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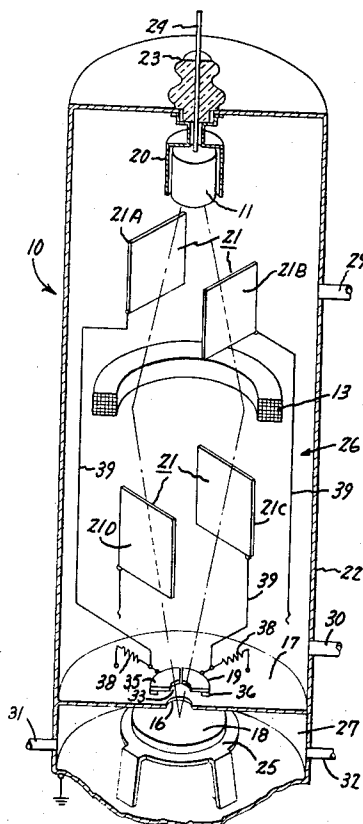
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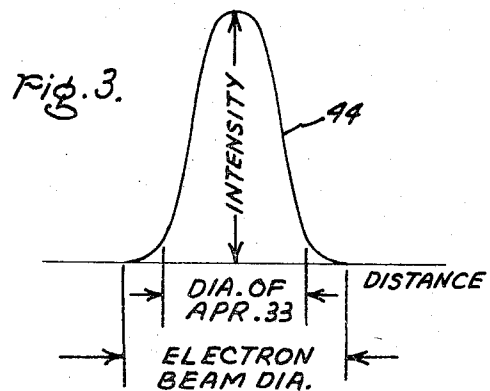
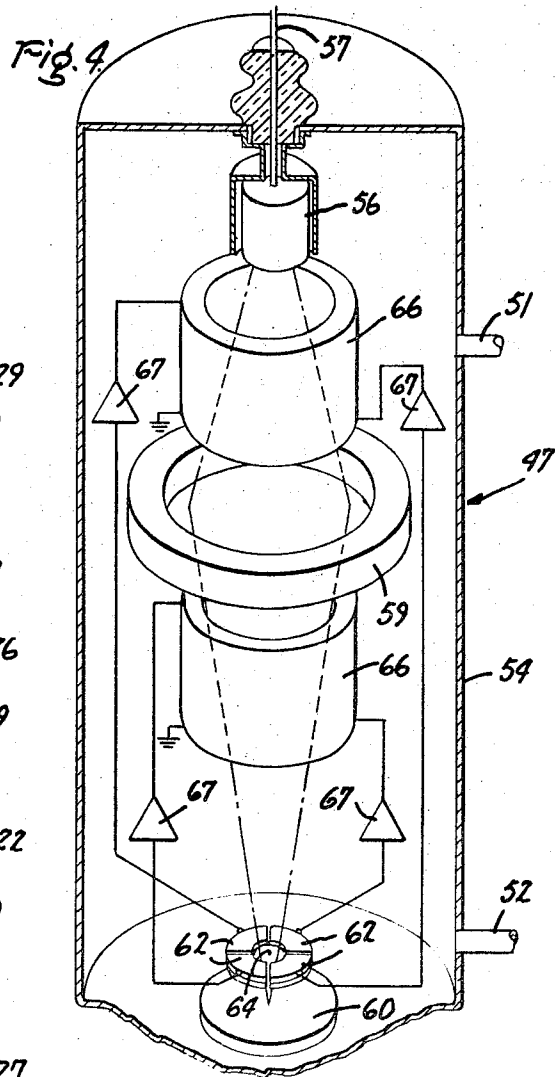
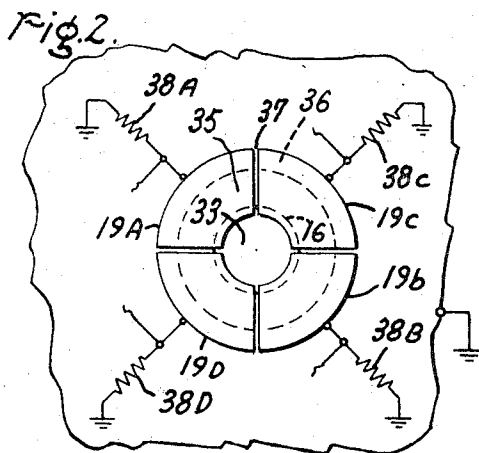
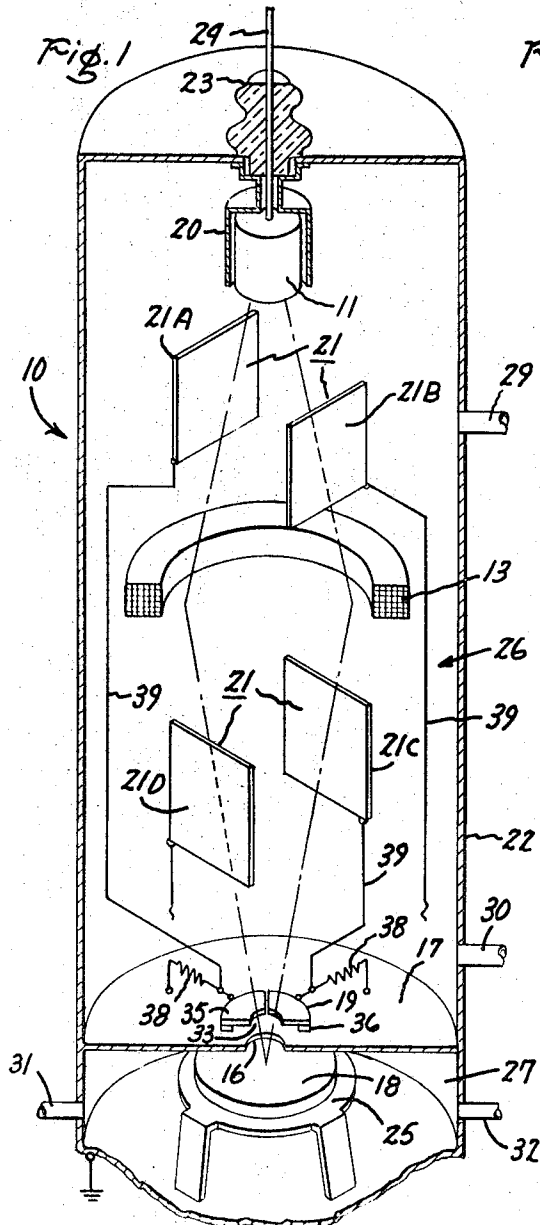
[54] **SELF ALIGNING ELECTRON BEAM WELDER**
2 Claims, 4 Drawing Figs.

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219/121
[51] Int. Cl. **B23k 9/10**
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18X, 21, 21X, 24; 219/121EB

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ABSTRACT: Alignment between a focused electron beam and an aperture within a partition plate separating a low pressure electron beam generating zone from a higher pressure welding chamber is obtained by positioning four carbon sensing electrodes in a circular pattern coaxial with and slightly above the aperture in the partition plate. The internal diameter of the circular pattern formed by the electrode disposition is no greater than the aperture in the partition plate to assure continuous impingement of a portion of a properly focused bell-shaped electron beam on the electrodes. The negative voltages produced upon diametrically opposite electrodes by the electron beam bombardment are fed back to an elongated pair of electrostatic deflection plates in the low pressure zone of the welding apparatus to deflect the beam at an angle proportional to the difference between the voltage signals from the electrodes. When a charged particle beam is generated in a zone having sufficient gaseous pressure to produce an electrostatic discharge between deflection plates, electromagnetic windings are employed to deflect the beam with a current amplifier being inserted between the electrodes and the electromagnetic windings to allow use of low inductance windings thereby reducing the response time of the system.





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SELF ALIGNING ELECTRON BEAM WELDER

THE DISCLOSURE

This invention relates to charged particle beam apparatus and in particular to a charged particle beam apparatus wherein the intensity of beam impingement upon surrounding sensors is utilized to automatically position the beam upon a desired location.

In many applications, such as ion deposition in the formation of semiconductors and electron beam welding, the accurate positioning of a charged particle beam upon a desired location is required. For example, the proper positioning of an electron beam in the plane of a workpiece is of critical importance in electron beam welding to assure a weld of maximum strength. Similarly, in an electron beam welding apparatus having a minutely apertured partition dividing zones of diverse pressure, the electron beam must be aligned with the aperture of the partition to inhibit enlargement of the aperture and the resulting gaseous seepage between zones. Although alignment of the electron beam source and the aperture generally is set during the manufacture of the welding apparatus, warping of the structure either by jarring during installation or by the intense heat generated during welding can destroy the desired alignment. Furthermore unless the welding apparatus is electromagnetically shielded, a perfectly aligned beam can be deflected from a predetermined location by stray magnetic fields and either the welding apparatus or the workpiece being welded may be damaged.

Prior attempts to automatically align an electron beam have included the mounting of search coils around the electron beam and the pulsing of the beam by a control electrode to induce a voltage in the coils indicative of the beam location. The pulsed beam method of sensing the position of the electron beam is deficient however because malalignment is detected only when the beam is pulsed. A finite period therefore exists between the commencement of a nonaligned beam condition and the pulsing of the beam. During this finite period, either the welding apparatus or the workpiece being welded can be seriously damaged.

It is therefore an object of this invention to provide a charged particle beam apparatus wherein the divergence of the beam from an aligned position is immediately sensed and corrected.

It is also an object of this invention to provide a charged particle beam apparatus wherein a constant intensity charged particle beam can be detected.

It is a further object of this invention to provide a charged particle beam apparatus wherein a charged beam of constant intensity is aligned by beam sensors disposed about the charged particle beam.

These and other objects of this invention generally are accomplished in one specific aspect of this invention by a charged particle beam apparatus having a source of charged particles and means for focusing the charged particles into a beam impinging upon a desired location by the positioning of detection means on opposite sides of the charged particle beam. Means are disposed along the length of the charged particle beam to deflect the beam along a line intersecting the detection means. Output signals are produced by the detection means proportional to the intensity of the charged particle beam impingement thereon and the output signals from the detection means are fed back to the deflection means to deflect the charged particle beam by an amount proportional to the difference in output signals from the detection means.

The features of the invention believed to be novel are set forth with particularity in the appended claims. The invention itself, however, both as to organization and method of operation, together with further objects and advantages thereof, may best be understood by reference to the following description taken in conjunction with the accompanying drawings in which:

FIG. 1 is an isometric section of an electron beam welding apparatus constructed in accordance with this invention,

FIG. 2 is a plan view of the sensing electrodes within the electron beam welding apparatus,

FIG. 3 is a graph depicting the variation of beam intensity with distance from the axial center of the beam, and

FIG. 4 is an isometric portrayal of an electron beam welding apparatus in accordance with this invention utilizing electromagnetic deflection coils to align the beam.

The charged particle beam apparatus of this invention is specifically disclosed in FIG. 1 as an electron beam welding apparatus 10 and generally includes a source of electrons 11, an electromagnetic focusing lens 13 for focusing the generated electron beam from source 11 through an aperture 16 in a partition plate 17 to impinge upon workpiece 18, and a plurality of sensing electrodes 19 to detect the alignment of the electron beam. The signals produced by the impingement of the electron beam upon sensing electrodes 19 are fed back to electrostatic deflection plates, generally identified by reference numeral 21, to return the beam toward an aligned position with aperture 16 upon movement of the centroid of the beam from the axial center of the aperture. An electrically grounded housing 22 serves as an airtight enclosure for the components forming the welding apparatus while an insulating bushing 23 serves to electrically insulate the electron beam source from the housing.

Electron beam source 11 may be any conventional source utilized to produce an electron beam of sufficient intensity for welding purposes, e.g. the source may comprise a hot cathode electron emitter such as a Pierce gun, and is electrically energized with a negative potential, e.g. 20 kilovolts, through an externally protruding conductive rod 24 connected to the electron beam source. A grounded shield 20 partially encloses electron beam source 11 to improve the efficiency of electron beam emission from the source.

The electron beam generated by source 11 passes through electromagnetic focusing lens 13 and is focused upon a suitable welding location for workpiece 18 which workpiece is mounted upon and electrically grounded through worktable 25. Although the worktable is depicted as stationary in FIG. 1, when elongated welds are desired in workpiece 18, a movable worktable (not shown) may be more advantageously utilized.

Because electron beam source 11 generally requires a low pressure atmosphere, e.g. 10 microns, for electron beam generation while the environment of the workpiece may be at a higher pressure, a partition plate 17 functions to isolate the beam generating portion 26 of welding apparatus 10 from the welding chamber 27 wherein the workpiece is bombarded by the electron beam. An exhaust conduit 29 and a gas input conduit 30 mounted within an aperture in the sidewall of housing 22 serves to maintain beam generating portion 26 at low pressure while suitable gases, e.g. nitrogen, may be admitted and exhausted from welding chamber 27 through conduits 31 and 32, respectively, mounted within apertures in the base plate of housing 22 to maintain a gaseous pressure within the welding chamber, as required. Aperture 16 axially disposed within circular partition plate 17 generally is small in diameter to inhibit the passage of gases from welding chamber 27 into electron beam generating portion 26 of the welding apparatus while permitting the electron beam to pass through the aperture with relatively little loss of power. Although the partition between beam generating portion 22 and welding chamber 27 of the electron beam welding apparatus is depicted as a single apertured partition plate for purposes of clarity, in actual practice a plurality of vacuum pumped chambers can exist between source 11 and welding chamber 27.

Referring to FIG. 2, four sensing electrodes 19, each having the general configuration of cylindrical quadrants and juxtaposed in a plane approximately $\frac{1}{4}$ inch above partition plate 17 to define a central aperture 33 coaxial with and of slightly smaller diameter than aperture 16, serve to detect the position of the electron beam. Each electrode generally comprises an upper carbon segment 35, utilized because of the ability of carbon to glow white hot and thereby radiate heat therefrom. Partially seated upon and in electrical contact with a copper support 36 of split annular configuration which support also

offers a convenient surface for external electrical connection to the sensing electrodes. A small insulating gap 37 is maintained between each of the sensing electrodes and each of the copper supports sections to electrically isolate the sensors from one another. Each of sensing electrodes 19 are connected to ground through a high value resistor 38, e.g. 1 megohm, with the voltage across each of resistors 38 being applied through external leads 39 to the electrostatic deflection plate 21 overlying and in common quadrature, relative to the electron beam, with the sensing electrode to which the resistor is connected. Thus the voltages produced across resistors 38A and 38B by two diametrically opposed sensing electrodes 19A and 19B are connected by external leads 39 to an uppermost set of opposed deflection plates 21A and 21B, respectively, which plates are in the same quadrant relative to the beam axis as the electrodes connected to the plates and function to deflect the beam along a diametrical line intersecting electrodes 19A and 19B. A second lower set of deflection plates 21C and 21D, in overlying and quadrature relationship with sensing electrodes 19C and 19D, respectively, are connected to the individual sensing electrodes through external leads 39 to produce a movement of the electron beam orthogonal to that produced by deflection plates 21A and 21B.

When the electron beam strikes one of sensing electrodes 19, the electrons impinging on the electrode flow to ground through resistor 38 electrically connected to the electrode, thereby producing a negative voltage upon the resistor terminal proximate the sensing electrode. The negative voltage upon the resistor terminal then is applied through external lead 39 to the deflection plate in a common quadrature relationship with the sensing electrode to produce a voltage gradient across confronting deflection plates thereby deflecting the beam in a direction away from the sensing electrode intercepting the beam.

Deflection plates 21 can be any metallic, preferably nonferromagnetic material, for example copper or tungsten, with the spacing between opposed plates being minimized to provide an electric field of maximum uniformity and intensity across the intermediate space. The deflection plates also are positioned proximate electron beam source 11 to produce a maximum beam deflection for a given voltage gradient across opposed plates and generally are as long as spacial requirements conveniently permit for maximum control of the electron beam with a minimum deflection voltage gradient. Preferably the lowest extension of the bottommost deflection plates 21C and 21D should terminate sufficiently above sensing electrodes 19 to inhibit electrons reflected from the electrodes from impinging upon the deflection plates and producing spurious deflection voltages.

Because it is desirous to have opposing deflection plates positioned as close as possible to each other to obtain a uniform field between the electrodes, the width of the deflection plates generally requires orthogonally disposed deflection plates to be positioned one above the other, as is shown in FIG. 1. When identical sensing electrodes 19 and identical resistors 38 are employed, lower deflection plates 21C and 21D preferably are of longer length than upper deflection plates 21A and 21B to produce equal orthogonal deflection spans of the electron beam along the plane of workpiece 18.

As can be seen more clearly in FIG. 2, central aperture 33 formed by sensing electrodes 19 preferably is of a dimension slightly smaller than aperture 16 within partition plate 17 to assure passage of the focused beam through aperture 16 without striking the partition plate. The sensing electrodes themselves are positioned as close as feasibly possible to the desired focal point of the beam, e.g. within a one-fourth inch of partition plate 17, and preferably are so situated as to be continuously impinged upon by equal portions of a perfectly positioned, bell-shaped electron beam 44 such as is shown in FIG. 3. To effectuate this result, aperture 33 is dimensioned slightly smaller than the beam diameter at the axial position of the sensing electrodes and approximately 1 percent, as shown in dashed lines of FIG. 3, of the electron beam impinges

uniformly the electrodes. The quantity of the beam intercepted by the sensing electrodes generally is dependent upon such factors as the magnitude of the voltage to be applied to deflection plates 21, e.g. to be produced across resistors 33, and the acceptable loss in welding efficiency. Preferably, the sensing electrodes intercept a sufficient portion of the beam periphery to be positioned proximate an initial sharply upward sloping portion from the edge of the beam intensity curve, e.g. an initial upward slope of 45° or more from the edge of electron beam intensity curve depicted in FIG. 3. As the electron beam then moves from a nonaligned position, the variation in electron beam impingement upon the sensing electrodes is relatively large per degree of electron beam nonalignment and a substantial variation in the voltages applied to mutually opposed deflection plates is produced to move the beam back toward an aligned position with aperture 16. By employing large resistors, e.g. at least 1 megohm, as the only path from the sensing electrodes to ground, a substantial voltage for a fixed number of impinging electrons upon a sensing electrode is obtained and voltage amplification between the sensing electrodes and the deflection plate, with the associated problems of space limitations within welding apparatus and the limited lifetime of the amplifier components, generally is not required.

Although the electron beam preferably continuously impinges upon all four sensing electrodes with the feedback voltages from diametrically opposed electrodes to pairs of deflection plates deflecting a malaligned beam by a field proportional to the difference in the voltage signals produced by the diametrically opposed electrodes, this invention also is operable when the electrodes are positioned immediately outside the edge of the beam. In such a situation, a malaligned beam produces a voltage upon a single electrode of a diametrically opposed pair and the voltage from the single electrode is fed back to a deflection plate to produce an electrical field tending to return the beam to an aligned position.

When the charged particle beam source is operated in a pressure region tending to produce electrostatic glow discharge between deflection plates 21, electromagnetic deflection of the charged particle beam can be employed, as is shown in the electron beam welding apparatus 47 of FIG. 4.

Input and exhaust conduits 51 and 52, respectively, positioned within the sidewall of electrically grounded housing 54 of the electron beam welding apparatus function to maintain the enclosed apparatus at a desired pressure for beam production and the electron beam produced by source 56 upon electrical energization of conductive rod 57 with a suitable voltage, e.g. 20 kilovolts, passes through and is focused by focusing lens 59 directly upon the workpiece 60 to be welded. Four electron beam sensing electrodes 62 are positioned in a circular configuration coaxial with the electron beam and are situated slightly above, e.g. one-fourth inch, the plane of the workpiece to be welded. Because the location of central aperture 64 formed by sensing electrodes 62 is known relative to workpiece 60, a proper alignment of the electron beam within aperture 64 assures a proper electron beam location upon the workpiece. As described relative to FIGS. 2 and 3, the beam sensing electrodes preferably are positioned to equally intercept the less intense edge portions of the electron beam while central aperture 64 is dimensioned to permit passage of the high intensity portion of the bell-shaped electron beam. The electrons impinging upon the sensing electrodes flow through bifilar electromagnetic deflection coils 66 to return to ground potential. Because a large number of turns are required to produce a substantial electromagnetic deflection of the electron beam using a minimum of current, current amplifiers 67 preferably are inserted intermediate sensing electrodes 62 and bifilar deflection coils 66 to reduce the number of turns in the deflection coils and the associated inductive time lag between the impingement of the beam upon the sensing electrodes and the production of the beam deflection fields from the electromagnetic deflection coils. To produce maximum gain for a given deflection force, electromagnetic deflection coils 66 are positioned as close as possible to the source 66 of electrons.

As the electron beam produced by source 56 varies from an aligned position with central aperture 64 formed by sensing electrodes 62, the sensing electrode in the path of the beam movement receives a substantial increase in the number of impinging electrons due to the location of the electrode relative to the electron beam intensity curve and the diametrically opposite electrode e.g. the electrode form which the beam is moving, sustains a decrease in impinging electrons. The electrons impinging on the sensing electrodes produce a current which is amplified in amplifiers 67 and fed to bifilar electromagnetic deflection coil 66 to produce a magnetic field proportional to the difference in current flow through the coils. The forces produced by the magnetic field deflect the electron beam passing through the deflection coil to move the beam toward a properly aligned position with aperture 64.

While several examples of this invention have been shown and described, it will be apparent to those skilled in the art that many changes may be made without departing from this invention in its broader aspects; and therefore the appended claims are intended to cover all such changes and modifications as fall within the true spirit and scope of this invention.

I claim:

1. An electron beam welder comprising a source for the production of an electron beam of welding intensity, means for focusing said electron beam upon a desired location through an aperture communicating zones of diverse pressure, detection means comprising a plurality of sensors circularly disposed to form a central orifice coaxial with and at most equal diameter relative to said aperture communicating said

diverse pressure zones, said detection means being situated above and on diametrically opposite sides of said aperture at locations to continuously intercept a portion of the edges of opposite sides of a properly positioned beam of welding intensity and producing output signals proportional to the intensity of electron beam impingement thereon, means disposed along the length of said electron beam to deflect said beam along a line intersecting said deflection means, and means interconnecting said detection means and said deflection means to deflect said electron beam by an amount proportional to the difference in output signals generated by said detection means.

2. An electron beam welder comprising a hot cathode electron emitter for the production of an electron beam of welding intensity, means for focusing said electron beam upon a desired location, detection means comprising a plurality of carbon segments seated upon and electrically contacting a metallic support, said detection means being positioned on opposite sides of said electron beam at locations continuously intercepting a portion of the edges of a properly positioned beam of welding intensity and producing output signals proportional to the intensity of electron beam impingement thereon, means disposed along the length of said electron beam to deflect said beam along a line intersecting said deflection means, and means interconnecting said detection means and said deflection means to deflect said electron beam by an amount proportional to the difference in output signals generated by said detection means.

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