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Lawrence

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[45] Sept. 10, 1974

[54] **TRIODE ELECTRON GUN FOR ELECTRON BEAM MACHINES**

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[73] Assignee: **United Aircraft Corporation,** East Hartford, Conn.

[22] Filed: **Nov. 29, 1973**

[21] Appl. No.: **420,240**

Related U.S. Application Data

[63] Continuation of Ser. No. 250,910, May 8, 1972, abandoned.

[52] **U.S. Cl.**..... **250/398,** 219/121 EB, 313/82 R, 313/83

[51] **Int. Cl.**..... **H01j 37/00,** G01n 23/00

[58] **Field of Search**..... 219/121 EB, 121 EM; 250/396, 398, 400; 313/82 R, 83

[56] **References Cited**

UNITED STATES PATENTS

2,151,803	3/1939	Rust et al.	313/82
3,013,171	12/1961	Beck	313/82
3,187,216	6/1965	Sciaky	219/121
3,329,849	7/1967	Jones	313/82
3,378,670	4/1968	Smith et al.	219/121
3,483,427	12/1969	Berglund	313/83
3,601,577	8/1971	Meyer et al.	219/121

FOREIGN PATENTS OR APPLICATIONS

1,505,059	12/1967	France	313/82

Primary Examiner—William F. Lindquist
Attorney, Agent, or Firm—Donald F. Bradley

[57] **ABSTRACT**

A high power electron beam machine for operating on a workpiece is disclosed in which the beam focus is automatically maintained constant without the necessity of lens current variation regardless of changes in beam current. The electron gun assembly for the machine consists of a Rogowski gun having a square ribbon filament recessed from an enlarged filament aperture, and a pin type anode with a reduced height and an increased gap from the bias electrode. The electron gun produces a stationary image or apparent source of electrons even though the beam current or the high voltage operating level of the electron gun is varied. Increased life of the ribbon filament is obtained by using a ribbon filament consistng of tungsten with 3 percent rhenium added thereto.

8 Claims, 8 Drawing Figures

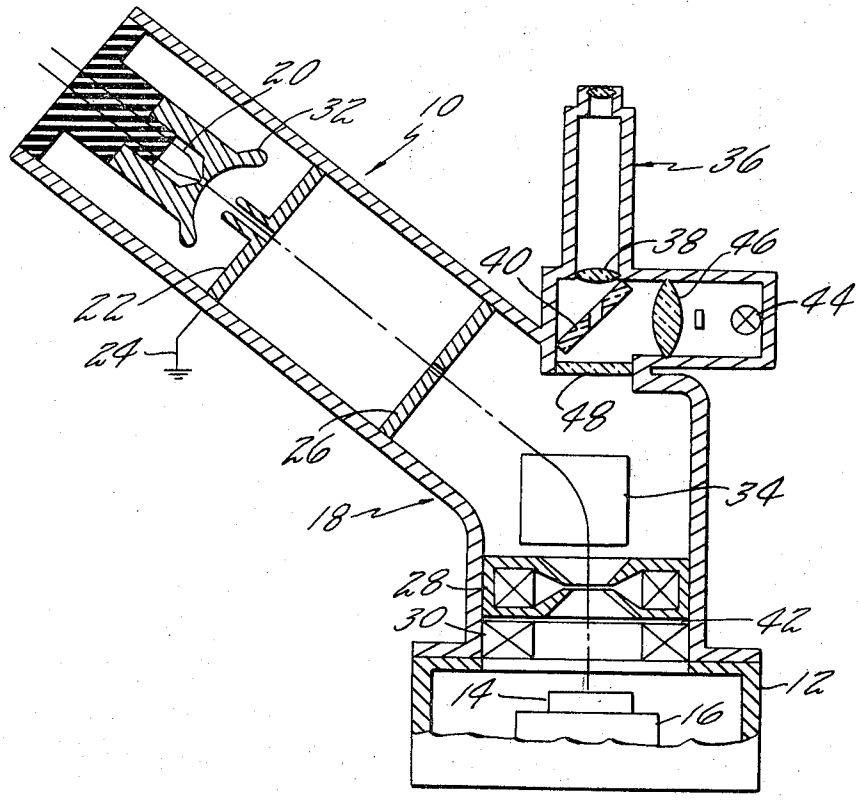


FIG. 1

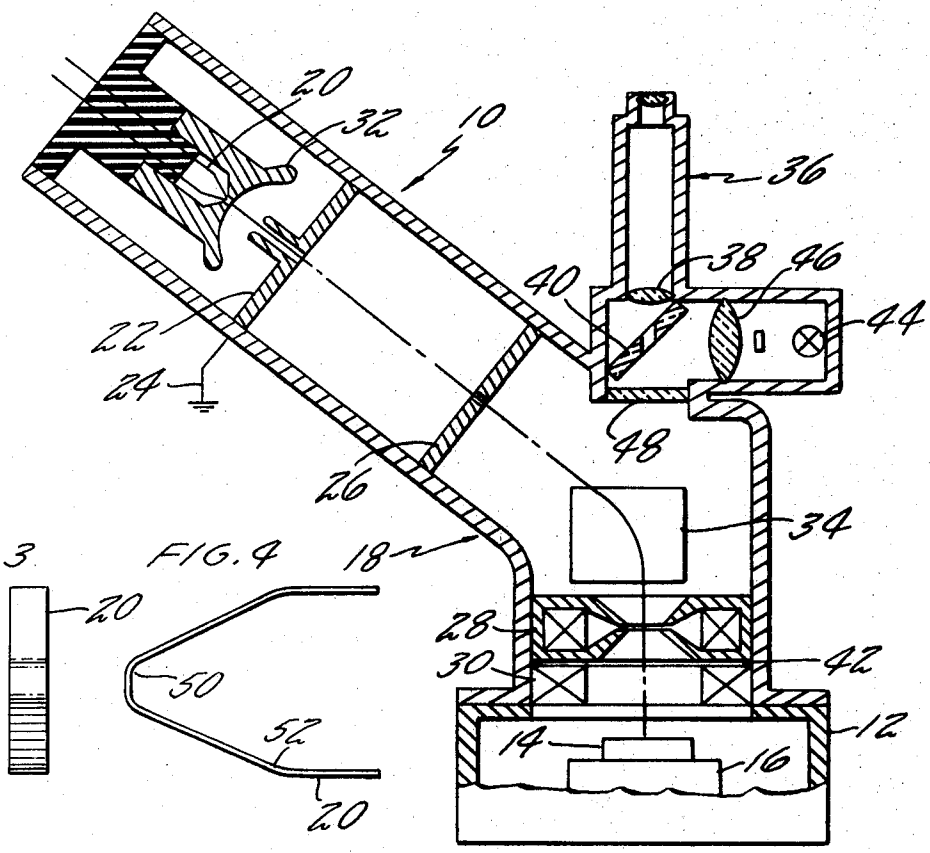


FIG. 3

FIG. 4

FIG. 2

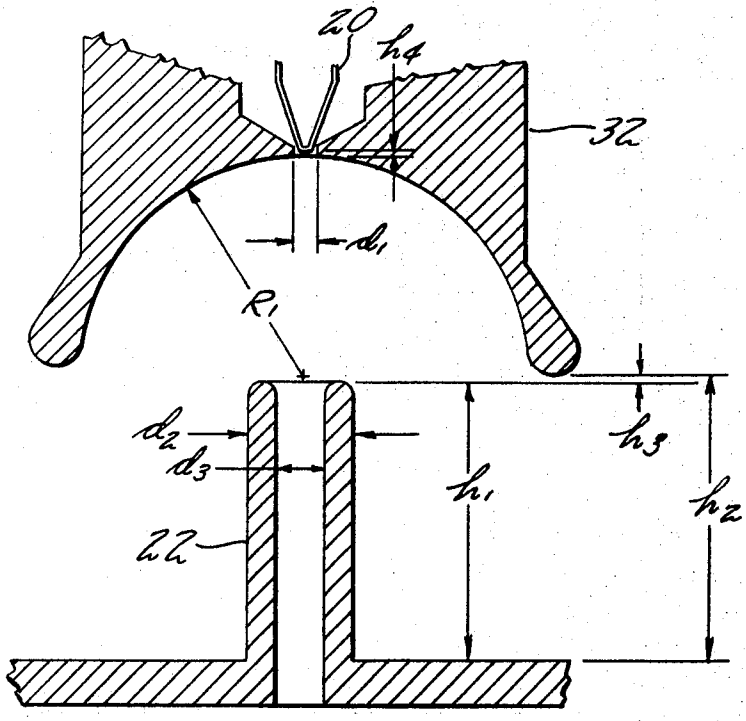


FIG. 5

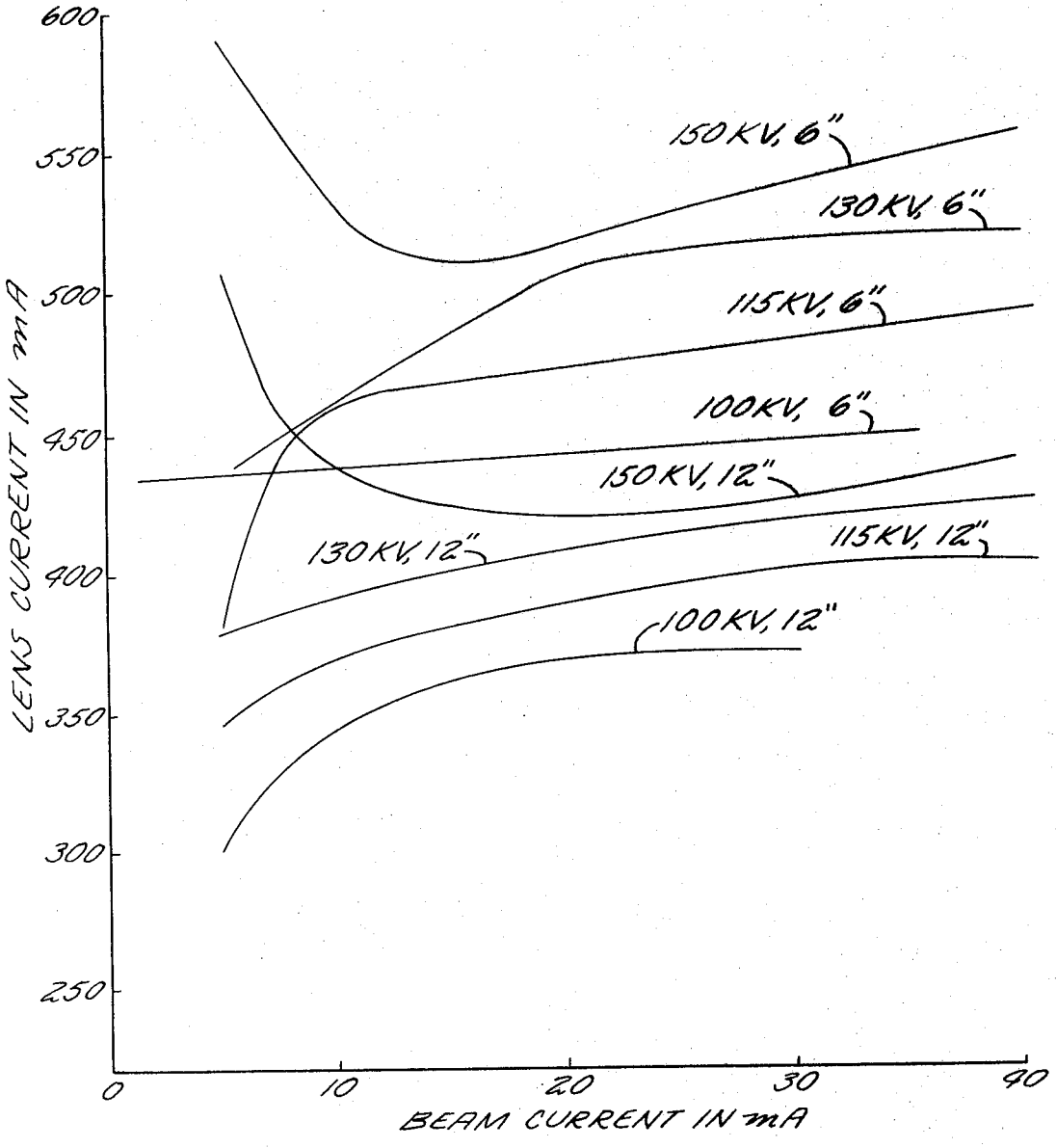

600
550
500
450
400
350
300
250
LENS CURRENT IN mA
0
10
20
30
90
BEAM CURRENT IN mA
150KV, 6"
130KV, 6"
115KV, 6"
100KV, 6"
150KV, 12"
130KV, 12"
115KV, 12"
100KV, 12"

FIG. 6

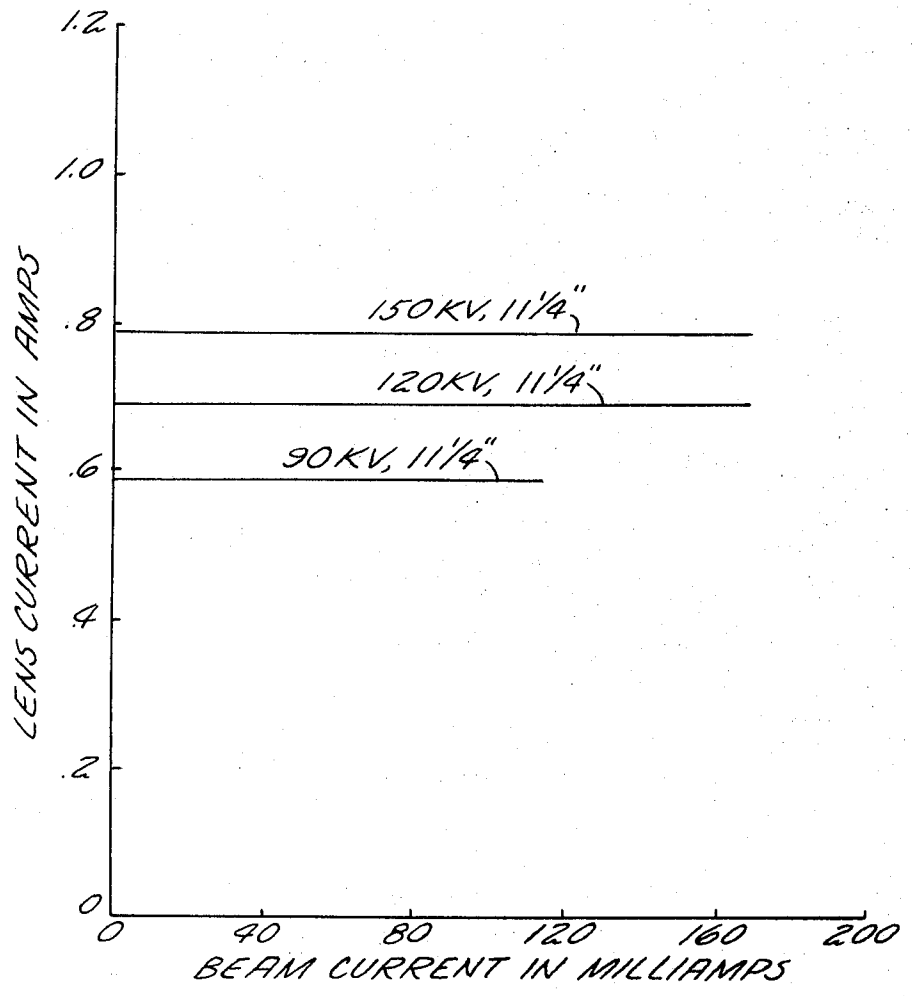

1.2
1.0
.8
.6
.4
.2
0
LENS CURRENT IN AMPS
150KV, 11¼"
120KV, 11¼"
90KV, 11¼"
0
40
80
120
160
200
BEAM CURRENT IN MILLIAMPS

FIG. 7

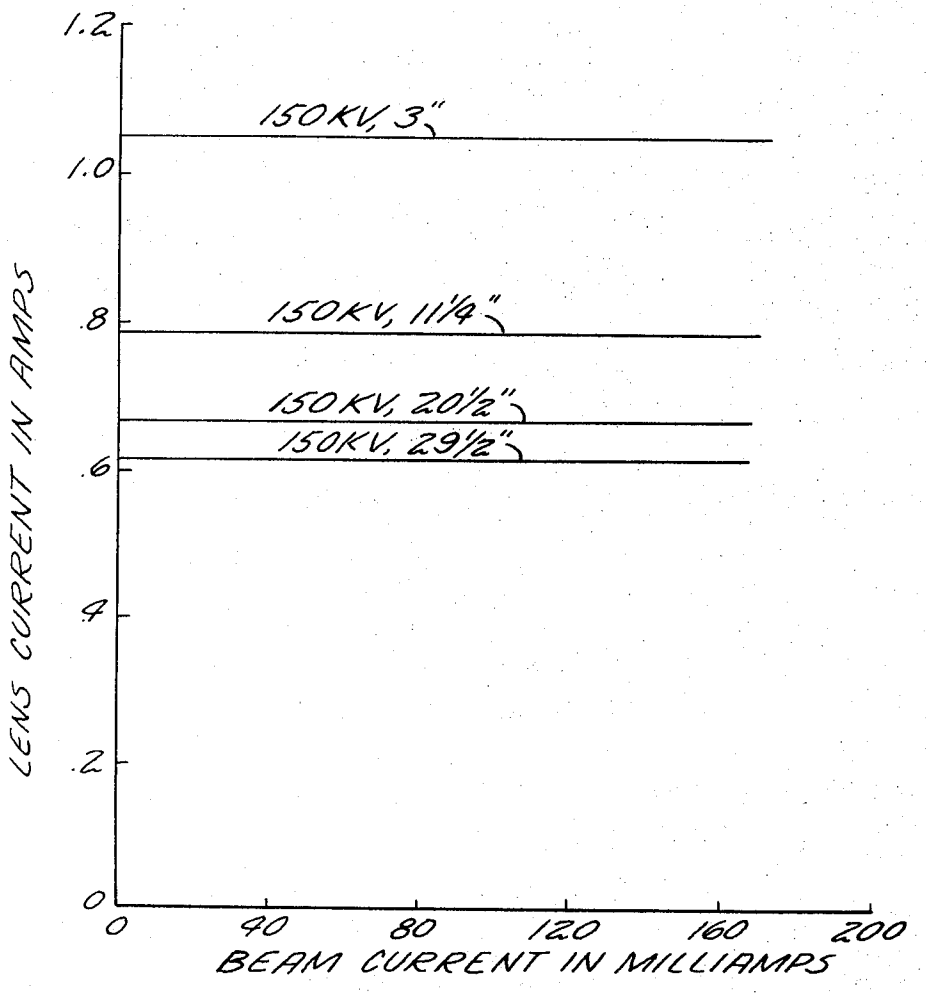
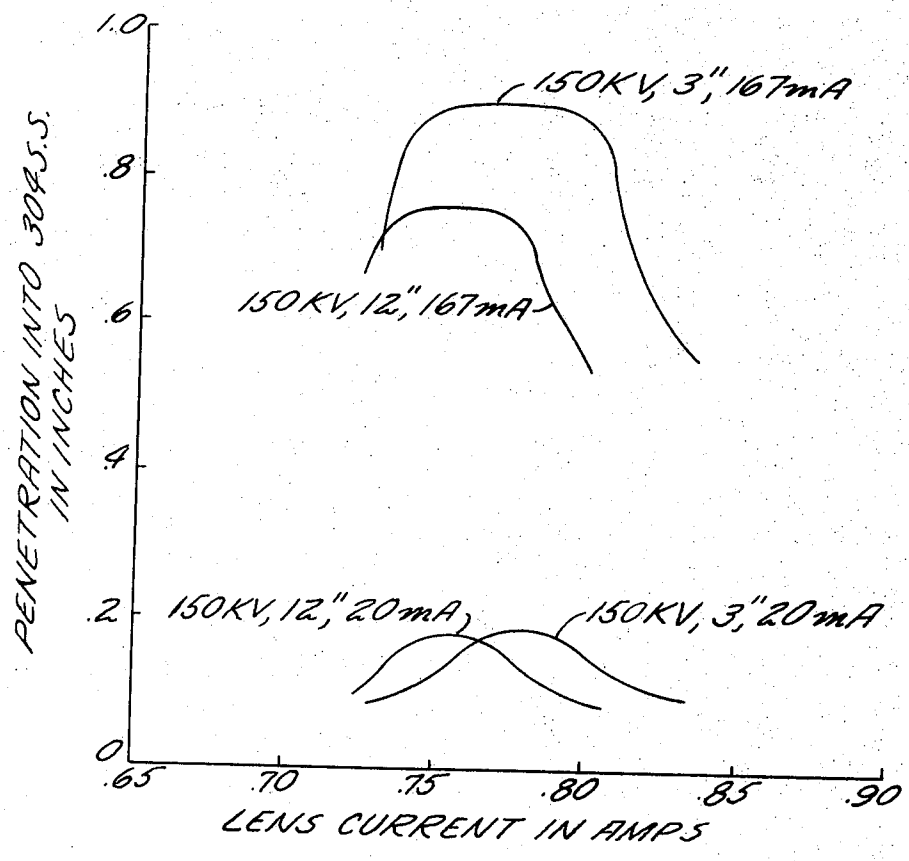

1.2
1.0
.8
.6
.4
.2
0
150KV, 3"
150KV, 11¼"
150KV, 20½"
150KV, 29½"
LENS CURRENT IN AMPS
0
40
80
120
160
200
BEAM CURRENT IN MILLIAMPS

FIG. 8


1.0
.8
.6
.4
.2
0
.65
.70
.75
.80
.85
.90
PENETRATION INTO 304 S.S. IN INCHES
LENS CURRENT IN AMPS
150KV, 3", 167mA
150KV, 12", 167mA
150KV, 12", 20mA
150KV, 3", 20mA

TRIODE ELECTRON GUN FOR ELECTRON BEAM MACHINES

This is a continuation, of application Ser. No. 250,910, filed May 8, 1972, now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to high power electron beam machines for operating upon a workpiece, and specifically to a novel electron gun which automatically maintains the focus of the electron beam even though the beam current is varied. More particularly, there is disclosed a novel Rogowski electron gun configuration for an electron beam machine which produces a stationary image of the source of electrons with variations in beam current or high voltage operating level of the electron gun.

2. Description of the Prior Art

Devices which use the kinetic energy of an electron beam to work a material are well known and commercially available. U.S. Pat. No. 2,987,610 to Steigerwald discloses an electron machine which operates by generating a highly focused beam of electrons. The electron beam is a welding, cutting, heating and machining tool which has practically no mass but has high kinetic energy due to the fact that high momentum is imparted to the electrons. The electrons lose their kinetic energy as they bombard the lattice structure, molecular structure and even the atomic structure of the workpiece. The transfer of this energy to the workpiece generates heat, melting, vaporization, atomic excitation (causing light and x-ray emission) and ionization. Transfer of this kinetic energy to the lattice electrons of the workpiece generates higher lattice vibrations which cause an increase in the temperature within the impingement area sufficient to accomplish work.

As taught by the Steigerwald patent, if the power density (power per unit area) of the electron beam is caused to exceed a threshold value, which value depends on the material being worked, the beam of electrons will penetrate deeply into the work and result in the melting of a fusion zone having a high depth-to-width ratio without reliance on thermal conduction through the work.

A beam of highest power density is more effective, that is, a high power density beam can accomplish the required work in the shortest possible time and thus minimize heat conduction to the material adjacent the area being worked. Of course, the beam power density must be varied in accordance with the type of operation to be performed and the characteristics of the material to be worked. In order to obtain high power density, precise electron optics must be applied in focusing the beam. The electron optics of an electron beam welder normally takes the form of an electron gun and a magnetic lens. The electron gun is a device that not only extracts the electrons and accelerates them to very high velocities by virtue of the electric potential applied to the electrodes, but it also serves as an electrostatic lens that shapes the electron flow into a beam and focuses the beam to form an image of the electron source. The image formed by the electron gun may be real or virtual. The image produced by the electron gun is the "object" that is focused or imaged by the magnetic lens onto the workpiece to be welded (or onto the target). Thus, the magnetic lens is used to project the

image onto the target. Although this lens is usually magnetic, electrostatic projector lenses are sometimes used.

In many operations it is necessary to vary the accelerating potential or the beam current to perform the desired operation on the workpiece. It is usually desirable to make the required beam modifications without changing the beam focus. However, in the past it has been observed that the beam focus changes with variations of beam current, necessitating the refocusing of the beam each time the beam parameters are varied. Automatic focusing systems have been suggested, but many such systems are not sufficiently sensitive or accurate to provide precise beam focusing for many applications.

The inability of the electron gun to maintain a fixed focus is caused primarily by the gun's failure to produce a stationary image or apparent source of electrons with variations in the beam current or high voltage operating level.

Most high voltage (150 kilovolts) electron guns used in electron beam welders historically have used tungsten wire hairpin filaments as a cathode. The wire hairpin filament has served as a fine approximation to a point source for the relatively small amount of beam current produced by the early welding guns. In addition, they are easily manufactured, inexpensive and have a reasonable life expectancy of 10 to 20 hours. The beam imaging characteristics of the electron guns, such as the Steigerwald gun and the Rogowski gun that use wire hairpin filaments, are beam current dependent; the beam has to be focused for a given beam current, and refocused for any change in beam current if a sharp focus is to be maintained. The focusing of the beam at low beam powers is not difficult and is easily accomplished by the machine operator using viewing optics that give a "beam's eye" view of the workpiece.

As the electron guns were upgraded to provide higher power levels, more beam current demands were placed on the wire hairpin filaments. The ideal point source provided by the wire hairpin filament became less ideal as the beam current requirements increased; the focused beam spot on the workpiece became decidedly oval. The weld penetration, with an oval beam, is dependent on the orientation of the beam spot and the weld direction. Making identical welds in two different directions could involve developing two sets of weld parameters, or searching for a compromise setting suitable for welding in both directions.

As the beam power increases, the task of obtaining a sharp focus also increases, requiring more operator skill or the reliance on predetermined focus settings. The need for an improved electron source for high voltage welding systems developed along with the need for improved focusing abilities as the systems operating capabilities were extending into the high power regime.

SUMMARY OF THE INVENTION

The present invention overcomes the failures of the prior art and provides a modified Rogowski electron gun which enhances both beam quality and beam controllability by maintaining the image produced by the electron gun stationary regardless of beam current or high voltage changes.

In accordance with the present invention there is provided a novel Rogowski electron gun in which a square ribbon filament is recessed from a filament aperture which is enlarged in order to permit sufficient clearance between the filament and the bias electrode. The amount of filament recession and aperture enlargement are important in producing a stable image. A pin type anode is used having a reduced height and an increased gap from the bias electrode. By constructing the ribbon filament from tungsten with a 3 percent rhenium content, increased filament life is obtained. The interaction of the square ribbon filament and its recessed position with the novel design features of the filament aperture and the anode pin results in an electron gun assembly which produces a stationary image of the filament even though beam current and voltage are varied.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic showing of a typical electron beam machine embodying this invention.

FIG. 2 is a schematic showing the modified Rogowski electron gun assembly.

FIG. 3 is a side elevation of the square ribbon filament used with the electron gun of FIG. 2.

FIG. 4 is an end elevation of the ribbon filament of FIG. 3.

FIG. 5 is a plot of lens current versus beam current for a focused beam using a prior art Rogowski gun with a hairpin filament with various beam voltages and workpiece distances.

FIG. 6 is a plot of lens current versus beam current using the improved Rogowski gun of this invention with changes in voltage.

FIG. 7 is a plot of lens current versus beam current using the improved Rogowski gun of this invention with changes in workpiece distance.

FIG. 8 is plot of weld penetration versus lens current for various beam currents and workpiece distances.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1, there is shown an electron beam machine indicated generally at 10 typical of those into which the novel electron gun of this invention may be incorporated. The machine consists of an evacuated work chamber 12 containing a workpiece 14 positioned on a table 16. The machine also comprises a bent electron beam column indicated generally at 18. The column 18 contains a source of the electrons, beam forming means and beam focusing means. The source of electrons comprises a cathode or filament 20 which may be directly heated by means of a dc voltage applied thereto. An apertured anode 22 is positioned in column 18 between the cathode and the workpiece. The anode is generally connected to the case of the machine which is grounded at 24. The electrons emitted by the cathode 20 are accelerated down column 18 and pass through the aperture in anode 22 to form a beam. The accelerated electrons are thereafter focused by an electron optical system comprising adjustment coils, not shown, and a series of diaphragms, only one of which is shown at 26. Other diaphragms, not shown, are often used as protective devices. After passing through diaphragms 26, the beam is bent through a predetermined angle and then passes between the poles of a magnetic lens assembly 28 which focuses the beam at the desired point. Under operating conditions the focused beam impinges upon workpiece 14 and its kinetic energy is transferred thereto. The workpiece 14 can be moved beneath the beam by moving table 16 and/or the beam may be deflected over the workpiece by means of varying the current to deflection coils 30.

Positioned adjacent cathode 20 is a control or bias electrode 32. This bias electrode is normally maintained at a voltage which is more negative than the voltage applied to the cathode. The magnitude of this bias or voltage difference is variable by adjusting a bias voltage control, not shown. The bias electrode, while aiding in the focusing of the beam, performs the same function as the grid in an ordinary triode vacuum tube to control beam current. The full electron acceleration potential will be applied between cathode 20 and grounded anode 22.

Prior to passing through the magnetic lens assembly 28, the beam of electrons is caused to pass through a field generated by an additional magnetic lens assembly 34. The field generated by lens assembly 34 will cause the beam generated in column 18 to be bent in such a manner that its normal undeflected axis will be perpendicular to the surface of workpiece 14.

Typically the electron beam machine contains an optical viewing system such as is indicated generally at 36. The optical viewing system is a means for viewing the workpiece by looking along the beam axis. For this purpose there is provided a microscope including an objective lens 38 which permits the operator to view the work by looking down through an apertured mirror 40, magnetic lens assemblies 28 and 34, and an apertured diaphragm 42. In order to illuminate the workpiece, a light source 44 is provided. The light from source 44 passes through lens 46 and is reflected by apertured mirror 40 to the workpiece. Positioned between the optical viewing system 36 and the electron beam column is a leaded glass window 48 which protects the operator from x-rays emanating from the beam impingement point. Means may be provided inside the electron optical column 18 for preventing the clouding of window 48 caused by condensation of metal vapors thereon. Other viewing systems are known and may be used.

The electron gun assembly is shown in greater detail in FIG. 2. Typical triode electron guns, including the gun of FIG. 2, contain three basic components: the anode 22, the cathode or filament 20 and the bias electrode 32. The cathode or filament 20 is the source of the electron beam and is normally made of tungsten or tantalum in wire or ribbon form. Electrons are extracted thermally by raising the temperature of the cathode to high temperatures, i.e., thermionic emission temperatures for tungsten are typically around 2,800°K. The cathode normally is operated at a high negative potential. The electrons emitted or "boiled off" from the cathode are repelled from the cathode and then accelerated toward the anode. In the prior art, the cathode wire or ribbon is bent into a hairpin shape, and the apex of the hairpin exposed to the high voltage field, while the remainder of the cathode is shielded by the bias electrode so that electron emission only takes place at the apex. The exact geometry of the apex can vary from a sharp point on a fine wire, to a circular emitting area coined into the apex of the hairpin.

The bias electrode performs several functions in the electron gun. It is used to contain, mount and shield from the high voltage field, the cathode assembly. Bias

voltage, negative with respect to the cathode, is applied to the bias electrode to regulate and to valve off the flow of electrons from the cathode. The external shape of the bias electrode forms one of the elements comprising the electrostatic lens of the electron gun. The anode forms the other.

Electrons emitted from the cathode are accelerated to velocities that are a large fraction of the speed of light by the electric potential between the cathode and the anode. As indicated previously, the anode is usually grounded and the cathode maintained at a high negative potential, typically 4,000–200,000 volts. The potential field is shaped by the configuration of the anode and the bias electrode. Electron flow during acceleration is concentrated into a paraxial flow with a small dispersion angle (or beam of electrons).

There are various types of triode guns, most of which, such as the Steigerwald gun, retain a flat anode. The Rogowski gun uses an anode pin projecting up toward the cathode to increase the strength of the positive electrostatic lens. The bias electrode **32** is cup shaped but with a spherical radius instead of the cylinder shape used in other electron guns. The anode pin ideally terminates in a spherical radius concentric with the bias electrode spherical radius. Rogowski guns are well known, and produce small diameter electron beams with very small dispersion angles.

Referring specifically to FIG. **2,** the biasing electrode **32** has a concave hemispherical surface with a spherical radius, R_1, and a circular filament aperture of diameter d_1. The anode **22** is a cylindrical pin centered on the anode plate. The pin has an outer diameter, d_2, an anode aperture with a diameter d_3, and a height above the anode plate h_1. The bias electrode **32** is positioned above the anode plate a distance h_2, so that a gap, h_3, is produced between the anode pin **22** and the bias electrode **32.** The filament **20,** or cathode, is centered in the filament aperture of the bias electrode, and is shown to be recessed a distance h_4.

The electron gun is simply a source of accelerated electrons and serves as the object of the focusing system. The focusing system, specifically magnetic lens **28,** focuses the beam into an image at the workpiece **14.** The workpiece which is to be welded or otherwise treated is thus subjected to the impingement of the electron beam formed by the magnetic lens. The electron beam is not always focused precisely on the workpiece, but the focus is chosen to achieve the desired type of operation.

The action of the magnetic lens is analogous to the operation of an ordinary optical lens, and the basic physics of electron optics and light optics are practically identical. The equations used to design glass lenses to focus light rays are similar to those for focusing electrons. The lenses in electron beam machines act as "thin lenses," that is, they focus the electrons emitted from the filament which is a distance "a" from the magnetic lens into an image which is at a distance "b" from the lens according to the equation:

Equation 1: $1/f = 1/a + 1/b$

where "f" is the focal length of the lens.

In the thin lens approximation, the measurement of "a," "b" and "f" can be made from the center plane of the lens pole gap since the principal planes of the lens and the center plane nearly coincide.

The focal length f of a magnetic lens is determined by the magnetic field strength and the momentum of the electrons being acted upon. This resolves into the lens current which is driving the magnetic lens, and the high voltage operating potential of the electron gun so that:

Equation 2: $f = K\, V_r/I_L^2$

where I_L is the lens current, V_r is the relativistic voltage, and K contains various constants and geometric factors such as the pole shoe bore and gap, and the number of turns in the coil. The relativistic voltage is related to the actual voltage by which the electrons were accelerated by:

Equation 3: $V_r \cong V(1 + 10^{-6}V)$

where V is the voltage in volts.

Considering Equation 1, one notes that to focus closer to the lens, lens current is increased, while to focus away from the lens, lens current is decreased. From the equation it is also seen that for a given workpiece location, b, the focal length, f, is constant if the object location, a, is constant.

The electron gun is an electrostatic lens system that not only extracts electrons from the filament and forms them into a beam, but also produces an image of the source which can be either real or virtual. The image of the filament produced by the electron gun is the "object" for the magnetic lens. Therefore, for f to be constant, the image produced by the electron gun must be stationary. These conditions have not been produced by prior art electron guns.

FIG. **5** shows typical variations in magnetic lens current which is required to produce a focused beam for a prior art Rogowski electron gun having a wire hairpin filament. The voltages are varied between 100 kv and 150 kv, with the workpiece being at a distance of either 6 inches or 12 inches from the magnetic lens. The irregularity of the curves indicate that the object location, a, must be changing with both beam current and high voltage.

To overcome this problem and produce a stationary image even though the beam current or high voltage operating level of the electron gun is varied, various modifications were made to the electron gun assembly.

Referring particularly to FIGS. **2, 3** and **4** there is shown a modified filament **20.** In the prior art electron guns, hairpin filaments were commonly used, usually made from tungsten. The new filament shown in the figures is made from a tungsten-rhenium alloy in ribbon form. For the embodiment to be described, the filament is 55 mils wide and 7 mils thick, although other configurations may be used. The ribbon is bent to form a simple, uncomplicated emitter with a square emitting face, in the present embodiment 55 mils by 55 mils. The bend radius **50** is preferably about .015 inch radius maximum, and bend **52** is preferably one-eighth inch radius maximum for the dimensions given. The bends are smooth and crack-free.

In the Rogowski gun of the present invention, the ribbon filament **20** is recessed from the end of the filament aperture so that the filament position, h_4, is −0.025 inch, where the negative sign indicates that the filament is recessed rather than projected from the filament aperture. In the prior art, the standard position, h_4, of the wire hairpin filament is +0.004 inch.

Referring again to FIG. **2,** the use of the ribbon filament without any other adjustments in the Rogowski electron gun configuration will not generally produce the stationary image desired. Additional modifications

of the gun are required. When the ribbon filament was initially installed in an electron gun, the anode pin height, h_1, was not modified from its initial 1.575 inch. The focus obtained with this anode was not well defined at low currents, and could not be determined at all for beam currents over about 50 ma. This condition could be caused by the fact that "$1/a$" would become infinity, or because "a" would become undefined, that is, no distinct image was being produced by the electron gun. This condition was rectified by reducing the anode height, h_1, to 1.300 inch which also increased gap, h_3, to 0.312 inch, thus causing the height of the bias electrode above the anode plate, h_2, to be 1.612 inch. Even with these changes, there was a lens current variation with beam current, thus indicating some change in the electron gun image with beam current.

By enlarging the filament aperture diameter, d_1, from its normal dimension of 0.1 inch to 0.157 inch, a reduction in the lens current variation with beam current was noted.

A further enlargement of the filament aperture diameter d_1 to 0.186 inch resulted in a constant lens current to focus the beam regardless of changes in beam current. An additional variation of the filament position, h_4, over the range −0.017 to −0.029 inch did not change the results.

For the above tests, the parameters d_2, d_3 and R_1 were not varied from the standard Rogowski electron gun, d_2 being 0.59 inch, d_3 being 0.278 inch and R_1 being 1.18 inch.

FIG. 6 shows the combined effects of changing beam current and high voltage with respect to lens current. Measurements were made with the filament recessed (h_4) −0.017 inch with the anode pin height (h_1) being 1.300 inch. The voltages were varied from 90–150 kv, and the distance of the workpiece from the magnetic lens was 11½ inches. If the electron gun image is truly stable, then the focal length f is constant, and from Equation 2 it may be seen that the lens current I_L should be proportional to the square root of V_r, or in other words the lens current should change with the square root of the relativistic voltage. From the figure it is seen that the lens current does not change with variations in beam current. Likewise, the lens current variation is proportional to the square root of the relativistic voltage. Therefore, the image produced by the electron gun is constant with voltage variations.

The magnification produced by a magnetic lens increases with increased working distance, so that minor variations in the electron gun image location would be more apparent at long working distances than at short working distances. Using a working distance of 20.5 inches at 150 kv, changes were made in the filament position, h_4. While not shown, the curves indicate some drift of electron gun image location occurred with beam current for values of h_4 −0.011 inch, and for −0.017 inch, but no change occurred when the filament position was −0.025 inch. This latter filament location is therefore considered optimum for the embodiment of Rogowski electron gun described herein.

FIG. 7 shows the effect of work distances which vary from 3 inches to 29.5 inches with the filament recessed −0.025 inch at 150 kv. The flat response over the entire range indicates no variation in the electron gun image location.

The significance of the stable focus produced by the improved filament in the improved gun design is shown in FIG. 8 where weld penetration into 304 stainless steel is plotted against lens current for various beam currents at 150 kv, a filament recessed at −0.025 inch and a table speed of 150 inches per minute. The beam currents and work distances are shown in FIG. 8. As shown in the figure, the peak in penetration is obtained at the same lens current. This characteristic simplifies both manual operation of an electron beam gun and the techniques involved in automating the machine such as for use in welding.

The beam quality produced by the improved gun and filament, judged by the welds produced, were far superior to those produced by prior art guns. The welds produced with wire hairpin filaments tend to be different in the x axis than in the y axis, that is, the weld characteristic changes with weld direction. The much more symmetric beam produced by the ribbon filament in the improved gun configuration is essentially independent of weld direction. Furthermore, the beam from a wire hairpin filament produces an oval beam spot on the workpiece which causes weld sensitivity to direction. The oval shape can also cause severe undercutting of the weld bead unless the weld direction is carefully aligned with the oval shape of the beam. By use of the square emitting face of the ribbon filament, its much more symmetric shape essentially eliminates these problems.

An unexpected advantage is provided when the ribbon filament is made using tungsten-rhenium alloy (3D alloy manufactured by General Electric Company, with 3 percent rhenium-tungsten or equivalent). Pure tungsten ribbons of the same design failed by cracking from stress, probably thermal stress, while tantalum filaments tended to experience rapid erosion and evaporation. The tungsten-rhenium alloy provides the erosion resistance of the tungsten with increased ductility and crack resistance from the rhenium additive. Greatly increased filament lifetime has been demonstrated by the new filament construction.

While the present invention has been described with respect to a preferred embodiment thereof, it is apparent that various changes may be made to the preferred embodiment without departing from the scope of the invention. For example, one aspect of the present invention is the achievement of a long-life filamentary cathode for electron beam machines in a ribbon figuration, shown in FIGS. 2–4, by combining a tungsten alloy (tungsten with 3 percent rhenium) into a simple ribbon shape, thereby avoiding a complex shaped ribbon or a wire configuration. Since the cross section of a wire changes as the square of the diameter, a 10 percent change in the diameter causes a 20 percent change in the cross-sectional area. For a ribbon, the cross-sectional area changes nearly linearly with the thickness so that a 20 percent change in the cross-sectional area does not occur until nearly 20 percent change of the thickness has occurred. Thus, a resistive hot spot should occur slower in a ribbon filament than in a wire filament. However, a wire is a stronger shape than a ribbon and a wire is less susceptible to cracking than a ribbon, so that until the present invention, which combined the tungsten-rhenium alloy with a simple ribbon shape, the ribbon filament lifetimes have never been equal to wire filament lifetimes.

Another aspect of the present invention is the achievement of a stable image in a Rogowski electron gun using a simple filament configuration and without

resorting to a complex or highly formed cathode. The anode was shortened to increase the cathode to anode distance, thereby increasing the beam divergence. The increase in beam divergence causes the electron gun image position to be well defined and causes the focusing of the image upon the workpiece by the magnetic lens to be sharp and well defined.

The filament aperture was enlarged to a diameter greater than three times the width of the ribbon filament. The filament could then be recessed to a position where the maximum required power could be obtained. The image was then stable over the entire current range (0 to 167 ma) and the normal voltage range (90 to 150 kv).

It is therefore evident that the image produced by a Rogowski-type high voltage electron gun can be stationary or invariant in position regardless of current or voltage fluctuations when using a ribbon filament with a flat emitting area. The emitting area can be square as described previously, slightly rectangular, or rounded into a circular shape. The image position is then defined by regulating the anode position with respect to the cathode and grid, and thus controlling the beam divergence angle. The image position is stabilized by enlarging the filament aperture in the grid until the aperture is several times larger than the filament, and recessing the filament until the image is stabilized. The degree of enlargement and recession will depend upon the required operating power, since the space charge limited current flow will decrease as the filament is recessed, but will increase as the aperture is enlarged.

A stationary image can thus be produced using a simple source such as a ribbon filament bent to produce a flat emitting face that is approximately square as described herein. A more ideal source would be a round, flat emitting face coined into a ribbon filament, or on the end of a rod. A square face on the end of a square rod, or a hexagonal or octogonal rod end or coined emitting face could also be used.

The shape of the electron gun could also be varied from the ideal Rogowski shape defined herein. The grid or bias electrode may be any concave, spherical shape with a central filament or cathode aperture. The anode may be flat with some degree of projection toward the cathode in the center thereof coaxial with the beam.

Other modifications of the present invention will be apparent to those skilled in the art.

I claim:

1. In an electron beam machine for generating and focusing an electron beam at a workpiece, the combination comprising

a bias electrode with a concave hemispherical surface and a substantially spherical radius and having a first circular aperture in the center thereof,

an anode spaced from said bias electrode and consisting of a flat annular plate member supporting a sleeve member which is integrally attached at right angles to said plate member and which extends toward said bias electrode, said sleeve member and the annular portion of said plate member defining a second aperture which is of a larger diameter than said first aperture and which is aligned with said first aperture,

a filament comprising a narrow ribbon of metallic material with a flat emitting face centered within said first aperture and being recessed between 0.017 in. and 0.029 in. from the concave surface of said bias electrode, said emitting face having a surface area which is smaller than the total cross-sectional area of said first aperture,

means for applying electrical potentials between said filament, said bias electrode and said anode to generate a beam of electrons which emanates from said filament and passes through said second aperture toward a workpiece,

and a magnetic lens having a lens current supplied thereto positioned between said anode and said workpiece for forming an image of said electron beam at said workpiece, the focal point of said image being variable with changes in said lens current,

the focal point of said electron beam image being maintained stationary independently of variations in the current of said electron beam and without changes in said lens current.

2. The apparatus as in claim **1** in which said sleeve member terminates a short distance below a plane defined by the outer edge of said bias electrode.

3. The apparatus as in claim **2** in which said distance is approximately 0.312 inch.

4. The apparatus of claim **2** in which the height of said sleeve member is approximately 1.3 inches.

5. The apparatus as in claim **1** in which said filament includes first and second leg portions extending into said aperture from opposite sides of said flat emitting face.

6. The apparatus of claim **1** in which the diameter of said first aperture is about 0.186 inch, and said filament is recessed from the concave surface of said bias electrode about 0.025 inch.

7. The apparatus as in claim **1** in which the flat emitting face of said filament is approximately rectangular.

8. The apparatus of claim **1** in which the width of said filament emitting face is about one-third of the diameter of said first aperture.

* * * * *

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,835,327 Dated September 10, 1974

Inventor(s) Glen S. Lawrence

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

Claim 1, column 10, line 15, after "is" insert --much--

Signed and sealed this 3rd day of December 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents