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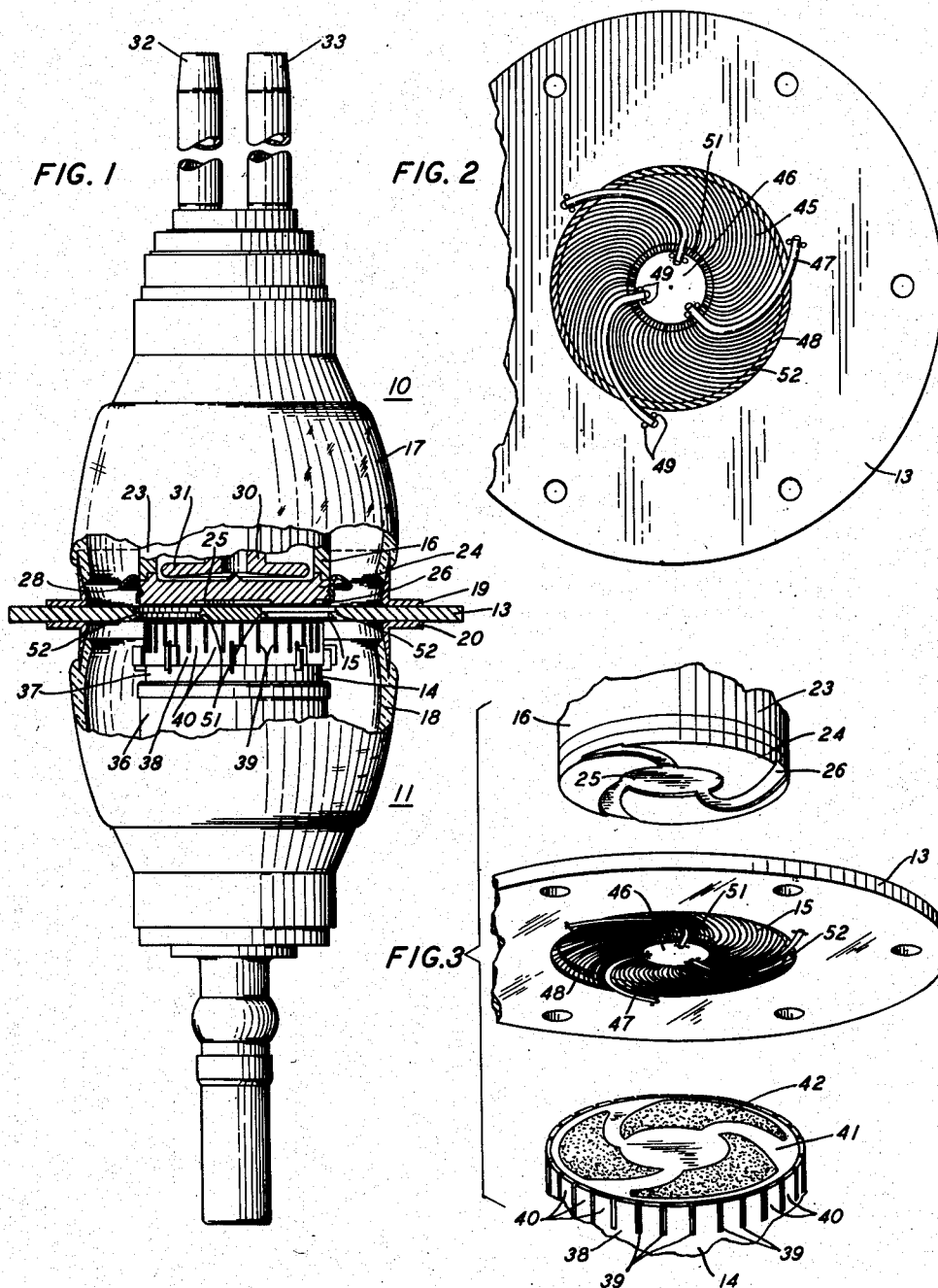
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2,617,959

ELECTRON DISCHARGE DEVICE

Filed Sept. 30, 1950

2 SHEETS—SHEET 1



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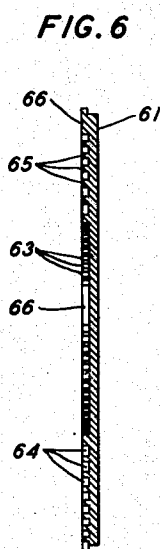
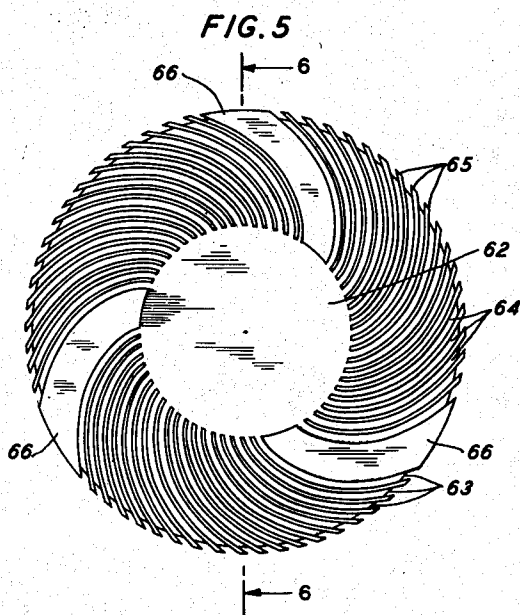
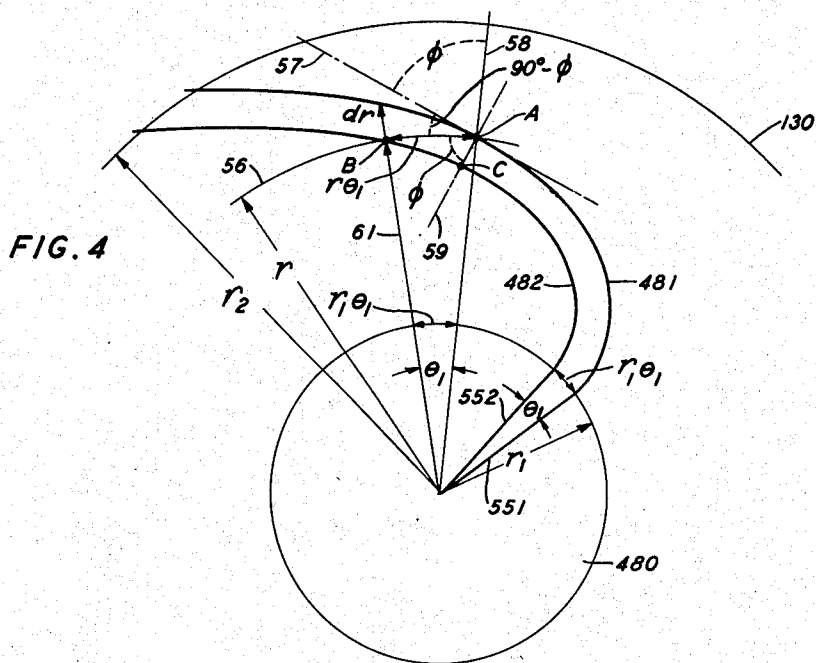
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2 SHEETS--SHEET 2



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UNITED STATES PATENT OFFICE

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ELECTRON DISCHARGE DEVICE

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13 Claims. (Cl. 313-293)

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This invention relates to electron discharge devices and more particularly to such devices especially suitable for use as high power generators or amplifiers at ultra-high frequencies.

In such devices, of which that disclosed in the application of D. A. S. Hale and R. J. Kircher, Serial No. 54,924, filed October 16, 1948 now Patent 2,531,623 is exemplary, the cathode, grid and anode are planar electrodes closely spaced adjacent each other. As the function of the grid or control electrode is to control the potential of a section of the stream of electrons between the cathode and the anode in a plane perpendicular to the electron stream, the ideal control electrode would consist of a very large number of small points arranged in that plane. As this is physically impossible, a control electrode having a finite mass and pervious to electrons must be employed as an approximation to the ideal. A plurality of very fine wires uniformly spaced or extending out from a central hub as radial spokes and slotted plates are types of control electrodes that have priorly been employed.

A control electrode of whatever type in effect shields the anode from the cathode. In this ideal case mentioned above, of a very large number of points this shielding would be uniform over the cathode surface. By a uniform shielding effect a uniform electron emission over the entire face of the cathode is obtained. However, when the control electrode comprises a plurality of wires which vary in position relative to each other shielding of the cathode consequently is not constant over the cathode surface.

A uniform shielding is attainable by several means, but difficulty has priorly been encountered in attaining it without sacrificing other design considerations, such as maintaining the mass of the control electrode at a minimum. Thus in certain types of operation of such devices, for example in grounded-grid operation, the control electrode is common to both the input and output circuits, and charging current flows in the control electrode as current of the input circuit and other charging current flows as current in the output circuit. If the control electrode has appreciable impedance to these currents, a voltage is developed across portions of the control electrode which is common to both circuits and results in feedback between the two circuits. Such feedback is generally undesirable in the operation of these devices. As the impedance of the control electrode is determined by the paths which the current must follow in flowing into the electrode and the number of such paths available,

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it is advantageous to make these paths as short and direct as possible and to provide a maximum number thereof.

However, there are also numerous other desiderata to be met by the control electrode. In electron discharge devices designed for ultra-high frequencies, the electrodes are closely spaced to minimize electron transit-time effects. With close electrode spacings the inter-electrode capacitances per unit area become high and in operation high charging currents flow in the electrodes. These high charging currents result in heating of the electrodes, which may also be heated by radiation from other electrodes and by bombardment by electrons. In order to prevent uneven heating of the control electrode and also to prevent an uneven distribution of impedance between parts of the control electrode it is desirable to have a uniform current flowing at all points equidistant from the center of the control electrode and feeding the inter-electrode capacitances.

Cathodes employable in such ultra-high frequency electron discharge devices are advantageously made in the form of a disc as an equipotential cathode by applying active coating material to one side or the face of the disc and providing means for heating the disc from the opposite side. In operation at ultra-high frequencies, charging current to the cathode-control electrode capacitance must flow over the surface of the cathode in addition to the convection current which leaves the cathode via the emitted electrons. These currents, being of ultra-high frequency, are constrained to the surface of the cathode. The coating material on the cathode disc is of the nature of a semiconductor and has appreciable resistance, so that the power loss resulting from the ultra-high frequency current flowing through the resistance of the cathode coating material tends to heat the cathode during operation.

Further, in such devices when the control electrode, which is positioned closely adjacent the cathode surface, has a positive potential with respect to the cathode, some electrons pass through the electron pervious control electrode but others impinge on it and are collected, contributing to the additional heating of the control electrode. Such electrons are mainly drawn from the portions of the cathode directly opposite the non-pervious portions of the control electrode, such as wires. These and the other heating effects mentioned above may cause the control electrode

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to operate at such an excessive temperature that it emits electrons by thermionic emission, which is undesirable as it results in a decreased efficiency of operation and may in turn result in the over heating of other electrodes. It is therefore desirable to both prevent electrons impinging on the control electrode and also to allow a rapid and even cooling from all parts of the control electrode.

Further because of the close spacings between the electrodes it is desirable that any expansion of an electrode be confined to its plane so that the expansion will not affect the inter-electrode spacings.

It is one object of this invention to improve the efficiency and stability of operation of electron discharge devices and particularly of such devices operable at high power output and ultra-high frequencies.

It is a further object of this invention to provide a grid structure which achieves each of the desired control electrode characteristics. Thus objects of this invention are to attain in a control electrode, both severally and together, an even shielding effect on the emitting cathode surface, a small control electrode impedance and particularly a small control electrode inductance, a uniform current flow in all parts of the control electrode, even heat distribution and an even and rapid cooling of the control electrode, and expansion of the control electrode only in the plane of the electrode. Further, it is an object of this invention to attain each of these advantages in a simple structure without the sacrifice of others.

A still further object of this invention is to reduce the power loss and resultant heating along the emitting surfaces of the cathode.

These and other objects of this invention are obtained in accordance with features of this invention in one specific illustrative embodiment by a control electrode positioned between closely spaced planar cathode and anode electrodes. The control electrode comprises a support, for example a disc, having a central aperture, a hub member centrally positioned in the aperture, and a plurality of fine wires extending from the hub to the disc, the distance between neighboring wires being at all times constant and equal for all wires. A plurality of support rods or straps also extend between the central hub and the disc support and conform to the same geometric configuration.

Further, in another specific embodiment of this invention the control electrode is positioned adjacent a cathode whose surface has radial grooves therein, extending from a central hub portion to the edge, each of the grooves conforming to the same geometric configuration as the elements of the control electrode. These grooves are filled with an electron emissive material and the cathode is so aligned that the emissive material is opposite the spaces between the wires of the control electrode, while the ridges between the grooves are opposite the wires themselves.

It is one feature of this invention that an electrode for an electron discharge device have active portions extending out from a central hub portion and be of such a geometrical configuration that each of the active portions is at all points equidistant from the neighboring active portions and that the distance is the same for each pair of neighboring active portions. This feature is accomplished in one specific way by having each active portion extending from the central hub portion in the form of a curve any point r , θ

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along which is given by the equation in polar coordinates

$$\theta = \frac{\sqrt{r^2 - r_1^2} - \cos^{-1} \frac{r_1}{r}}{r_1} + \text{constant}$$

where r_1 is the radius of the circle whose radii are tangent to the curved active portions and the constant is the angle coordinate of the curve at the point r_1 .

It is a feature of this invention that the control electrode wires extending to an outer disc support each follow the curve defined by the above coordinates. It is also a feature of this invention that all the grid wires intersect the circle defined by the outer disc support at the same angle.

It is a further feature of this invention that a cathode have grooves or depressions in its surface emanating from a central hub portion, each of the grooves being curved to follow the above coordinates and each of the grooves being filled with an electron emissive material.

It is a further feature of this invention that such a cathode and control electrode be cooperatively related in an electron discharge device, the cathode being positioned adjacent the control electrode and oriented so that the emitting or active portions of the cathode are spaced between the wires or active portions of the control electrode, and the ridges between the grooves in the cathode surface are positioned opposite the wires of the control electrode.

A complete understanding of this invention and of the various features thereof may be gained from consideration of the following detailed description and the accompanying drawings, in which:

Fig. 1 is an elevational view of an electron discharge device incorporating the various features of this invention, a portion of the device being shown in section to show the close spatial relationship of the electrodes;

Fig. 2 is a plan view of a control electrode illustrative of one specific embodiment of this invention and employable in the device of Fig. 1;

Fig. 3 is an exploded perspective view of the coplanar electrodes of the device of Fig. 1;

Fig. 4 is a sketch of two of the wires of the control electrode of Fig. 2 illustrating the derivation of the equation of the curve of the wires;

Fig. 5 is a plan view of a cathode illustrative of one embodiment of this invention; and

Fig. 6 is a sectional view along the line 6-6 of Fig. 5.

Referring now to the drawings, Fig. 1 shows a grounded-grid type ultra-high frequency electron discharge device operable at high power output in which the various features of this invention may advantageously be incorporated. The device illustrated in Fig. 1 is of the type described in the application of D. A. S. Hale and R. J. Kircher, Serial No. 54,924, filed October 16, 1948, now Patent 2,531,623. As more fully described in that application, the device comprises similarly shaped anode section 10 and cathode section 11 joined to a medial copper ring 13 to form the enclosing vessel for the cooperating cathode 14, control electrode 15, and anode 16 within the device. The glass bell portions 17 and 18 of the anode and cathode sections 10 and 11 are joined to the copper ring 13 by copper ring members 19 and 20, respectively.

The anode 16 advantageously comprises a hollow cylindrical housing 23 having a thick copper

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disc 24 secured to the lower end of the housing 23. The disc 24 has a central groove 25 and radial grooves 26, as best seen in Fig. 3, in its surface adjacent the other electrodes, as explained more fully below. A protective shield 28 is mounted on the periphery of the anode disc 24 to prevent bombarding electrons being projected from the cathode 14 towards the glass-to-metal seal of the anode section 10.

A central hollow tube 30 extends axially in the hollow cylindrical housing 23 and terminates in a mushroom-shaped nozzle 31 adjacent the inner surface of the anode disc 24. Inlet and outlet pipe connections 32 and 33 extending through the end of the anode section 10 allow a cooling fluid to be circulated and projected against the anode disc 24 in a thin film to carry away the heat absorbed by the anode disc during operation of the device, as more fully disclosed in the above-mentioned copending application.

The cathode assembly 14 comprises a sleeve 36, which may be of copper-plated Kovar alloy, a slotted ring member 37, as of nickel, secured to the end of the sleeve 36, and a castellated ring member 38, which may also be of nickel, which is secured to the ring member 37. The ring member is provided with a number of vertical slots 39 to form a plurality of resilient fingers 40 which are spot-welded to a heavy nickel disc 41. The surface of the disc is coated with an active electron emissive material, such as barium and strontium oxides, the coating 42 being applied to only certain areas of the disc 41, as best seen in Fig. 3 and discussed more fully below. The fingers 40 form yielding supports for the disc, being forced outwardly by expansion of the disc during heating so that the planar position of the disc is practically unchanged in the axial direction regardless of expansion and contraction of the disc.

Referring now to Fig. 2, the grid or control electrode 15 in accordance with this invention comprises a copper ring frame or disc 13 which has a central aperture 45 therein, a hub member 46 located axially within that aperture and concentric with the ring frame 13, heavy support rods or straps 47 and grid wires 48, the support rods or straps 47 and the grid wires extending out from the hub member 46 and connecting it to ring frame 13.

The ring frame 13 and the hub 46 advantageously both have grooves adjacent the aperture 45 in which grooves the support rods or straps 47 are positioned so that they do not rise substantially above the surface of the ring frame 13. The rods or straps are advantageously secured in the grooves by stakes 49. The grid wires 48 may be secured to the hub 46 and ring frame 13 as by being spot welded to ledges 51 and 52 on the hub and ring frame members 46 and 13, respectively.

In accordance with this invention, each grid wire 48 is secured to the hub 46 and in extending across the aperture 45 to the ring frame 13 remains at all points equidistant from each of the neighboring wires. Thus it is a characteristic of the grid wires 48 that they are so curved that each wire makes the same acute angle with the outer of the circles bounding the aperture 45, and also each wire makes the same angle with the inner of the circles bounding the aperture.

Referring now to Fig. 4, the equation of the curve which defines the optimum structure of grid wires may be derived as follows from the

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desired conditions. Two of the grid wires 481 and 482 are shown in Fig. 4 and are illustrated as being tangent to the radii 551 and 552 of a circle 460, which circle determines the origin of each of the curves of the electrode and has a radius of a specific value r_1 . As more fully discussed below after the derivation of the general equation of the curve, the circle 460 may or may not be in actuality the hub circle, that is, the physical hub 46 of the electrode shown in Fig. 2. In this derivation it shall be so referred to, as it is thus shown in the electrode of Fig. 2 and discussed above. However whether the circle 460 is the hub circle or not, the radius r_1 in the following derivation is known constant whose value is given by the theoretical circle defined by having its radii tangent to the curves of the electrode. In the electrode shown in Fig. 2, as noted above, this theoretical circle is the hub 46.

The angle between the two radii 551 and 552 and therefore between the grid wires 481 and 482 at the point of intersection with the hub circle is θ_1 . The pitch distance or the distance between the two wires 481 and 482 on the circle 460 is

$$\text{Distance between wires} = r_1 \theta_1 \quad (1)$$

where θ_1 is given in radians. As one desired characteristic of the control electrode 15 is that the distance between any grid wire 48 and its neighboring wires be constant and the same for all wires 48 and for any point along them, the distance between any two adjacent wires at any point in the grid structure is given by Equation 1.

As the number of wires in the grid does not vary over the grid between the hub circle 460 and the rim circle 130, which has a radius r_2 , the two grid wires 481 and 482 will intersect any circle 56 between the hub and rim circles 460 and 130 at points A and B which are separated by the angle θ_1 or by the distance $r \theta_1$ where r is the radius of the circle 56. The line 57 is tangent to the curve of the wire 481 at the point A and makes an angle ϕ with the radius 58 of the concentric circles. Line 59 is drawn through point A normal to the curve of the wire 481 and thus to the line 57 and intersects wire 482 at point C. The wire 482 intersects the circle 56 at point B and line 61 is the radius of the concentric circles through that point.

If the angle θ_1 is considered to be small the curves AB and BC may be assumed to be straight lines, which assumption becomes correct as these distances approach the limiting conditions. Then ABC is a right triangle with an angle BAC equal to the angle ϕ , that is, the angle between the normal line 59 and the arc of the circle through A is ϕ . Thus

$$AC = r \theta_1 \cos \phi \quad (2)$$

As the initial condition is that AC be always constant and thus is equal to $r_1 \theta_1$ from Equation 1 there may be substituted

$$AC = r_1 \theta_1 \quad (3)$$

in Equation 2. Thus,

$$r_1 \theta_1 = r \theta_1 \cos \phi \quad (4)$$

or

$$\frac{r_1}{r} = \cos \phi \quad (5)$$

which gives the requirement of the curve of the wires for the grid desired, namely that each wire

of the grid be of such shape that at any point along the wire the ratio between an initial radius and the radius at that point be equal to the cosine of the angle between the tangent to the curve and the radius at that point.

To determine the equation of the curve of any wire in the grid we may consider the incremental dr of the radius 61 and the triangle formed by the incremental dr and the incremental $d\theta$. In the limit the relationship between these increments may be written as

$$\frac{dr}{r d\theta} = \tan(90^\circ - \varphi) \cot \varphi \quad (6)$$

$$d\theta = \frac{\tan \varphi}{r} dr \quad (7)$$

which gives the rate of change of the curve in terms of r and θ . However

$$\tan \varphi = \frac{\sin \varphi}{\cos \varphi} = \frac{\sqrt{1 - \cos^2 \varphi}}{\cos \varphi} \quad (8)$$

Substituting Equation 5 in Equation 8 we have

$$\tan \varphi = \frac{\sqrt{1 - \left(\frac{r_1}{r}\right)^2}}{\frac{r_1}{r}} = \frac{\sqrt{r^2 - r_1^2}}{r_1} \quad (9)$$

Equation 9 may be substituted in Equation 7 to obtain the equation

$$d\theta = \frac{\sqrt{r^2 - r_1^2}}{r r_1} dr \quad (10)$$

which may be integrated to obtain the equation of the curve

$$\theta = \frac{\sqrt{r^2 - r_1^2} - \cos^{-1} \frac{r_1}{r}}{r_1} + \text{constant} \quad (11)$$

The constant is the value of θ for the initial condition of $r=r_1$ and may be defined as ψ , so that the general equation of the curve is

$$\theta = \frac{\sqrt{r^2 - r_1^2} - \cos^{-1} \frac{r_1}{r}}{r_1} + \psi \quad (12)$$

If r_1 is assumed to be equal to unity then the equation simplifies down to

$$\theta = \sqrt{r^2 - 1} - \cos^{-1} \frac{1}{r} + \psi \quad (13)$$

or, where, ψ the initial angle is zero,

$$\theta = \sqrt{r^2 - 1} - \varphi \quad (14)$$

where r is the radius in units of r_1 , the radius of the hub 130 and the angles are expressed in radians.

In the above development the hub was assumed to be at radius r_1 where the wires became tangent to radii. This of course is the minimum radius hub for which the desired conditions are obtained. It is quite possible to make the hub of radius larger than r_1 , in which case the angle φ is not zero at the hub. It is usually desirable to make angles φ as small as possible in the interest of maximum rigidity and minimum impedance so that the hub may advantageously be at $\varphi=0$. However electrodes in accordance with this invention are not limited to any portion of the curve of the generalized equation stated above. Thus the initial point of the curved portions may advantageously be at any radius along the curve either equal to or larger than r_1 , the radius of the circle for which $\varphi=0$.

Control electrodes having active portions or

wires curved in accordance with the general equation 12 provide an even shielding effect over the face of the cathode because of the equal and even spacing of the active portions of the electrodes relative to each other. Further as all of the wires of the electrode are directly connected to the disc or frame 13 the charging currents are carried substantially uniformly by all the wires, thereby providing a minimum inductance of the electrode. Further all the wires conduct heat to the disc or frame 13, thus aiding in enabling the wires to operate at reasonable temperatures such that thermionic electron emission from them is minimized.

As all of the electrode wires 48 are of the same length, they present substantially equal impedances to the charging currents thereby permitting even distribution of current flow into the electrode from frame 13. Further since all of the wires 48 and the support rods or straps 47 have a curvature in the plane of the control electrode, any expansion of these members is biased in this plane, there being no constraints to cause buckling normal to the plane.

Referring again to Fig. 3 it is seen that the cathode, control electrode, and anode are so oriented that the support rods 47 are positioned opposite the non-coated portions of the cathode disc 41 and in turn also fit into the groove 26 in the anode disc 24, each of these also following the contour of the curve of the control electrode wires 48. Similarly the hub member 46, uncoated hub portion of the cathode disc 42 and central groove 25 in the anode disc are positioned in alignment. Thus collection of electrons by the control electrode support rods 47 is avoided and closer inter-electrode spacing with a concomitant reduction in electron transit time and increase in transconductance is obtained.

Referring now to Fig. 5, there is shown a cathode embodying further the principles of this invention. The cathode comprises a disc 61 of similar over-all configuration to disc 41 and similarly adapted to be held in the cathode assembly 14 by the resilient fingers 40, as discussed above. The surface of the disc 61 adjacent the other electrodes of the device has a central or hub portion 62 from which emanate a plurality of grooves 63. Each of the grooves 63 is filled with an electron emissive material 64 and comprises the active portion of the cathode. The grooves 63 are closely spaced together being separated by the ridges 65 integral with the cathode disc 61. Portions 66 are left without grooves 63 therein.

The grooves 63, ridges 65, and portions 66 each advantageously are curved to follow the equation

$$\theta = \frac{\sqrt{r^2 - r_1^2} - \cos^{-1} \frac{r_1}{r}}{r_1} + \psi$$

so that the active portions of the electrode are everywhere equidistant from the neighboring portions and that distance is constant over the whole electrode.

The cathode is advantageously employed in an electron discharge device together with a control electrode in accordance with this invention by being aligned so that the emissive material 64 in the grooves 63 is opposite the spaces between the wires 48, the ridges 65 between the grooves 63 are opposite the wires 48 themselves, and the portions 66 are opposite the support rods or straps 47. Electrons emitted from the electron emissive material 64 will then tend to be formed into beams which will substantially avoid the grid wires as

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well as the support rods and thus the number of electrons impinging on the control electrode and collected thereby will be greatly reduced.

Further the charging current to the cathode-control electrode capacitance, which being of ultra-high frequency is constrained to the surface of the cathode, will choose the lower resistance paths offered by the metallic ridges 65 and substantially avoid the higher resistance paths through the electron emissive materials 64. As the power loss by current flowing through the low resistance metallic ridges 65 is appreciably less than that which would be caused by the charging currents flowing through the higher resistance emissive materials, the cathode heating is considerably reduced allowing a higher efficiency of operation.

It is to be understood that the above-described arrangements are illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. An electrode for an electron discharge device having a central hub portion and curved active portions attached to and emanating out from said hub portion and coplanar therewith, said active portions being curved so that the distance between adjacent active portions is substantially constant at any point along said active portions.

2. An electrode for an electron discharge device having a central hub portion and curved active portions emanating from said hub portion, each of said curved active portions following the equation

$$\theta = \frac{\sqrt{r^2 - r_1^2} - \cos^{-1} \frac{r_1}{r}}{r_1} + \psi$$

where r_1 is the radius of the circle whose radii are tangent to said curved active portions, ψ is the angular coordinate of the point of tangency, and r, θ is a point further along the curve.

3. An electrode for an electron discharge device comprising a plurality of wires each of which is a curve following the equation

$$\theta = \frac{\sqrt{r^2 - r_1^2} - \cos^{-1} \frac{r_1}{r}}{r_1} + \psi$$

where r_1 is the radius of the circle whose radii are tangent to the curves, ψ is the angular coordinate of the point of tangency, and r, θ is a second point further along the curve.

4. An electrode for an electron discharge device comprising a conducting member having an aperture therein, a plurality of curved wires attached to said member and extending inwardly across said aperture, each of said wires having a curvature such that the distance from one of said wires to an adjacent wire in a direction normal to said first wire is substantially constant at any position along the length of said wires in said aperture.

5. An electrode for an electron discharge device comprising an outer member having a circular aperture therein, a central hub member substantially concentrically positioned in said aperture, and a plurality of wires extending across said aperture between said outer and said hub members, each of said wires being curved such that the distance from any wire to an adjacent wire in a direction normal to said first wire is substantially the same at any point along any

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wire between said outer and said hub members.

6. An electrode for an electron discharge device comprising an outer support member having a circular aperture therein, an inner support member positioned in said aperture, and a plurality of curved wires connected to each of said support members, the curve of each of said wires being of the same equation and each wire intersecting the circular inner boundary of the outer support member at the same acute angle.

7. A planar electrode for an electron discharge device comprising a conducting disc having a central circular aperture therein, a circular hub member located substantially concentrically in said aperture, a plurality of wires extending across said aperture and secured to said disc and said hub member, said wires each conforming substantially to a curve of the equation

$$\theta = \frac{\sqrt{r^2 - r_1^2} - \cos^{-1} \frac{r_1}{r}}{r_1} + \psi$$

where θ is the angular coordinate, r is the radial coordinate, r_1 the radius of said circular hub member, ψ the angle of intersection of the wires with the periphery of each circular hub member, and the origin of the polar coordinates is at the center of said aperture and said hub member.

8. An electrode for an electron discharge device in accordance with claim 7 wherein certain of said wires are of greater thickness than the remainder of said wires, said thicker wires serving to support said hub member in said aperture.

9. A planar cathode for an electron discharge device comprising a metallic disc member having a plurality of grooves therein, said grooves being closely spaced and defining metallic ridges therebetween, said grooves and ridges extending from the periphery toward the center of said disc member, and an electron emissive material positioned in said grooves only whereby high frequency charging currents for the cathode control electrode capacitance are constrained to the surface of the cathode and flow substantially entirely in the low resistance metallic ridges.

10. A planar cathode for an electron discharge device comprising a metallic disc member having a central surface hub portion and a plurality of closely spaced grooves therein emanating from said central surface portion, said grooves defining a plurality of ridges therebetween and an electron emissive material positioned in said grooves only, whereby high frequency charging currents for the cathode control electrode capacitance traverse the surface of said cathode between the periphery thereof and said hub portion by flowing substantially entirely in the low resistance metallic ridges.

11. A planar cathode for an electron discharge device comprising a metallic disc member having a central surface hub portion and a plurality of closely spaced curved grooves therein emanating from said central hub portion, said grooves defining a plurality of curved ridges therebetween, and an electron emissive material positioned in said grooves only, the curve of each of said grooves and said ridges following the equation

$$\theta = \frac{\sqrt{r^2 - r_1^2} - \cos^{-1} \frac{r_1}{r}}{r_1} + \psi$$

where r_1 is the radius of the circle whose radii are tangent to said grooves, ψ is the angular coordinate of the point of tangency, and r, θ is a point further along the curve.

12. A high frequency high power electron dis-

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charge device comprising an enclosing vessel and a closely spaced planar cathode, control, and anode electrodes in said vessel, said control electrode comprising a metallic disc member extending through said vessel having a circular aperture therein, a hub member concentrically located within said aperture and a plurality of curved wires secured to said disc and hub members and extending across said aperture, said cathode comprising a metallic disc member having a central surface hub portion and a plurality of closely spaced curved grooves therein emanating from said hub portion, said grooves defining a plurality of curved ridges therebetween, and an electron emissive material positioned in said grooves solely, said cathode and control electrode being oriented so that the grooves are opposite the space between said wires and said ridges are opposite said wires, the curve of each of said grooves, ridges, and wires conforming substantially to the equation

$$\theta = \frac{\sqrt{r^2 - r_1^2} - \cos^{-1} \frac{r_1}{r}}{r_1} + \psi$$

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where r_1 is the radius of the circle whose radii are tangent to said grooves, ψ is the angular coordinate of the point of tangency, and r, θ is a point further along the curve.

- 5 13. An electron discharge device in accordance with claim 12 wherein each of the curves is initially a continuation at the periphery of said hub member or said central surface hub portion of a radius of said hub member or said central surface hub portion respectively.

CLIFFORD E. FAY.

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