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GRID ELECTRODE FOR AN ELECTRON DISCHARGE DEVICE

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FIG. 1

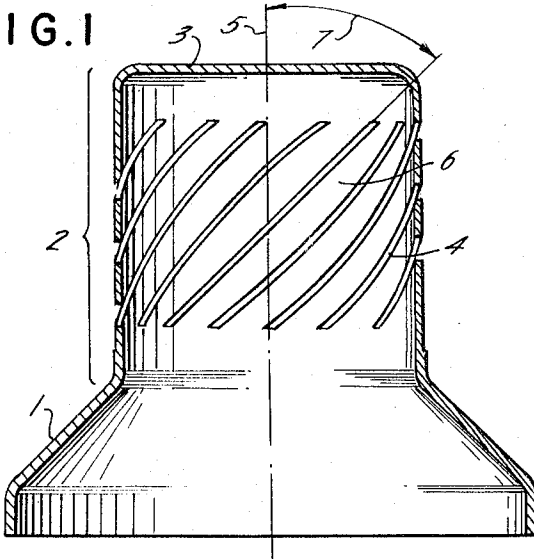
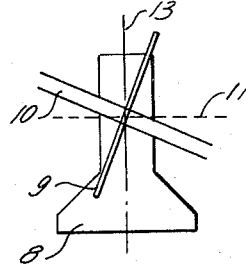


FIG. 2

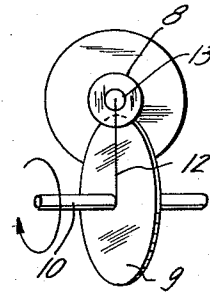


FIG. 3

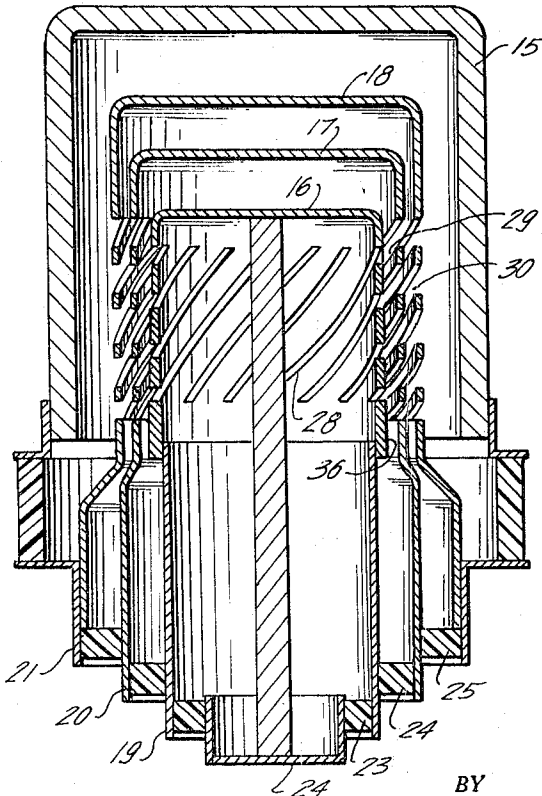


FIG. 4

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1

3,305,748

GRID ELECTRODE FOR AN ELECTRON DISCHARGE DEVICE

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12 Claims. (Cl. 313—348)

This invention relates to electrode structures for electronic tubes, especially tubes designed for operation at high power and frequency values. It relates more especially though not exclusively to grid electrode structures for such tubes, having improved performance characteristics.

Objects of the invention include the provision of: electrode structures having improved dimensional stability and thereby imparting more uniform operating characteristics and longer service life to electron discharge tubes in which such structures are incorporated; electrode structures capable of being machined to extremely close dimensional tolerances and of retaining such tolerances over prolonged service; electrode structures especially well-suited for electron tubes having very small inter-electrode spacings and/or high power and frequency ratings; improved electronic devices such as electron-discharge tubes for high power and frequency operation, having heightened performance characteristics due to improved electrode structure embodied therein. Other objects will appear.

In the field of electron-discharge tubes for high power levels and high frequencies, as currently used, it is necessary to reduce the inter-electrode spacings to extremely small values. This raises difficult problems in regard to the geometrical accuracy of the shape to which the electrodes are formed and the positions in which they are mounted. The problem is of especial difficulty due to the fact that in operation the electrodes are exposed to considerable heating and consequent thermal expansion. Where different portions of an electrode are carried to different temperatures, the electrode in addition to sustaining a bodily increase in all its dimensions is exposed to differential distortion, and in many cases assumes a permanent set. Differential heating and expansion of this sort is especially difficult to avoid in the case of control grid electrodes. One particularly frequent result of such differential heating and distortion occurring in the case of tubular electrodes, such as control grids, is an inaccurate centering of the electrode around an inner emissive electrode, such as a cathode, which should theoretically extend along the axis of the tubular grid. In such an imperfectly centered electrode system, the portions of the grid positioned nearest the cathode (or the like) are exposed to a stronger electron current than other parts of the grid and hence to stronger heating and expansion. It is to be noted in this connection that the centering accuracy of an electrode generally is many times poorer, in order of magnitude, than the dimensional accuracy thereof.

One form of grid electrode widely used at present in tubes having small inter-electrode spacings comprises a hollow metallic cylinder formed with longitudinal slots along generatrices of the cylinder. Such electrodes can be manufactured to very close dimensional tolerances. They are mechanically strong at ordinary temperatures and retain their shape and strength when heated so long as the temperature distribution therein remains substantially uniform. However, in the presence of even a slight degree of non-uniformity in the temperature distribution, i.e. creation of even a small temperature gradient in any

2

area of such a tubular grid, as by reason of imperfect centering as mentioned above or owing to non-uniform emission of the cathode positioned axially of such a grid, the solid strips defined between the slots of the grid are apt to be deformed unpredictably inwards or outwards of the cylinder, and/or in a tangential direction. When this occurs the inwardly-warped strips are exposed to a further increase in electron flux, resulting in a further increase in the heat supplied to such inwardly-warped portions. The distortion of the grid structure thereby tends to increase more and more, until one or more strips enter into contact engagement with the axial electrode (cathode or control grid), at which time the tube is put out of commission. Tangential distortion of the strips, though usually less damaging, also may result in seriously affecting the desired discharge characteristics of the tube.

In a known variation of this slotted tubular electrode structure, developed in an attempt to overcome the objectionable instability occurring in the operation of the straight-slotted tubular electrode just described, the tubular grid electrode is composed of two coaxial cylindrical sheets of intercrossed helically wound wires, soldered together at part or all of the cross-over points. In such a structure, owing to the initial outward curvature present at all points of each of the individual helical wires, the heating of any part of one or more wires in excess of the surrounding parts of the electrode due to aforementioned imperfect centering or non-uniform emission, will result in the overheated part warping outwardly, thereby reducing the electron current received by such part and reducing the rate at which it receives heat. The previously overheated part is thus cooled, and tends to move back towards its initial undistorted position; thus any part of such a grid that may tend to overheat will assume a balance position. However, electrodes of this self-stabilizing character are expensive to manufacture nor is it possible to construct them with the close dimensional tolerances applicable to the simpler slotted tubular electrodes first mentioned, in which the slots can be simply cut in the tubular blank by means of a milling cutter or the like. Moreover, such double-helix electrode structures are less stable dimensionally in operation and the thermally-induced distortions of certain parts of the helical wires often tend, in practice, to result in permanent warping or distortion of the electrode as a whole, due especially to the bonds at cross-over points between different wires.

Specific objects of this invention are to provide electrode structures which will combine the advantageous features of both the straight-slotted tubular electrode, and the double-helically wound electrode described above without introducing the defects of either type. That is, an object is to provide a cylindrical electrode which will be inherently self-stabilizing in that an increase in the electron current to which any portion of the electrode is exposed will tend to increase the distance of such portion from the axis of the cylinder and thus result in the establishment of a balance position, and which will nevertheless be easy and inexpensive to manufacture to very close dimensional tolerances and will have considerable mechanical strength and dimensional stability in service.

According to the invention, the improved electrode for use in electron discharge devices comprises a hollow cylinder formed with angularly spaced slots, and is characterized in that the said slots are angled with respect to the generatrices of the cylinder over at least a major part of their extent. In a preferred form of the invention, the slots constitute planar curves, i.e. arcs of ellipses, defined by the intersections of the hollow cylinder with a family of spaced planes angled with respect to the cylin-

der axis, preferably planes all lying at a common angle with respect to said axis. Preferably also, the slots extend symmetrically on opposite sides of points positioned on a middle circumference of the cylindrical body of the electrode.

An exemplary embodiment of the improved electrode of the invention and a procedure for the manufacture thereof, will now be described with reference to the accompanying drawings, wherein:

FIG. 1 is a simplified and exaggerated view of the improved electrode in longitudinal section;

FIG. 2 is a smaller-scale view of a blank and a milling-cutter tool during the manufacture of the electrode of FIG. 1, with the blank being shown in longitudinal elevation;

FIG. 3 is an overhead plan view corresponding to FIG. 2.

FIG. 4 is a longitudinal cross sectional view of a tube using electrodes according to the invention.

The grid-type electrode shown in FIG. 1 comprises a part in the general form of a surface of revolution, having a frustoconical base section 1, a cylindrical main body section 2 and a flat top 3. The electrode may be made from any suitable refractory material, e.g. molybdenum, tantalum, or other substances. The cylindrical body section 2 is formed with a series of slots 4 angled with respect to the generatrices, such as 5, of the cylindrical surface. Specifically, the slots 4 and hence also the midlines of the inter-slot strips 6 forming the elements of the grid electrode, are elliptical arcs defined by the intersection with the cylinder 2 of a family of spaced planes inclined at a common angle to the axis of the cylinder. For clarity, both the angle of inclination of the slots, indicated at 7, and the pitch spacing between them, are shown larger than would actually be used in most practical applications. The average inclination of the slots and interslot strips with respect to the generatrices of the cylinder should in each instance be predetermined with a view to the following opposing conditions. On the one hand, decreasing said angle, i.e. forming the slots more nearly parallel to the generatrices as in the earlier-described conventional construction, will increase the mechanical rigidity of the electrodes, but will also increase the radial outward excursion or warping amplitude of any strip that may be exposed to local overheating, since the initial curvature of the strip is low. On the other hand, increasing the inclination angle will somewhat reduce the rigidity of the resulting grid structure but will reduce the amount of warping. A preferred range of angles according to the invention is from about 10° to about 30° to the generatrices of the cylinder.

In one specific embodiment of a grid electrode constructed as illustrated in FIG. 1, which has been satisfactorily tested, the following dimensional characteristics were used:

Wall thickness, molybdenum sheet—0.25 mm.
Diameter of cylindrical body section 2—60 mm.
Axial height of cylindrical body section—50 mm.
The slots 4 extend over an axial length of 25 mm.
Slope angle of slots relative to the generatrices—20°.
Slot width (as determined by grinder thickness)—0.70 mm.
Inter-slot spacing—0.25 mm.

It will be noted that the grid elements or strips as defined between adjacent slots are square in cross-section.

A grid electrode thus constructed can very easily be manufactured to accurately predetermined initial dimensions, by well-known precision machining techniques, as will be more fully described hereinafter. At the same time, and in contrast with the straight-slotted cylindrical electrodes previously known and described above, the skew-slotted electrode of the invention is inherently and very markedly self-stabilizing in regard to distortions induced by differential heating from an axially positioned

electrode, e.g. cathode, since any inter-slot strip 6 that may be subjected to overheating will, in view of its initially outwardly convex form, be distorted in a radially outward direction due to such overheating, thereby increasing its distance from the emissive source, and reducing its temperature until a position of equilibrium has been reached. In contrast with the double-helix structures of the prior art which exhibited a comparable self-stabilizing feature, the electrode illustrated is not only cheaper and easier to manufacture to very close dimensional tolerances, as already mentioned, but is stronger, dimensionally more stable, and less prone to bodily distortion, since the individual strips 6 defined between the slots 5 are mechanically independent over their major extent, rather than being bonded, as by solder, at intermediate points with neighbouring elements as is the case in the double-helically wound wires of the conventional self-stabilizing electrode.

The improved electrode may be made from any of the materials currently used for similar purposes, such as molybdenum or tantalum sheet. However, the high mechanical strength and stability of the improved electrode makes it possible to fabricate it out of materials which, though very desirable from the functional point of view, could not heretofore conveniently be used due to the frailty and/or dimensional instability of earlier electrode structures, e.g. graphite. The advantages stemming from the use of graphite under certain specific conditions in the construction of electrodes has been disclosed in co-pending application Serial No. 269,919.

It will be understood that the particular form of electrode illustrated in FIG. 1 and described above is exemplary and that many variations be made therein while retaining the basic teachings of the invention. Thus, the end wall 3 may be perforate, or omitted, and the electrode provided in the form of an open-ended tube. The frusto-conical base 1 may be omitted, or replaced by another form of base, e.g. flanged. Inwardly and/or outwardly directed flanges may be provided at one or both ends of the tubular electrode body. The tube comprises a generally cylindrical copper casing 15 which constitutes the anode of the tube. Within this anode casing are disposed three coaxial electrodes, including an innermost cathode 16 surrounded by a control grid 17 surrounded by a screen grid 18, each of these electrodes being a closed-top tubular member. The three electrodes are extended at their lower ends by the tubular extensions 19, 20, 21 respectively, which are sealed in the base of the tube by means of ceramic insulator rings 23, 24, 25 and serve to connect the electrodes to an external circuit. A central conductor rod 26 serves to supply heating current to the cathode 16.

The arrangement just described is conventional, and the invention resides, as has been pointed out, in the provision of the helical slots 28, 29, 30 in the cylindrical sidewalls of the cathode 16, control grid 17 and screen grid 18 respectively. The slots in each electrode are arranged substantially as described with reference to FIG. 1. The slots 29 in control grid 17 are shown as registering with the solid strips between the slots 28 of the cathode 16, as earlier described in the specification. The slots 30 in screen grid 18 are here shown as positioned opposite the slots 29 of the control grid. Other relative arrangements may be used.

According to a further advantageous feature, the wall thickness of the electrode, rather than being uniform throughout its axial length as here shown, may taper down from the base to the free end of the electrode as shown exaggerated at the inner electrode 16 of FIG. 4, at 36; it is found that such a conformation substantially improves performance under conditions of shock and vibrations.

The improved electrode of the invention may be manufactured by any suitable methods, including mechanical machining, electro-erosion, and the like. According to

5

one particularly desirable method of manufacture, the following procedure is used.

Starting with a tubular blank 8 (see FIGS. 2 and 3), having the desired overall geometrical shape of the final electrode, and produced by stamping or otherwise, a rotary tool 9 is used, such as a small flat milling cutter or grinding wheel corresponding in thickness with the width of the slots to be cut. The tool 9 may be a grinding wheel comprising particles of Carborundum imbedded in a suitable resin. The tool 9 is supported for rotation on the spindle 10. A suitable jig, not shown, is provided whereby the spindle 10 is maintained normal to a radial line 12 extending through the centre axis 13 of the blank 8 in the transverse horizontal plane defining a mid-circumference 11 of the cylindrical body section of the blank 8, while the spindle 10 is simultaneously maintained at a predetermined angle to the axis 13. Indexing means are provided for imparting uniform steps of angular rotation to the blank 8 about its axis 13 and means for feeding the tool into the blank to a predetermined depth along the radial line 12 at each indexed position of the blank, and thereafter withdrawing the tool out of the blank along the same radial line prior to indexing the blank to its next position. The means for performing these operations are preferably automatic, and their construction lies easily within the capability of the average machine-tool engineer. Correcting means are preferably provided for automatically correcting the feed depth of the tool to compensate for wear of the tool during the machining process.

Using the above procedure, or an equivalent one, there is obtained the finished electrode structure previously described with reference to FIG. 1, wherein the cylindrical body of the electrode is cut with equally spaced slots each in the form of an arc of an ellipse, all the slots lying on planes forming equal angles to the corresponding generatrices of the cylinder, and each slot being symmetrical to opposite sides of its point of intersection with a mid-circumference such as 11 (in FIG. 2).

After the above machining operations have been completed, the slotted electrode may be subjected to a stabilizing heat treatment to remove any internal stresses in the material, such as heating at 1000° C. in the case of a molybdenum electrode, around a suitable supporting core.

While the main use of the improved electrode is its use as a non-emissive electrode such as a control grid or screen grid, in many cases a similar electrode can advantageously be used as an emissive electrode, especially a cathode, for an electron discharge tube. Such a cathode or other emissive electrode will possess a remarkably high dimensional and mechanical stability even after prolonged use. In one desirable embodiment of an improved electron discharge device according to the invention, the device embodies two or more tubular skew-slotted electrodes arranged coaxially with respect to one another, such as a cathode surrounded by a control grid possibly surrounded in turn by a screen grid. In such an assembly according to the invention, the solid parts or inter-slot strips of the cathode are preferably positioned approximately in register with the slots of the control grid, thereby minimizing grid current.

In connection with this aspect of the invention, two (or more) similar grid electrodes can be machined simultaneously by the process described with reference to FIGS. 2 and 3, in a single operation. The resulting grid electrodes then have their respective slots and inter-slot strips positioned angularly in register with one another, with generally acceptable accuracy especially in cases where the inclination angle of the slots to the generatrices is comparatively low. For the convenience of the reader "generatrix" can be defined as a straight line, whose motion generates a ruled surface. When the generatrix is real, cones, cylinders, hyperboloids and hyperbolic paraboloids can be generated. See "Inter-

6

national Dictionary of Physics and Electronics," D. Van Nostrand Company, "Surface Ruled" and "Generatrix."

We claim:

1. An electrode for an electron discharge device comprising a tubular cylindrical body having a plurality of separate, elongated slots formed through the wall of said body, said slots being inclined all in a common direction with respect to the generatrices of the cylindrical surface of the body over at least a major portion of their extent so as to have between said slots skew strips having a substantial free length without transverse bonds therebetween.

2. An electrode as claimed in claim 1, wherein said slots are inclined to said generatrices at an angle within the range of from about 10° to about 30°.

3. An electrode as claimed in claim 1, including an enlarged base portion integral with said body at one end thereof.

4. An electrode as claimed in claim 1, including an enlarged base integral with the body at one end thereof and a cross wall integral with the body at the other end thereof.

5. An electrode as claimed in claim 1, wherein the tubular body tapers down in wall thickness from a base end to a free end thereof.

6. An electrode as claimed in claim 1, which is made of graphite.

7. An electrode for an electron discharge device comprising a tubular cylindrical body having a plurality of separate elongated slots formed through the wall of the body, said slots being all inclined in a common direction with respect to generatrices of the cylindrical surface of said body, and slots being substantially in the form of arcs of ellipses defined by the intersection of said body with planes inclined to the axis thereof.

8. An electrode for an electron discharge device comprising a tubular cylindrical body, having elongated slots formed through the wall of the body, said slots being all inclined in a common direction with respect to generatrices of the cylindrical surface of said body, and said slots being substantially in the form of arcs of ellipses defined by the intersection of said body with a plurality of planes angularly equispaced around the axis of the body and forming a common angle with said axis in a common direction.

9. An electron discharge device having an enclosure and at least two coaxially disposed electrodes therein, each of said electrodes comprising a tubular cylindrical body having a plurality of separate, elongated slots formed through the wall of said body, and slots being inclined all in a common direction, with respect to the generatrices of the cylindrical body surface by an angle of at least about 10° and said slots having intervening skew strips having a substantial free length without transverse bonds therebetween.

10. An electron discharge device, having an enclosure, and at least one electrode in said enclosure, said electrode comprising a tubular cylindrical body having elongated slots formed through the wall of said body, said slots being all inclined in a common direction with respect to generatrices of the cylindrical surface of said body, and said slots being substantially in the form of angularly equispaced arcs of ellipses defined by the intersection of said body with planes inclined to the axis thereof.

11. The discharge device of claim 9, wherein said coaxially-disposed electrodes include a control grid and a screen grid electrode.

12. The discharge device of claim 9, wherein said coaxially-disposed electrodes form a cathode and a control grid, respectively, and the slots of one of said electrodes are substantially in registry with the inter-slot strips of the other.

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