability and long life of the electron emitter. Efficiency is indicated by power densities at the target and minimum spot size. Reliability is indicated by ease of operation and freedom from down-time adjustments. Power densities of several million watts per square inch are maintained with the gun of the instant invention.

It is another and more specific object of this invention to provide an electron beam welder, incorporating the above gun, for electron beam machining operations, such as welding, etching and the like. Metals ranging from aluminum to tungsten are welded with a focal range of from one half inch to ten inches below the gun.

Other objects of the invention will in part be obvious and will in part appear hereinafter.

The invention accordingly comprises the apparatus involving the several steps and the relation and the order of one or more of such steps with respect to each of the others which are exemplified in the following detailed disclosure and the scope of the application of which will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention reference should be had to the following detailed description taken in connection with the accompanying drawings wherein:

FIG. 1 is a diagrammatic, partly sectional view of a preferred embodiment of the electron beam welder;

FIG. 2 is an isometric view of the electron gun cathode and grid cup aperture;

FIG. 3 is a diagrammatic view showing the arrangement of a detail of FIG. 1 as viewed in the direction indicated III—III in FIG. 1;

FIG. 4 is a sectional view of a magnetic deflector, an optional substitution for a part of the apparatus shown in FIG. 1.

The essential parts of a self-accelerated electron gun comprise an electron emitting cathode, an electrostatic focusing grid (focus electrode) and a perforated anode. The focus electrode and cathode are biased negatively with respect to the anode. The focus electrode is at the same potential or slightly negative relative to the cathode. The electrostatic field between the focus electrode and anode is generally set up to force the electron beam from the cathode towards the apertures in the anode whereby

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the electrons emerge from the anode apertures as a coherent beam. The cathode may be of the direct heated or indirect heated type. It is preferred, in the present invention, to use a directly heated cylindrical coil as the cathode since this is less expensive than the indirect cathode, yet affords good focusing. In connection with this, it should be noted that grid-cathode spacing and alignment are critical parameters, much more vital than anode-grid or anode-cathode spacing and alignment. Shifting of the grid-cathode relation can occur in replacing filaments or as a result of thermal expansion or vibrations during operation. The present invention therefore provides means for adjusting the grid-cathode spacing and alignment continuously so that the operator can keep this relation optimized while operations continue. The field around the filament due to the heating current in the filament causes electrons to be emitted at different directions than always normal to the metal; this bending is compensated for partially by the filament-grid adjustability. This is very difficult to optimize unless done while watching the spot. Abberations are minimized by this flexibility. Furthermore, the gun can be operated continually in the space charge limited condition (where target spot size is smallest at a given current) at varying electron current levels. This makes maximum use of the electrostatic focusing function performed by the grid. The space-charge-limited condition at any current level is very quickly obtained. Two runs on one piece at different levels can be made. Variation in filaments (e.g., due to manufacturer's tolerances) are immediately adjusted out.

Electron guns generally comprise one or more magnetic coils to focus the beam emerging from the anode. In the present invention, a first coil is placed in close proximity to the anode to increase the depth to width ratio of holes drilled at the target. The use of a second coil is preferred, especially where the target is located a substantial distance from the gun, e.g., on the order of 15 inches as in metal evaporating operations, compared to distances on the order of 2 inches for welding operations. Further, the additional coil permits an increased distance and an improved beam pattern from cathode to work to inhibit arcing within the gun. The first coil collimates the beam to a cylindrical shape and the second coil converges the beam towards the target.

The design of the power supplies is based on the consideration that beam voltage and focus coil current are the electric circuit values which have the greatest effect on depth to width ratio at the weld. Electron momentum is a function of beam voltage and focus depends on focus coil current. These parameters are maintained constant.

Referring now to FIG. 1, there is shown a vacuum chamber 20. The chamber is evacuated by a diffusion pump 22, the primary pump backed by a mechanical secondary pump 24 of the rotary gas ballast type. A primary vacuum pump is necessary to maintain chamber pressure below 1 micron, the working range for electron beam welding with contamination and arcing limited. Within the chamber a work holder 26 is provided. Such work holders are similar to those found in milling machines, providing for rotary movement, as well as linear movement along x and y axes. Such work holders have been adapted for electron beam welders, as shown in the patents to Candidus, 2,981,823, and Steigerwald 2,793,281, 2,987,610 and 2,989,614. A conventional work holder is designated at 26 in the chamber. It is driven by a D.C. motor 32 via mechanical linkage 34 passing through a conventional rotary motion feedthrough 36. A variac speed control 38 modulates the motor speed.

The chamber 20 is provided with a port 40 having a mounting flange 42 for receiving the electron beam gun.

The electron beam gun, indicated at 50, comprises a mounting flange 52 for mating with the flange 42 of the chamber. The essential elements of the gun are a thermionically emissive cathode 54, a grid cup 56, and an accelerating anode 58. Since the anode performs the electron accelerating function, this type of gun is known as a self-accelerated gun in contrast to the work accelerated guns known in the art. The grid focuses the electron stream which emerges through the central aperture of the anode 58 as a coherent beam.

A metallic drift tube 60 forms a tubular extension of the anode. It terminates in a gas shield 62 which partially blocks gases evolved from the work from entry into the gun. A pair of electromagnetic lenses are provided along the length of the tube. These comprise first and second focus coils 64 and 66. The effective width of the lenses is indicated by the chain lines crossing the drift tube. It will be noted that the lenses are very narrow compared to coil diameter. The coils are independently suspended and adjustable with respect to each other and the drift tube 60 by a plurality of threaded rods 68 circumferentially distributed around the gun and supported by the mounting flange 52. Thus, the electromagnetic centers of the coils, which do not necessarily coincide with their respective geometric centers, can be aligned with the geometric center of the drift tube to permit precise control of beam focus.

The cathode is supplied with direct current for heating by circuit 72. A voltage on the order of 3 volts is used for this heating. A negative potential of 15 to 45 kilovolts is applied relative to the grounded anode to establish the electron accelerating field. The grid can be at this same 15-45 kilovolt voltage or biased negatively with respect to the cathode via grid control 74 for stronger focusing. The high voltage is supplied by a D.C. power supply 70. A set D.C. output is fed to focus control 92 to maintain constant current in the first and second focus coils. The first focus coil 64, which is located in close proximity to anode 58, collimates the beam to a cylinder and the second focus coil 66 converges the beam so that it produces a minimum spot size at the target.

Adjustable grid-cathode alignment

The cathode leads go through insulating feedthroughs 76 in an adjustable platform 78. The platform is connected to grid cup via a metallic bellows 80. Adjusting screws 82 opposed by springs 84 are provided for changing the spacing and alignment of the platform and consequently of the cathode, with respect to the grid cup.

Referring now to FIG. 2, the cathode 54 is shown in greater detail. It is a three turn coil of tungsten wire. The coil shape permits a thick dimension for carrying higher currents and has less tendency to sag out of alignment compared to hairpin and pancake filaments. Also, this produces a field which is better for initial electron direction. The cathode is in close proximity to an aperture 86 in the base of grid cup 56.

Referring now to FIG. 3, there is shown a layout of the adjusting screws 82 and springs 84 acting on platform 78. An odd number of screws (three) equally spaced and alternated with three equally spaced springs provides a sensitive adjustment. It will be appreciated that there must be some play in the threads and spring holders to permit tilting of the platform.

Referring now to FIG. 4, there is shown a deflecting arrangement which can be substituted for coil 66 of FIG. 1 or surrounding shield 62. The arrangement comprises opposed coils such as those indicated at 166 and 167 for deflecting the electron beam. The current to the coils can be manually adjusted or automatically controlled by

a cyclical output to cause the beam to sweep across the work.

A sight port 44 is provided in the chamber 20 for observing the target 46, the point where the geometric center line of the drift tube 60 intercepts the path of movement of the work. This permits the operator to observe the brightness of the spot produced by the beam at the target—an indication of proper focus. He can then adjust the grid-cathode relation, as noted above, in accordance with his observations. Other means for monitoring intensity of the spot at the target point can be provided in addition to or in place of the sight port 44.

Since certain changes may be made in the above apparatus and process without departing from the scope of the invention herein involved, it is intended that all matter contained in the above description, or shown in the accompanying drawing, shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A self-accelerated electron beam gun for emitting a focused stream of electrons to provide intense local heating at a target of small area, the gun comprising in combination: an electron emitting cathode, an acceleration anode comprising an aperture, a focus electrode adapted to establish an electrostatic field focusing the electrons toward the anode aperture as a coherent beam, means for establishing a potential difference on the order of 15-45 kilovolts between said cathode and anode, means for adjusting the relative spacing and alignment of the cathode and focus electrode while the gun is operating, and means for focusing the electron beam after it passes through the anode aperture.

2. A self-accelerated electron beam gun comprising a thermionically emissive filament, a grid cup containing an aperture in the base of the cup, the filament being located in close proximity to said aperture, an accelerating anode located outside said cup and comprising an aperture aligned with the grid cup aperture, means for maintaining the filament at a negative potential relative to the anode on the order of minus 15-45 kilovolts, at least one electromagnetic lens located beyond said anode, a first one of said lenses in close proximity to said anode, a gas blocking wall with an exit aperture downstream of said lenses, means for adjusting the axial and radial position of the cathode relative to the grid cup aperture while the gun is in operation.

3. The electron beam gun of claim 2 wherein the means for adjusting the cathode comprises a stable platform, a movable platform for the cathode, a screw thread linkage connecting the movable platform to the stable platform, damping means opposing the screw thread linkage, and flexible wall means connecting the platforms.

4. The gun of claim 3 wherein the screw thread linkage comprises a plurality of adjusting screws located at peripherally spaced points around the adjustable platform and the damping means comprises a plurality of peripherally spaced springs acting on the platform.

5. The gun of claim 3 wherein the flexible wall means comprises a metal bellows.

6. The gun of claim 2 wherein the filament comprises a cylindrical coil.

7. A high vacuum electron beam heated machining apparatus for performing electron beam machining operations such as welding, etching and the like, comprising a vacuum chamber, pumping means for reducing chamber pressure to less than 10^{-3} torr, said pumping means comprising a primary pump backed by a mechanical secondary pump, a work holder in said chamber, driving linkage passing through the chamber wall for transmitting driving motion from outside the chamber to the work holder, an electron beam gun comprising a major geometrical axis, said axis intercepting the path of work permitted by said mechanical linkage, means for monitoring conditions at said point of intercept, said gun further comprising a thermionically emissive direct heated cathode, an electrostatic focus grid spaced from said cathode and means for

adjusting the relative spacing and alignment between said cathode and grid while the gun is in operation.

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5 RICHARD M. WOOD, *Primary Examiner*.
JOSEPH V. TRUHE, *Examiner*.