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ELECTRON BEAM PRODUCING AND FOCUSING ASSEMBLY

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2 Sheets-Sheet 2

Fig. 2.

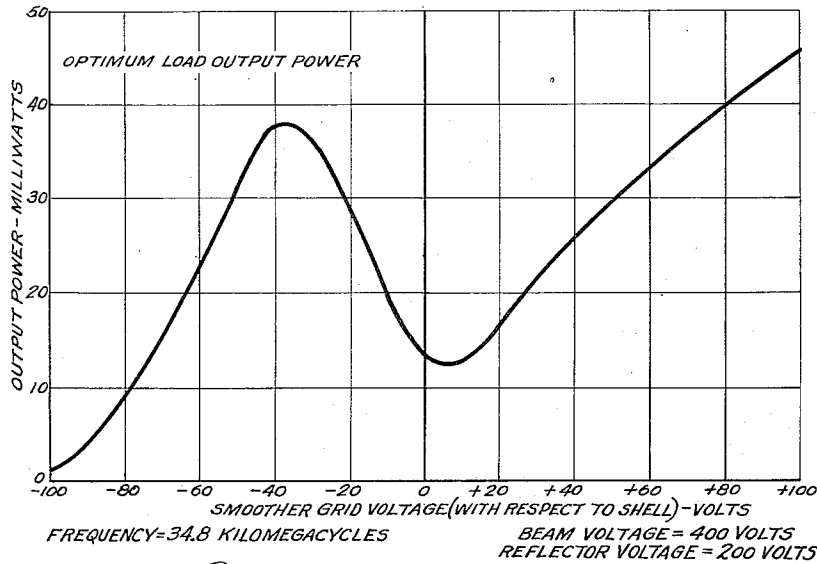
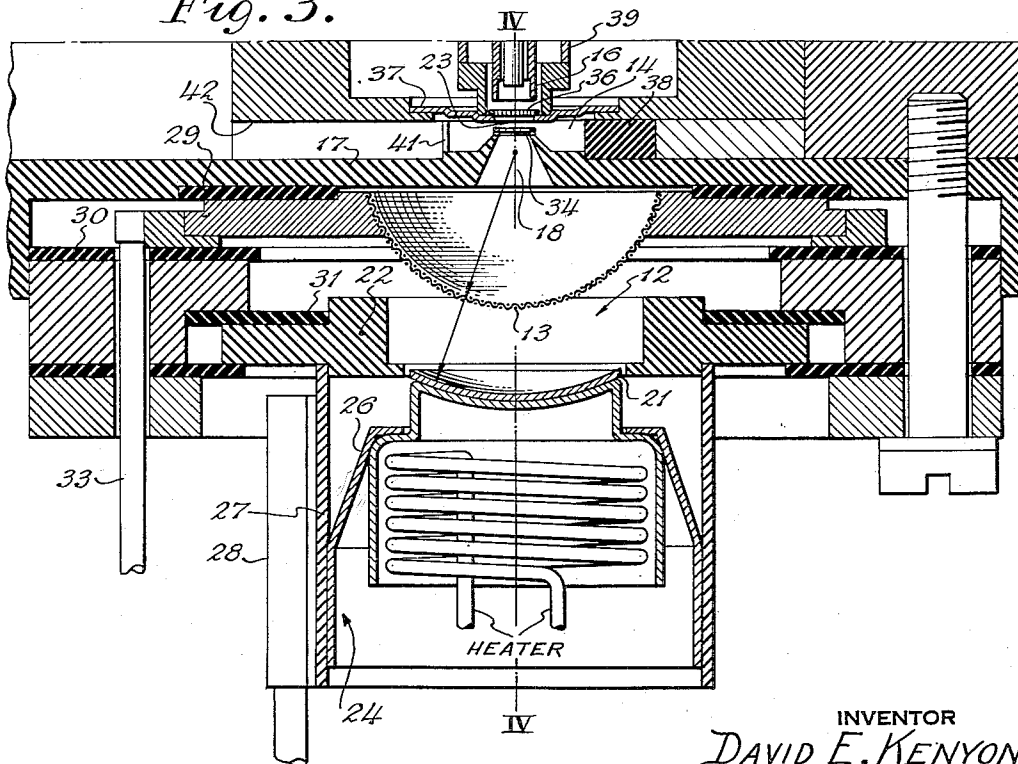


Fig. 3.



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ELECTRON BEAM PRODUCING AND FOCUSING ASSEMBLY

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7 Claims. (Cl. 315—5.22)

This invention relates to an electron beam producing and focussing assembly, and is particularly concerned with apparatus for generating a convergent electron beam which is focussed to a minimum cross-sectional dimension in a region at a predetermined distance from the beam source, and means for insuring that said distance is maintained constant regardless of the production of positive ions along the beam path near said region. This application is a continuation-in-part of copending application Serial No. 298,861, filed July 14, 1952, by the same inventor and assigned to the same assignee, now U. S. Patent No. 2,777,968, issued January 15, 1957.

In very high frequency vacuum tubes such as klystrons, for example, it is desirable to produce an electron beam having an extremely small diameter region for passage through minute electron permeable grids. In some reflex klystrons, which have been constructed for operation in the frequency range of 30,000 to 60,000 megacycles per second, the entrance grid to the resonator gap thereof has an inner diameter of only .025 inch.

In electron discharge devices it is generally desirable to employ a cathode having a relatively large area and low current density so that the cathode life will be long. In order to utilize such a cathode in klystrons operating at the frequencies mentioned above, it is required that an extremely convergent electron beam be produced. In a reflex klystron, it is necessary that such a beam be focussed to a region of minimum cross-sectional dimension no greater than the inner diameter of the entrance grid to the klystron resonator gap, and that the aforesaid region occur in the vicinity of said gap. Therefore, the electron beam contains collimated electron paths at the resonator gap, and substantially collimated paths between the gap and reflector electrode.

Electron gun assemblies for producing and focussing a convergent electron beam to a narrow diameter region containing collimated electron paths are known in the art, one type of which is described in U. S. Patent 2,564,743 to C. C. Wang, dated August 21, 1951. When using such an assembly in high frequency reflex klystrons of the type mentioned above, klystron efficiency and available power output have heretofore been undesirably low.

To utilize a highly convergent electron beam in a high frequency reflex klystron, a smoother (anode) grid comprised of a curved fine wire-mesh having extremely small openings is preferably employed to preserve the desired geometry of the beam. One of the reasons it has been previously impossible to obtain a desirable amount of output power and efficiency in such a klystron is because of trapping of positive ions in the space between the entrance grid to the resonator gap and the smoother grid. Positive ions produce an undesired focussing effect on the electron beam causing it to converge to a minimum diameter at a region closer to the electron gun assembly than computed. This lowers the klystron efficiency since the beam becomes divergent in the vicinity of the resonator gap and the reflector electrode. Available output power is re-

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duced because the design of the reflector is predicated on the electron beam containing substantially collimated electron paths in the vicinity of the aforementioned gap, and the reflected beam becomes excessively wide.

The degree of ion intensity in an evacuated electron tube varies with changes in pressure within the tube envelope. Since electron tubes repeatedly experience minute internal pressure variations because of the constant liberation and absorption of gas from the tube elements, the number of ions formed by bombardment of atoms and molecules therein with electrons of the electron beam is variable. An erratic ion focussing effect is therefore produced, rendering it desirable to provide means for eliminating such ions from a critical space in the tube wherein they can affect the beam.

It is an object of this invention to provide means, in an evacuated electron discharge device, for maintaining a predetermined geometry of a high current density electron beam by removing or neutralizing positive ions from a critical space in the tube.

It is another object of this invention to provide means for producing an electron beam which converges to a predetermined minute cross-sectional dimension at a predetermined distance along the tube axis from the beam source.

It is a further object of this invention to provide means for improving the efficiency and output power derivable from reflex klystrons designed to operate at extremely high frequencies.

Other objects and advantages of this invention will become apparent from the following specification, taken in connection with the accompanying drawings.

In accordance with the present invention, the geometry of a highly convergent electron beam in a high frequency klystron tube is preserved by employing a curved, extremely fine-mesh smoother grid, and by removing positive ions produced in the space between the smoother grid and entrance grid to the klystron resonator. Ions are removed by electrically insulating the smoother grid from both the cathode and anode, and establishing a de-ion electric field between the smoother grid and anode. Such a field causes positive ions in the aforementioned space to be attracted to the smoother grid or anode, depending on the polarity of the de-ion field. When the field is of one polarity, some of the ions are swept through the smoother grid and some are neutralized by surface recombination on the grid surfaces. When the field is of opposite polarity, the ions are neutralized by surface recombination at the anode. In either situation, the undesired focussing effect of positive ions in the space between the smoother grid and the entrance grid to the klystron resonator is avoided, and the minimum diameter region of the convergent electron beam is maintained at a predetermined region beyond the anode.

In the drawings,

Fig. 1 is a sectional view of a reflex klystron embodying the present invention;

Fig. 2 is a plot of the power output from such a klystron as a function of separate bias voltages applied to the smoother grid; and

Fig. 3 is an enlarged sectional view of a portion of the klystron shown in Fig. 1.

Referring to Figs. 1 and 3, a reflex klystron is shown comprising an electron gun structure 12, a smoother grid 13, a microwave resonator 14, and a reflector electrode 16. Ring member 17, which includes a conical opening 18 for passage of an electron beam, comprises an electron permeable anode for the klystron. All of the aforementioned elements are substantially concentric with tube axis IV—IV, and are supported within an evacuated portion

of a tubular metallic envelope 19. Anode member 17 is electrically connected to the envelope 19.

The electron gun structure 12 comprises a cathode 21, the emissive surface thereof being concave and similar to the interior of a portion of a hollow sphere, and a focussing electrode 22. Focussing electrode 22 includes different diameter apertures along the tube axis IV—IV. Such apertures comprise beam forming edges of the type shown at 24 and 26 in Fig. 5 of Wang Patent 2,564,743, mentioned above. The electron gun structure 12 is adapted to produce a convergent electron beam which converges to a minimum diameter in the region of resonator gap 23.

Conductive supporting member 24, having a conical section 26, and cylindrical conductive member 27 connect the cathode 21 to the focussing electrode 22. Lead 28 is connected to member 27 to supply a negative bias voltage from a suitable source (not shown) to maintain focussing electrode 22 and cathode 21 at a high negative direct-current potential with respect to the anode member 17. If preferred, the cathode 21 and electrode 22 may obviously be operated at ground potential, with the metallic envelope 19 and anode member 17 operated at a high positive potential above ground.

The smoother grid 13 comprises a spherically-shaped mesh of extremely fine wires, the center of curvature of the sphere being located along tube axis IV—IV within conical opening 18 and substantially coincident with the center of curvature of the cathode 21. The grid 13 is designed to preserve the desired geometry of the electron beam by insuring that all conductive grid elements are substantially perpendicular to the beam electron paths. Typical grids which have been employed for use in klystrons operating in the thirty to sixty kilomegacycle frequency range mentioned above, comprise a wire-mesh having openings .009 inch wide, the diameter of the wires being .001 inch. The openings are extremely small to reduce grid aberration effects by insuring the existence of a substantially uniform potential distribution along the spherical boundary of grid 13. Even with a grid comprising openings of such small size, approximately 80 percent of the electron beam is passed therethrough.

Smoother grid 13 and the electron gun structure 12 are concentrically supported within tubular envelope 19 in the manner shown in Figs. 1 and 3.

Entrance grid 34, for resonator 14, is mounted on the top of the small end of conical opening 18. An exit grid 36 is supported opposite the entrance grid 34 by a diaphragm 37. A portion of anode member 17 defines the bottom wall of resonator 14, annular member 38 the side wall, and diaphragm 37 constitutes the upper wall thereof. Output coupling to the resonator 14 is effected through a rectangular coupling iris 41 and output wave guides 42 and 43.

Diaphragm 37 is flexible for tuning the klystron by changing the intergrid spacing between the entrance and exit grids 34 and 36, respectively. This is effected by axially adjusting a tubular actuating member 39, which is rigidly attached to flexible diaphragm 37.

The tuning adjustment system in the present tube comprises a manual control knob 55 and tuning screw 54. Screw 54 acts through ball 57 on a raised plate 58 of a rocker-arm lever 49, to vary the angle of lever 49 about pivot balls 51, and thus to provide very finely controlled movement of ball 53 as to its vertical position. Ball 53, in turn, acts against the outer end of a second lever 46, shown as a cantilever, to the middle of which is attached the upper end of tubular member 39. A spring 59 serves to urge the free end of lever 49 upward against ball 57, and a coil spring 48 similarly urges the outer end of cantilever 46 upward against ball 53. Member 39 serves as the coupling between the dual-lever tuning mechanism and the upper grid 36, for minute adjustments of the spacing thereof relative to grid 34.

Reflector electrode 16 is supported within the tubular

member 39 and provides means for establishing a reflecting electric field to decelerate incident beam electrons and return them to resonator 14. Electrode 16 is cup-shaped and designed to preserve the focus of the electron beam. Lead 44, which protrudes through an opening in tubular member 39, is employed to supply the proper negative bias voltage from a suitable source (not shown) to produce the aforementioned field in the vicinity of electrode 16.

Ring member 47 and diaphragm 61 support the tubular actuating member 39 and maintain the coaxial alignment of the reflector electrode 16 with the tube axis IV—IV. In addition, members 47 and 61 serve as a vacuum seal for the klystron, which is maintained at a vacuum of approximately 2×10^{-7} to 2×10^{-8} mm. of Hg vacuum pressure.

In accordance with an important feature of the present invention, grid 13 is electrically insulated from anode member 17 by an annular dielectric spacer element 29, and from the electron gun structure 12 by annular dielectric spacer elements 30 and 31.

A dropping resistor 32 is connected to the smoother grid 13 by means of lead 33. Resistor 32 is connected to the envelope 19 and is supported in the base of the klystron tube below the evacuated portion of envelope 19, although it may be supported within said portion if desired. By employing a resistor of a proper value, a de-ion field may be maintained between grid 13 and anode 17 through the action of smoother grid current. Undesired changes in focussing of the electron beam, because of the presence of an irregular amount of ions in the vicinity between smoother grid 13 and entrance resonator grid 34 are therefore nullified.

The reflex klystron shown operates generally in a manner well-known in the art. By electrically isolating smoother grid 13 from the anode member 17, and connecting a resistor 32 of proper value to grid 13 in the manner shown, the efficiency and output power derivable from the klystron tube is increased.

A typical reflex klystron, constructed in accordance with the present invention, has the following characteristics:

Klystron frequency.....	kilomegacycles...	33-36
Beam voltage (between anode 17 and cathode 21).....	volts...	400
Beam current.....	milliamperes...	46
Reflector voltage (between reflector and cathode).....	volts...	0 to -300
Approximate minimum beam diameter.....	inch...	.025
Radius of curvature of cathode 21.....	do.....	.258
Radius of curvature of smoother grid 13.....	do.....	.160
Spacing of center of resonator gap 37 to geometrical center of cathode 21.....	do.....	.050

An electron gun designed in accordance with the Wang Patent 2,564,743, mentioned previously, is employed. Such a gun has an electron perveance of 6×10^{-6} amperes/volt^{3/2}. The gun is designed to produce a highly convergent electron beam which is collimated with the beam axis at a minimum diameter region in the center of resonator gap 36 beyond the effective plane of anode member 17 closest to the cathode. The minimum diameter region of the beam is, therefore, spaced from the center of curvature of cathode 21 along the beam axis by a predetermined distance which is small compared to the radius of curvature of the cathode. A line from the center of curvature of the cathode 21 to the outer edge of the emissive surface thereof forms an angle of 29° with the beam axis.

Fig. 2 is a plot of output power from a klystron constructed in accordance with the present invention wherein a separate source of direct current potential (not shown) was employed to bias the smoother grid 13 in lieu of the resistor 32 shown in Fig. 1. As is evident from the graph in Fig. 2, moderate departures (of the order of fifty volts,

positive or negative) of the smoother grid 13 from the potential of anode 17 result in improved output power as compared to a condition where the voltage at the smoother grid 13 is the same as that at the anode member 17. A drastic reduction of smoother grid potential, however, would reduce the effective electron gun perveance, causing the output power to diminish.

The reason for increased power output over a range of negative smoother grid potentials is because of the de-ion field established between the smoother grid 13 and anode member 17 shown in Fig. 1. If the smoother grid potential is negative with respect to the anode potential, positive ions are swept from the space between the entrance grid 34 and smoother grid 13, and are neutralized by surface recombination on the surfaces of smoother grid 13, or are swept into the region of high electric field between the cathode 21 and smoother grid 13.

If the smoother grid 13 is positive with respect to the anode member 17, positive ions are attracted to the anode 17 and are neutralized by surface recombination on the surfaces of anode member 17 and grid 34. Power output at positive smoother grid potentials is also increased because positive grid potentials increase the effective beam current. However, increased beam current is not desired for it may destroy the fragile grid elements of the tube.

In the absence of a de-ion field, positive ions remain in the space between smoother grid 13 and grid member 34, and alter the desired electron trajectories of the electron beam. Positive ions cause the electron beam to focus to a minimum diameter at a region closer to the cathode 21 than the desired region at resonator gap 23, whereby the beam becomes divergent at gap 23. Therefore, the reflected portion of the electron beam, caused by the negative field in the vicinity of reflector electrode 16, is excessively wide in the vicinity of the resonator gap 23 and the efficiency and effective output power derivable from the tube is considerably less than when the smoother grid 13 is at a ± 50 volt potential difference from anode 17.

By utilizing a dropping resistor 32, which is connected between the smoother grid 13 and anode member 17, the need for a separate source of smoother grid potential is avoided. Such a resistor 32 is of an experimentally determined value of from approximately 2,000 to 10,000 ohms to maintain the smoother grid 31 at a desired negative potential of approximately 40 to 50 volts with respect to the anode 17. Resistor 13 provides a de-ion field between smoother grid 13 and anode 17 because of current therethrough derived from the electron beam. A resistor having a typical value of approximately 4,000 ohms was employed in a tube designed and operating under conditions mentioned above.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. An electron beam producing and focussing assembly, comprising an evacuated tubular envelope, an electron gun supported within said envelope, said gun including a curved cathode for producing and directing a highly convergent electron beam of predetermined geometry and dimensions along an axis within said envelope, the minimum diameter region of said beam being spaced from the center of curvature of said cathode along said axis by a predetermined distance which is small compared to the radius of curvature of said cathode, means defining an electron permeable anode spaced in said path from said cathode, said defining means establishing an effective anode plane facing said cathode and being be-

tween said center of curvature and said cathode, said anode means including a small aperture coaxial with said electron beam and of the same order of size as said beam minimum diameter and located in the immediate vicinity of said beam minimum diameter region in the absence of positive ion focussing a grid interposed between and insulated from said anode and said cathode, said grid comprising means for preserving the predetermined geometry of said electron beam, means for maintaining said cathode at a direct-current potential which is greatly negative with respect to said anode, and biasing means providing a D.-C. voltage between said grid and said anode of a value necessary for maintaining said grid at a direct-current potential which is different from said anode potential by appreciably less than one-half of the potential difference between said anode and said cathode to establish a de-ion electric field between said anode and said grid, whereby said predetermined distance between the center of curvature of said cathode and said beam minimum diameter region is maintained substantially constant.

2. An electron beam producing and focussing assembly as defined in claim 1, wherein said grid biasing means comprises a resistor connected between said grid and said anode.

3. An electron discharge device, comprising a metallic tubular envelope containing an evacuated portion therein, an electron gun supported within said evacuated portion of said envelope, said electron gun comprising means including a curved cathode for producing and directing a highly convergent electron beam of predetermined configuration having a predetermined focus along an axial path within said evacuated portion of said envelope, the spacing of said focus from said cathode being of the order of the radius of curvature of said cathode along said path, anode means spaced in said path from said cathode, said anode means including a small aperture coaxial with said electron beam and of the same order of size as said beam diameter and located in the immediate vicinity of said beam minimum diameter region in the absence of positive ion focussing means supporting and electrically connecting said anode to said metallic envelope, grid means interposed between and insulated from said anode and cathode, and a resistor supported within said tubular envelope, said resistor being connected between said grid and said envelope for providing a D.-C. voltage between said grid and said anode means of a value necessary to establish a de-ion electric field between said grid and anode means through the action of grid current derived from said electron beam, whereby the spacing of said beam focus from said cathode along said axis is maintained substantially constant.

4. High frequency velocity modulation apparatus, comprising a housing containing an evacuated portion therein, means within said housing including a curved cathode for producing and directing a highly convergent electron beam of predetermined geometric configuration along an axis within said evacuated portion of said housing, the minimum diameter location of said beam being spaced from the center of curvature of said cathode along said axis by a predetermined distance which is small compared to the radius of curvature of said cathode, a resonator supported within said portion of said housing, said resonator including an electron permeable gap spaced along said axis from said cathode in the vicinity of said beam minimum diameter location in the absence of positive ion focussing, an electron permeable anode, means supporting said anode between said resonator gap and said cathode, means for maintaining said cathode at a negative direct-current potential with respect to said anode, a smoother grid interposed along said axis between said anode and cathode and electrically insulated therefrom, a resistor supported within said housing, and means connecting said resistor to said smoother grid and said anode for providing a D.-C. voltage between said

grid and said anode of a value necessary to establish a de-ion electric field between said grid and said anode, whereby said predetermined distance between the center of curvature of said cathode and said beam minimum diameter location is maintained substantially constant.

5. High frequency velocity modulation apparatus as defined in claim 4, wherein said cathode has a spherically-shaped concave emitting surface, and said grid comprises a spherically-shaped mesh of wires comprising extremely small openings to preserve the convergency of said beam, whereby the minimum diameter region of said electron beam is maintained at a predetermined distance from said cathode regardless of the occurrence of ions between said electron permeable resonator gap and said smoother grid.

6. A high frequency klystron for operation in the frequency range of the order of 30 to 60 kilomegacycles, comprising a tubular envelope containing an evacuated portion therein, an electron gun supported within said evacuated portion, said electron gun comprising means including a spherically-shaped cathode for producing a highly convergent electron beam having a predetermined minimum diameter region along the axis of said electron beam, the minimum diameter region of said beam being spaced from the center of curvature of said cathode along said axis by a predetermined distance which is small compared to the radius of curvature of said cathode, a microwave resonator supported within the evacuated portion of said tubular envelope, said resonator including an electron permeable gap region spaced along said axis from said cathode at said beam minimum diameter region in the absence of positive ion focussing, electron permeable entrance means to said resonator gap, said entrance means being aligned with said axis and

having a cross-sectional dimension of the same order of size as said predetermined diameter region, an electron permeable anode supported within said envelope between said resonator gap region and said cathode, a smoother grid supported within said envelope between said anode and said cathode, said smoother grid comprising a spherically-shaped mesh of extremely fine mesh openings to preserve the convergency and geometry of said electron beam, means for insulating said smoother grid from said cathode and said anode, and a resistor connected between said smoother grid and said anode for providing a D.-C. voltage between said grid and said anode of a value necessary to maintain a de-ion electron field between said anode and said smoother grid, whereby said predetermined distance between the center of curvature of said cathode and said beam minimum diameter region is maintained substantially constant.

7. A high frequency klystron as defined in claim 6, further including a reflector electrode supported along said axis beyond said resonator, said reflector electrode comprising means for reflecting said electron beam back to the vicinity of said resonator gap.

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