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[54] **COMPACT DEPRESSED ELECTRON BEAM COLLECTOR**

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[73] Assignee: **Sperry Rand Corporation,** New York, N.Y.

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[21] Appl. No.: **173,053**

[52] **U.S. Cl.** **315/3.5,** 315/5.38, 313/18, 313/30, 313/46

[51] **Int. Cl.**.....**H01j 25/34**

[58] **Field of Search** 315/3.5, 5.38; 313/18, 30, 313/46

[56] **References Cited**

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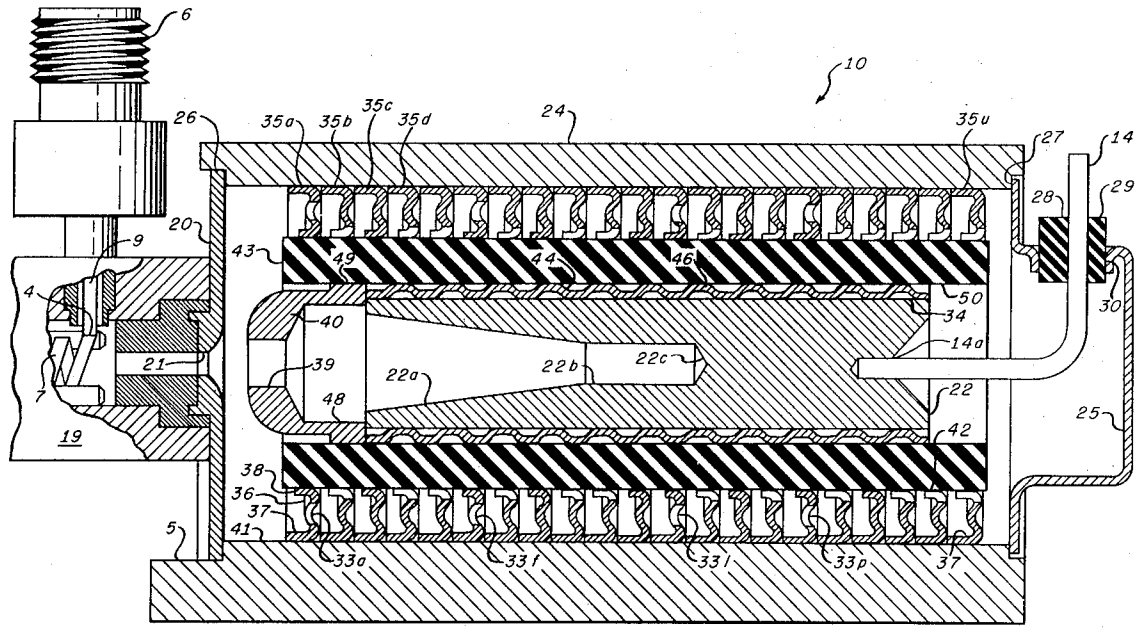
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[57] **ABSTRACT**

A rugged and compact electron beam collector structure for velocity modulation or other high power electron beam vacuum tubes is characterized by means for providing high electrical voltage insulation along a low thermal impedance heat flow path. The device employs a central beam collector as a core flexibly supported within a hollow cylindrical insulator in turn flexibly supported within a vacuum envelope.

9 Claims, 4 Drawing Figures



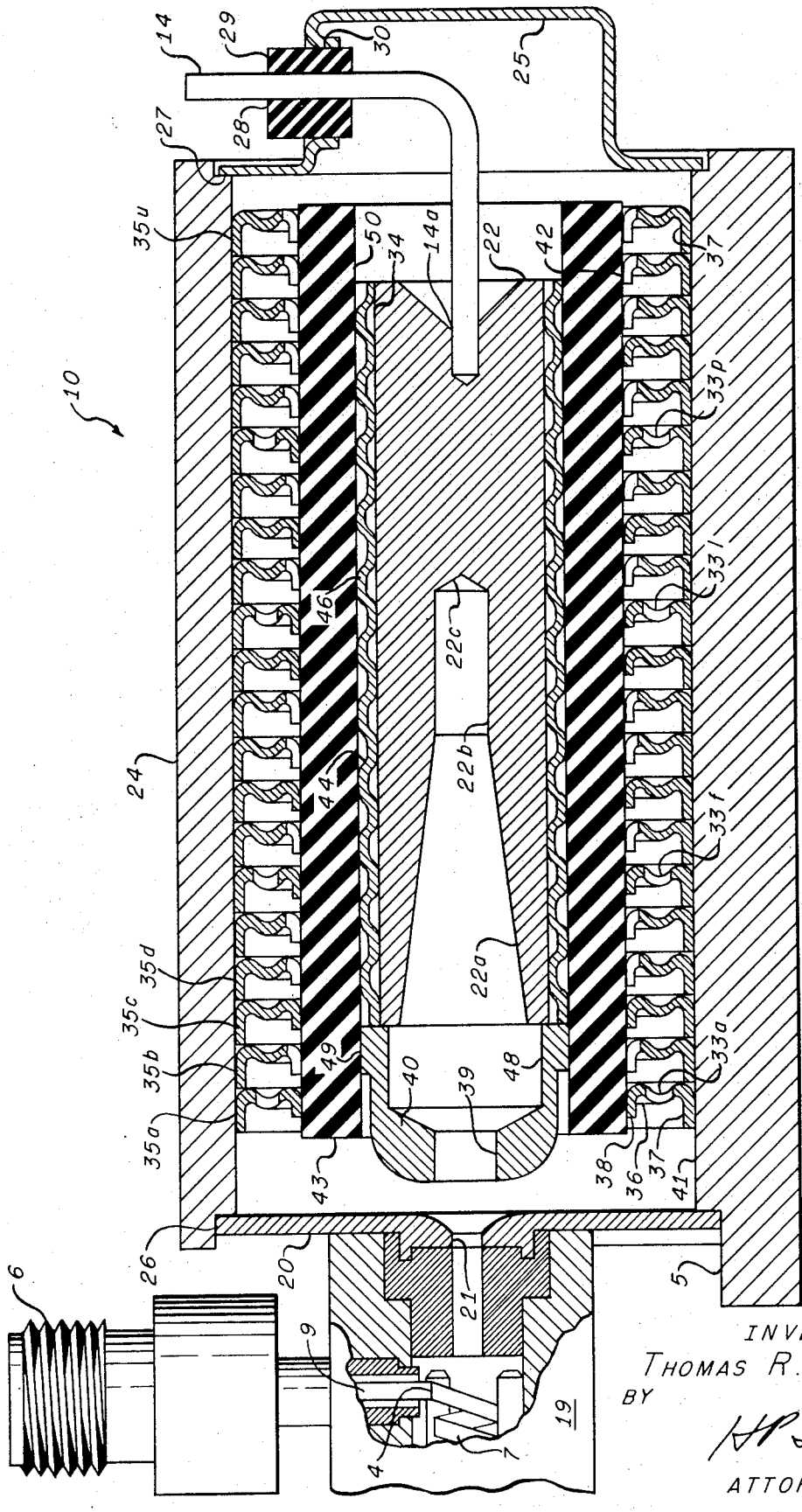


FIG. 1.

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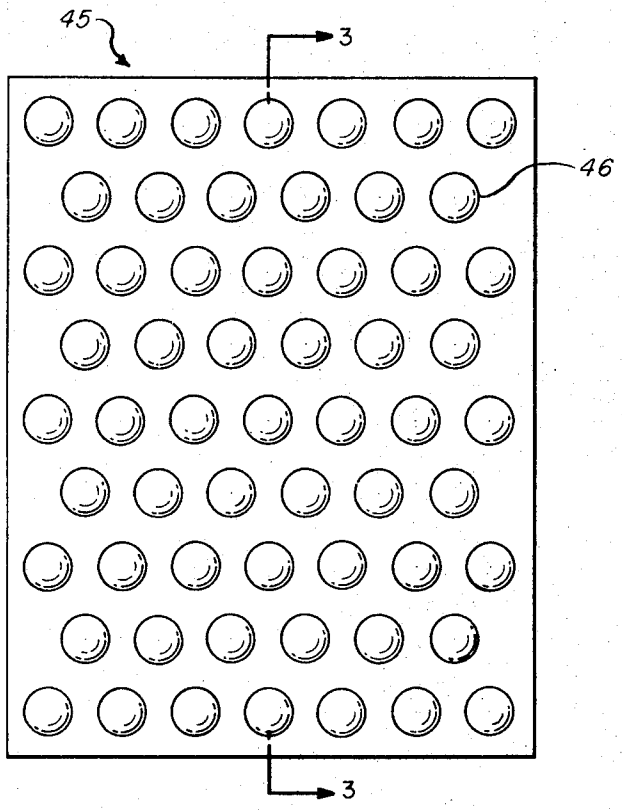


FIG. 2.

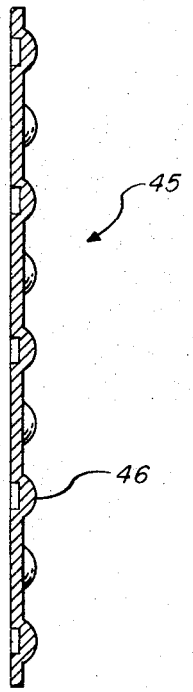


FIG. 3.

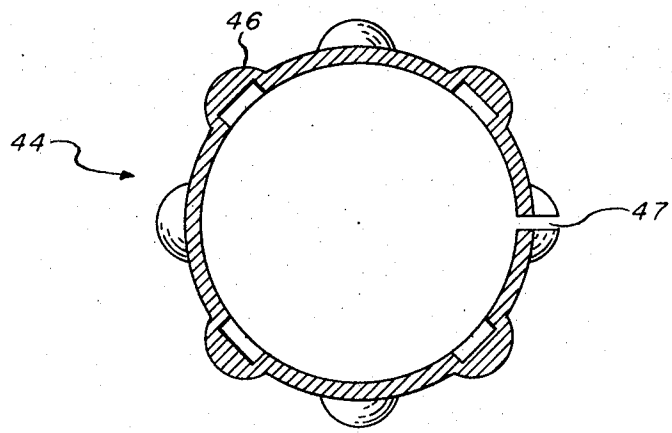


FIG. 4.

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COMPACT DEPRESSED ELECTRON BEAM COLLECTOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention pertains to means for improving the efficiency and life of operation of compact electron beam power tubes and more particularly concerns a rugged, thermal-shock-proof electron beam collector of compact design for operation at depressed potentials in a velocity modulation high frequency power vacuum tube.

2. Description of the Prior Art

Several types of high frequency power vacuum tubes employ electron beams having high density electron currents driven at high velocities, such as velocity modulation tubes of the traveling wave and klystron types. In these devices, production and acceleration of the electron beam occurs in a cathode-anode region. The electron beam then passes into a separate region in which its kinetic energy is used to amplify high frequency electromagnetic oscillations. In early designs of such tubes, the electron beam, still having quite high kinetic energy, passed on out of the high frequency interaction structure to be dissipated in a third region as heat in a collector electrode held at the same potential with respect to ground as the interaction structure. The power wasted as heat directly caused low efficiency of operation and made necessary the use of additional power for operating fluid cooling means to hold the temperature of the collector at a reasonable operation temperature level. The high velocity electrons striking such a collector interior often also generated intensive x-radiation, making heavy and expensive shielding a health protection necessity.

The over-all efficiency of such beam tubes may be considerably increased by the use of specially designed electron beam collectors operated at potentials considerably below the potential of the high frequency interaction structure. Such collectors are known as depressed collectors and permit improved use of the total kinetic energy of the electron beam. Also, with greatly reduced heating of the collector, considerably less power is lost for cooling the collector and simple air cooling systems may be used in place of complex liquid cooling systems. X-radiation is also reduced, permitting reduction in shielding against its destructive properties.

Depressed collectors have a number of generally conflicting and difficult requirements which have, in the past, made their construction in compact and inexpensive form hard to achieve. The large electrical potential difference between the high frequency interaction structure of the tube and the depressed collector requires provision of adequate high voltage insulation between the two elements. The structure must at the same time feature a low thermal impedance heat path from the core of the collector to an external heat sink. The metal and insulator parts of the collector system are subjected to high temperature-gradients and to high temperature-gradient rates of change or thermal shock. Repeated cycles from the zero to the operating thermal gradient state must be tolerated if the vacuum tube is to exhibit satisfactory operating characteristics over an acceptable life. Prior art designs for vacuum tubes with depressed collectors are notoriously prone to abrupt failures, during manufacture as well as in the field, because of the above-mentioned problems. Rupture of bonds between insulator and metal parts is a common occurrence because of thermal shock in operation or because of simple mechanical shock during handling of the tube.

SUMMARY OF THE INVENTION

The present invention is a rugged and compact electron beam collector electrode system of the depressed potential type for application in velocity modulation vacuum tubes, such as traveling wave tubes and klystrons, and in other beam power tubes for improvement in their operational life and efficiency. The invention is characterized by the presence of a collector electrode system operated at potentials below the potential of the electron tube high frequency interaction structure so that a significant portion of the kinetic energy remaining in the electron beam as it exits from the high frequency interaction region may be recovered, rather than lost as heat. The novel depressed electron beam collector electrode system is constructed of a flexible cylindrical element and an array of flexible metal elements bonded to a hollow cylindrical ceramic element in a manner providing reduced shear forces on ceramic-to-metal bonds and accordingly affording long-life operation of the vacuum tube assembly.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross section view of a preferred embodiment of the invention.

FIGS. 2 and 3 are respective plan and end views of a portion of the device of FIG. 1.

FIG. 4 is an end view of the structure of FIGS. 2 and 3 prepared for insertion in the structure of FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 illustrates the novel depressed potential electron beam collector in use in a representative helix traveling wave tube of the general type illustrated in the J. L. Rawls patent application Ser. No. 54,943 for a "-Depressed Electron Beam Collector," filed July 15, 1970, issued May 9, 1972 as patent 3,662,212, and assigned to the Sperry Rand Corporation. While FIG. 1 therefore represents a particular application of the invention, it will be recognized by those skilled in the art that other known high frequency, slow wave propagation elements may be substituted for the helix high frequency interaction circuit shown in FIG. 1. Further, it is to be recognized that other types of high frequency interaction circuits may be substituted for the helix, including the cavity resonator systems characteristic of the klystron, such alternative arrangements being illustrated, for example, in U.S. Pat. No. 3,172,004, entitled "Depressed Collector Operation of Electron Beam Device," issued Mar. 2, 1965 to R. J. Von Gutfeld and C. C. Wang and assigned to the Sperry Rand Corporation.

In the apparatus of FIG. 1, it is understood that a conventional electron emitting cathode is held at a negative potential with respect to ground by a suitable cathode supply source. Consequently, a lineal electron beam of circularly symmetric character is projected

through an aperture in a grounded anode and then flows in conventional energy exchanging relation through a grounded high frequency energy exchanging circuit device or helix **7** having respective input and output terminals of which only output coaxial line terminal **6** is shown. Amplified high frequency energy is coupled from helix **7** at junction **4** to the inner conductor **9** of output coaxial terminal **6**. Electrons passing out of helix **7**, after exchanging energy with the traveling high frequency fields within helix **7**, are collected by electron beam-collector electrode **10**. Such is accomplished with the collecting electrode **22** of collector **10** at a potential considerably depressed with respect to the ground potential of helix **7** by virtue of a conventional collector potential source (not shown) one side of which may be connected via lead **14** to collector **10** in the conventional manner.

As an example of operating potentials applied for operation of a traveling wave tube embodying the novel electron beam collector, the cathode may be operated at about −9,000 volts, the anode and helix **7** at ground potential, and the collector electrode **22** at about −4,500 volts. The cited electrical potential values are to be taken merely as representative examples and are not necessarily intended to describe limiting or optimum values for operation of a traveling wave, klystron, or other beam power tube according to the invention.

FIG. **1** represents a preferred embodiment of the invention in which the apertured diaphragm **20** may be spoken of as lying in a plane between old and new parts of a traveling wave amplifier tube embodying the invention. As is generally illustrated in the above mentioned Von Gutfeld et al Pat. No. 3,172,004, diaphragm **20** and parts to the left of diaphragm **20** such as vacuum envelope **19** are conventional parts to be recognized as being assembled in the manner that they are customarily assembled in prior art traveling wave amplifiers. Parts to the right of diaphragm **20** make up the novel depressed collector structure of the present invention. It is to be observed that aperture **21** of diaphragm **20** is aligned with the axis of the electron beam and that the electron beam, after having interacted with high frequency fields such as those within helix **7** passes through aperture **21** of FIG. **1** into collector **10**.

The electron beam is actually stopped or collected by the generally symmetric interior walls of hollow electron beam-collector core **22**, these inner walls being provided by cooperating axially aligned and axially extending interior sections forming wall portions **22***a* and **22***b*. The core **22** may be made of a material such as annealed oxygen-free copper. Wall portion **22***a* is in the form of a frustrum of a cone. It is joined at its small diameter end to a circularly cylindric wall portion **22***b*. Wall portion **22***b* is then joined to a conical end wall **22***c*.

The collected electron beam current may be drawn from hollow core **22** via lead wire **14** which may also be comprised of copper and may be fastened by any of several known suitable means at junction **14a** to the outer end of core **22**. The collected current, as suggested previously, may be drawn off at a voltage which is negative with respect to the voltage on helix **7** and which is typically **40** to **60** per cent of the voltage supplied to the beam forming cathode.

The progressively decreasing size of axially extending interior walls **22***a* and **22***b* permits each wall section to collect substantially the same fraction of the total electron beam current. Thus, the portions of the total remaining kinetic energy of the electron beam converted to heat at wall sections **22***a*, **22***b*, and **22***c* may be substantially equal. As a consequence, such heat is relatively evenly distributed along the length of core **22**.

Core **22** is supported within an outer jacket or generally cylindrical vacuum envelope **24**, which may be supplied with a base **5** adapted for use as a heat sink, and which may also be constructed of a metal such as oxygen-free copper. One end of wall **24** is closed by the diaphragm **20** sealed at its periphery to wall **24**, for example, by a circular brazed junction **26**.

A drawn cup-shaped metal end wall or cap **25** is fastened at the opposite end of vacuum envelope **24** by a circular brazed vacuum tight junction **27**. End wall or cap **25** is of sufficient volume to accommodate collector lead **14**, which is formed with a right angle bead and projects out of the interior of cap **25** through insulator **29**. Insulator **29** may be formed of any of several available ceramic materials having good high voltage insulation properties and adapted to form a vacuum tight seal with the metal of cap **25** at circular junction **30**. Lead wire **14** is similarly sealed within a hole in insulator **29** at surface **28**. Although other materials may be used, certain nickel-iron-chromium alloys have been found to be useful for cap **25**, since they are capable of being generated by pressure drawing and since they readily form vacuum tight seals with certain ceramic materials.

From the foregoing, it is apparent that outer wall **24**, cap **25**, and insulator **29** complete the vacuum envelope means of the high frequency tube structure embodying the invention. Wall **24** has additional significant functions, in that it cooperates in the support of core **22** by means providing high electrical voltage insulation along radial, low thermal impedance, heat flow paths from core **22** to wall **24**, as will be described. For dissipating such heat, the vacuum wall **24** may as previously noted be supplied with an enlarged flat or otherwise shaped portion **5** capable of being mounted on a suitable heat sink. It is clear that alternative external heat sink arrangements may readily be applied by those skilled in the art. It will also be seen that vacuum jacket or wall **24** is arranged in an advantageous manner so that substantially all parts of the collector system are within its interior and therefore are not accessible, reducing the possibility of injury to persons by electrical shock and of mechanical damage to the collector parts.

Heat from collector core **22** is conducted directly in a plurality of radial paths from the outer cylindrical surface **34** of core **22** by a regular series of annular, flexible, and generally radial support elements **35***a*, **35***b*, **35***c*, **35***d*, . . . , **35***u*. Each such oxygen-free copper support element comprises, as in the instance of support element **35***a*, an annular reentrant flexible portion **36**, a first or outer annular ring shaped portion **37**, and a second or inner ring shaped portion **38** substantially parallel to outer ring **37**. Each such successive flexible portion **36** is supplied with holes, of which only holes **33***a*, **33***f*, **33***l*, and **33***p* are seen in FIG. **1**. Other similar annular support elements, such as element **35***b*, are equipped with similar holes which may lie in planes

other than the plane of the drawing and are therefore not seen in FIG. 1. The array of holes including holes 33*a*, 33*f*, 33*l*, 33*p*, and others not seen in FIG. 1 permits passage of gas from the interior of the collector structure 10, such as gas from the interior of end cap 25, when the electron tube interior is being evacuated.

Each annular support element, such as annular support element 35*a*, has respective parallel outer surfaces associated with the respective ring portions 37 and 38 for the purpose of permitting bonded seals to be made thereto. For example, the outer surface of outer ring shaped portion 37 is sealed to the inner cylindrical surface 41 of vacuum envelope 24. Similarly, the outer surface of each successive ring shaped portion 38 of all of the flexible support elements, including, for example, support element 35*u*, is sealed to the outer cylindrical surface 42 of insulator 22. Thus, an array of annular flexible support elements 35*a* to 35*u* is formed, each element being solidly affixed to cylindrical wall 41, and each element affording an outward and radial heat flow path. The several seals between flexible supports 35*a* to 35*u* and wall 41 may be made by conventional brazing methods using a gold-copper solder alloy.

The outer surface of the inner ring shaped portion 38 of annular support 35*a* is sealed to the cylindrical outer surface 42 of a relatively thick-walled hollow tube 43 of electrically insulating, thermally conducting nature, preferably fabricated of a material such as beryllium oxide. Similarly, the outer surface of each successive outer ring shaped portion 37 of all of the flexible support elements, including for example support element 35*u*, is sealed to the inner surface 41 of the outer vacuum jacket 24. Thus, an array of flexible support elements 35*a* to 35*u* is solidly affixed to the electrically insulating cylindrical wall 42 in radially outward heat transfer relation. The several seals made to the flexible supports 35*a* to 35*u* may be made by conventional methods, such as by the use of a gold-copper solder or brazing alloy.

The electrically insulating and radially heat conducting structure of the novel electron beam collector system is further completed by a thin and generally symmetric tubular sleeve structure 44 resiliently affixed between the outer surface 34 of the collector core 22 and the inner cylindrical surface 50 of the thermally conducting, electrical insulator tube 43. As seen in FIGS. 2 and 3, the resilient sleeve 44 is fabricated from a thin oxygen-free copper sheet 45. It may be made in any of several conventional ways, such as illustrated in FIGS. 2 to 4, wherein FIG. 2 represents a flat sheet 45 of oxygen-free copper material in which an array of dimples has been pressed in a conventional manner by a standard material press or roller operation. Each dimple, such as dimple 46 in FIGS. 2 to 4, is one dimple of a substantially regular array of dimples, which array may take any of several convenient geometric forms. In any event, the dimpling tool is preferably operated from one side of the suitably supported sheet 45 so that the material in the vicinity of each contacting punch face is moved out of the normal plane of sheet 45 to form the raised or extruded dimples 46, for example. After dimples 46 are formed in the flat sheet 45, sheet 45 may be rolled into the shape of a cylindrical tube about a suitable mandrel to form the hollow tube 44 shown in FIG. 4. The tube 44 may be left with an unclosed gap 47, if desired, so as to permit its ready insertion into insulating tube 43.

In construction of the novel electron beam collector, tube 44 is inserted between the collector core 22 and the beryllium oxide tube 43 is affixed in place by a conventional furnace brazing process using, for instance, a conventional gold-copper brazing or solder alloy. In considering the dimensions selected for the illustration of sleeve 44 in FIGS. 1 to 4, it will be appreciated that the proportions shown are shown merely for convenience in making the several drawings clear; for example, only FIGS. 2 and 3 are substantially to the same scale and none of the figures necessarily presents dimensions which would be used in actual practice. It will be understood that the brazing of tube 44 between collector core 22 and the beryllium oxide tube 43 may be accomplished, as is often the practice, at the same time that brazed joints between other similarly constructed seals are made. As is seen from FIGS. 1 and 2, the dimples 46 may be arranged in offset array fashion such that gases in the volume between tubular insulator shell 43 and the collector core 22 are readily exhausted during evacuation of the collector prior to sealing off the tube.

The support of collector core 22 within insulator tube 43 is further completed adjacent electron beam aperture 21 by a shaped collector core electron beam entrance element 40 having an electron entrance aperture 39 shaped and spaced relative to aperture 21 so as to permit entrance of the expanding electron beam into the interior of core 22. For this purpose, it is seen that the diameter of aperture 39 may be correspondingly greater than the diameter of aperture 21. Element 40 may be constructed of oxygen-free copper and has an annular expanded region 48 with a ring surface 49 adapted to be brazed or soldered to the inner surface of insulator tube 43.

The composite depressed collector device is seen to have several significant characteristics. Its compact construction provides fully adequate electrical insulation of parts at high electrical potential from ground potential and at the same time features a low thermal impedance path for heat flow to an external thermal sink. Problems with excessive relative differential thermal expansion of ceramic and metal parts are significantly reduced.

A primary beneficial feature of the invention lies in the presence of flexibility or relative freedom of movement of the parts of the compact assembly. For example, when the electron collector is cold, all collector parts are at substantially the same temperature. When beam power is turned on, the electron collector core 22 heats more rapidly than its surroundings and increases in both radial and axial dimensions. The outwardly extending arrays of flexible support elements 35*a*, 35*b*, . . . , 35*u* are made of a soft flexible material, easily flexed, thus allowing many repeated cycles of such dimensional changes without placing destructive shearing stresses on the ceramic-to-metal bonds. In a similar manner, the dimpled shell 44 adjacent the electron beam collector core 22 is readily flexed as temperatures and temperature gradients rapidly change, again allowing many repeated heating and cooling cycles of the beam collector system without fear of damage to ceramic-to-metal seals.

The compact collector configuration is such as to permit maximum axial translation of the collector core **22** with respect to the envelope **24**, for instance, and also substantially to convert the tendency toward radial expansion of the assembly into axial expansion, thus further reducing shear stresses on ceramic-to-metal bonds. Among other advantageous features of the compact collector structure, such as relative freedom from exposure of personnel to high voltage parts, is the feature that all surfaces of the insulator tube **22** are protected from exposure to moisture and dust. Similar features of the interior portions of the collector protect interior surfaces of the insulator **22** from degradation by deposition thereon of material evaporated or otherwise removed from the inner walls of core **22** by highly energetic electrons.

It is seen that the invention represents a significant improvement over the prior art, permitting realization of a rugged, compact, shock proof electron beam collector such as may be used for operation at depressed potentials. The rugged structure incorporates novel features assuring long life of an electron beam power tube under repeated cycles of operation without damage to cooperating metal and insulator parts of the collector and to bonds between those parts. Expansion effects are beneficially directed so that shear stresses on such metal-to-insulator bonds are significantly reduced, permitting long life of the vacuum tube structure even under severe operating conditions.

While the invention has been described in its preferred embodiment, it is to be understood that the words which have been used are words of description rather than of limitation and that changes within the purview of the appended claims may be made without departure from the true scope and spirit of the invention in its broader aspects.

I claim:

1. A linear electron beam device comprising:

electron beam forming means,

high frequency circuit means in energy exchanging relation with said electron beam,

hollow electron beam collector means spaced from said high frequency circuit means and having an axially extending interior surface means for collecting said electrons and an axially extending outer surface means,

vacuum envelope means supporting said electron beam forming means and said high frequency circuit means,

flexible support means for supporting said electron beam collector means in electrically insulated, thermally conducting relation within said vacuum envelope means comprising:

thin walled hollow metal tube means sealed to said axially extending outer surface means and having an array of radially extruded dimples raised above said axially extending outer surface means,

thick walled electrical insulating, thermally conducting tube means having axially extending inner and outer concentric surface means, said thick walled tube means axially extending inner surface means being sealed to said dimples, and

an array of annular flexible metal support means sealed to said axially extending outer surface means of said thick walled tube means,

said array being additionally sealed within said vacuum envelope means in heat exchanging relation therewith.

2. Apparatus as described in claim **1** wherein said electron beam collector means is coupled to electrical conductor means passing in insulated relation through said vacuum envelope means and adapted to be operated at a potential negative with respect to said high frequency circuit means and positive with respect to said electron beam forming means.

3. Apparatus as described in claim **1** wherein said annular flexible support means each comprise:

outer ring-shaped wall means having a first surface adapted for sealing to said vacuum envelope means,

inner-ring-shaped wall means substantially parallel to said outer ring-shaped wall means and having a second surface adapted for sealing to said thick walled tube means, and

annular reentrant flexible means forming a continuous link between said outer and inner ring-shaped wall means.

4. Apparatus as described in claim **3** wherein said annular reentrant flexible means are provided with apertures for permitting gas flow therethrough during manufacture of said electron beam device.

5. Apparatus as described in claim **4** wherein said collector means, said thin walled metal tube means, and said array are made of oxygen-free copper.

6. Apparatus as described in claim **5** wherein said thick walled tube means is made of beryllium oxide.

7. Apparatus as described in claim **4** wherein said dimples of said thin walled hollow metal tube means are arranged in a substantially regular array in mutually spaced relation for permitting gas flow therethrough during manufacture of said electron beam device.

8. Apparatus as described in claim **1** wherein said hollow electron beam collector means includes electron beam collector entrance aperture defining means sealed in abutting relation with said thin walled hollow metal tube means to said axially extending inner surface means of said thick walled tube means.

9. Apparatus as described in claim **8** wherein said entrance aperture defining means is made of oxygen-free copper.

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