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HIGH FREQUENCY ELECTRON DISCHARGE DEVICE
AND COOLING MEANS THEREFOR
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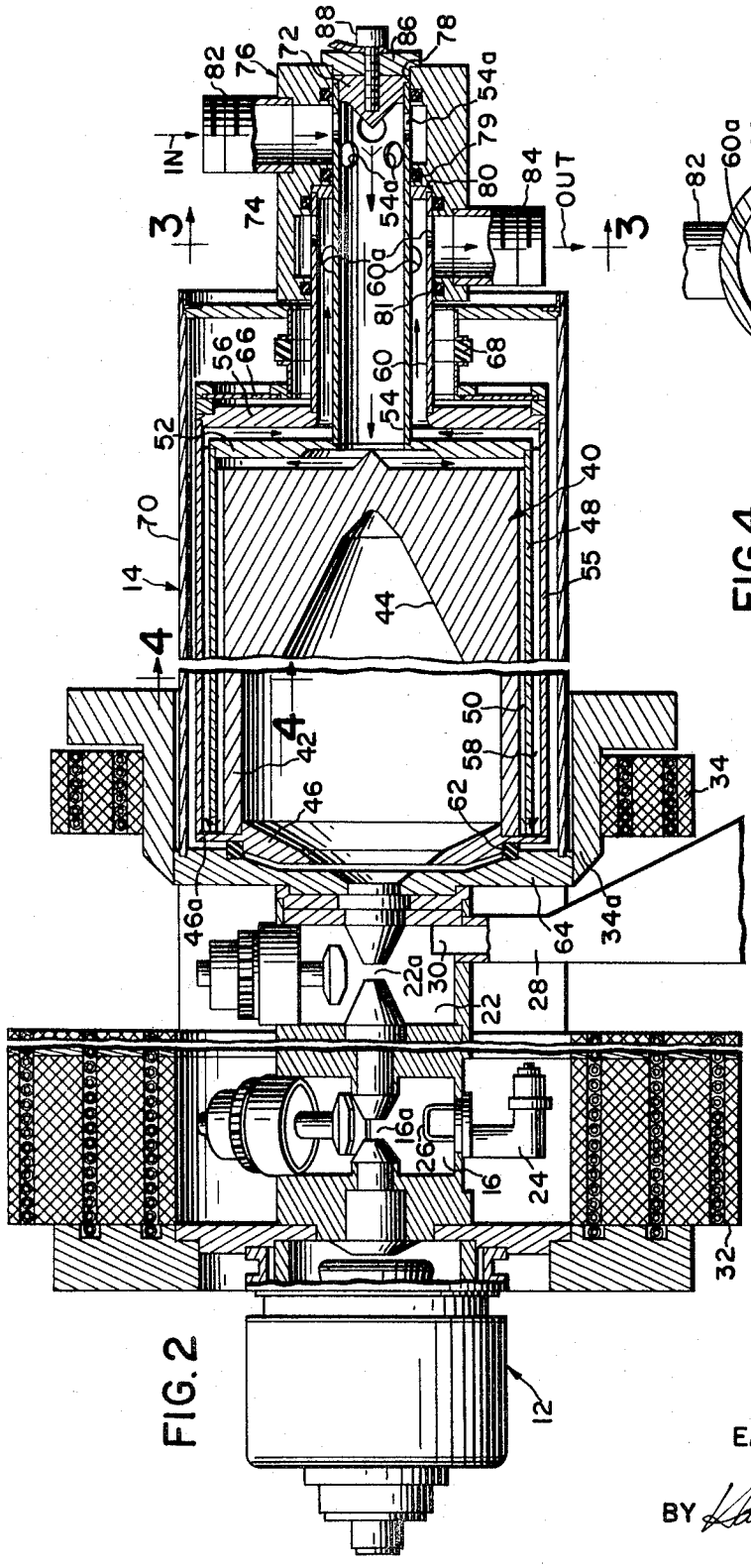


FIG. 2

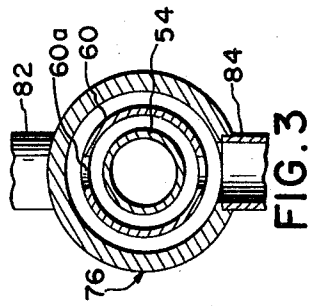


FIG. 3

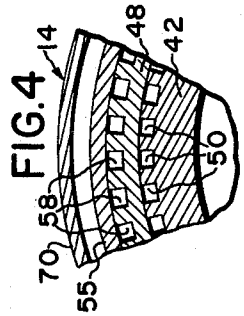


FIG. 4

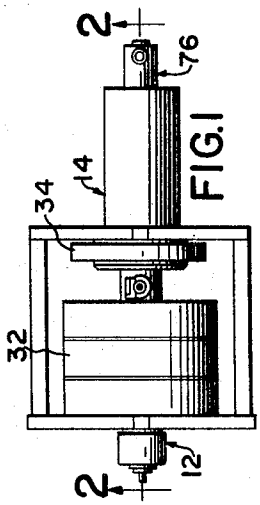


FIG. 1

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HIGH FREQUENCY ELECTRON DISCHARGE DEVICE AND COOLING MEANS THEREFOR

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The present invention relates generally to high frequency tubes and more particularly to improvements in klystrons, traveling wave tubes and other similar tube structures operable at relatively high frequencies for the generation or amplification of radio frequency energy via the mechanism of electromagnetic interaction between an electron beam and appropriately established radio frequency fields.

Extremely serious problems are encountered when attempts are made to design high frequency tubes of the designated type for operation at high power levels. As the output radio frequency power level increases, a corresponding increase in the beam power of the tube is requisite. In turn, the high powered electron beam is intercepted by various structural components of the tube wherefore substantial amounts of heat are generated, particularly under conditions of C.W. operation as opposed to intermittent or "pulsed" operation. By way of example, a multi-cavity klystron amplifier arranged for C.W. operation with a radio frequency power output of 100 kw. will require an electron beam power in the neighborhood of 300 kw. Such beam, after traversing the klystron cavities, is conventionally collected by a bucket-like collector structure in which a considerable amount of heat will be generated. One problem then is to provide adequate and efficient cooling of the collector.

In addition, heat will be similarly generated in the cavity-forming structures themselves to an extent determined by the amount of beam interception with such cavity structures. Normally, a magnetic solenoid or the like can be utilized to focus the beam to a pencil-like shape which traverses most of the cavities without appreciable interception. However, since the radio frequency power in the final or output cavity of the klystron is normally delivered therefrom through a laterally projecting output waveguide, constituting the preferable structure for handling radio frequency power at high levels, a physical requirement for termination of the solenoid at the waveguide exists and the beam, in turn, will spread not only as a result of existent space charge forces in the beam itself but also as a result of certain transverse forces exerted on the electrons of the beam by the existent radio frequency fields in the final or output klystron cavity. As a result, substantial heat is commonly generated in the output cavity of high power klystrons, the amount being sufficient to change the dimensions of the metallic structure forming the cavity to an extent such that detuning of the cavity and reduction in overall efficiency of the amplifier results.

Accordingly, it is a general object of the present invention to provide a high frequency tube which incorporates means arranged to control the generation of heat by a high power electron beam so that the tube is capable of operation at very high power levels.

A feature of the invention is the provision of a collector assembly for the electron beam including an extremely efficient coolant arrangement so that both the size of the collector and the amount of coolant requisite for tube operation are minimized.

More specifically, it is a feature of the invention to provide a collector assembly that incorporates a coolant arrangement maximizing the heat transfer between the collector walls and the coolant medium.

Additionally, it is a feature of the invention to provide a high frequency tube which incorporates a novel arrangement for connecting the supply of fluid coolant to the tube collector in a manner enabling maximum velocity and volume of coolant flow.

A related feature is the provision of such coolant-connecting means for a high frequency tube arranged to facilitate making or breaking of such connection and positional adjustment thereof.

Other features and advantages of the present invention will become apparent on a perusal of the following specification when taken in connection with the accompanying drawings wherein;

FIG. 1 is a longitudinal view showing a multi-cavity klystron amplifier embodying the present invention,

FIG. 2 is an enlarged, longitudinal, fragmentary sectional view taken along line 2—2 of FIG. 1, illustrating details of interior construction,

FIG. 3 is a transverse section view taken along line 3—3 of FIG. 2 and

FIG. 4 is an enlarged fragmentary transverse, sectional view taken along line 4—4 of FIG. 2.

With initial reference to FIG. 1, the klystron amplifier generally includes an elongated tubular metallic envelope arranged to maintain vacuum conditions therewithin. At one end, an electron gun assembly **12** is mounted and arranged to generate and direct a beam of electrons lengthwise through the entire tubular structure to a collector assembly **14** at its remote extremity. In its transit, the beam traverses sequentially four tunable cavity resonators, two of which are indicated at **16**, **22**, each arranged with re-entrant drift tube portions defining cavity gaps **16***a*, **22***a*, which support standing-wave radio frequency fields in interacting relationship with the beam.

The radio frequency energy to be amplified is delivered to the first cavity resonator **16** through a coaxial line **24** and an input coupling loop **26**, and after amplification, the output radio frequency energy is transmitted from the final output cavity **22** through a conventional waveguide **28** which is connected to the final cavity resonator through a suitable coupling iris **30** and projects laterally therefrom. Briefly, the well known amplification mechanism includes an initial velocity modulation of the electron beam by the input radio frequency energy by way of coupling at the first cavity gap **16***a*. As the beam travels, a bunching or current density modulation results, the effect being further enhanced as the electrons traverse the second and third cavity gaps. The tightly bunched beam of electrons subsequently excites radio frequency fields in the final or output cavity resonator **22** which energy is then delivered through the output waveguide **28** to a suitable load (not shown). Further details of the described structure and its operation are not presented since they are not germane to the present invention and alternate known electron gun and/or interaction structures can be substituted therefor.

The electron beam during its transit has a tendency to spread both as a result of space charge forces existent within the beam itself and also as a result of force components established within the resonator cavities, such forces attaining considerable magnitude in the final or output cavity resonator **22** where a high radio frequency power level has been developed through the described amplification mechanism. In order to maintain the beam in a confined pencil-like trajectory during its transit of the cavity resonators, a beam focusing solenoid **32** of generally tubular configuration surrounds the interaction region of the tube, terminating at one end adjacent the electron gun assembly **12** and at the other end adjacent the laterally projecting output waveguide **28**. If the

focusing effect of such single solenoid is considered by itself, substantially a constant magnetic focusing field can be established through the first three cavity resonators of the klystron amplifier but since the solenoid **32** terminates adjacent the output waveguide **28**, fringing fields would exist in the final or fourth cavity resonator **22** and the focusing effect will thus diminish considerably and allow substantial interception of the electrons with the cavity forming structure.

An auxiliary coil **34**, as most clearly illustrated in FIG. 2 encompasses the entrance end of the aforementioned collector assembly **14** so as to be positioned on the longitudinally opposite side of the output waveguide **28** from the described solenoid **32**. More particularly, this auxiliary coil **34** surrounds a pole piece **34***a* integrated with the magnetic circuit of the main solenoid **32** and functions conjointly therewith so that ultimately a constant magnetic field exists across the entire magnetic gap, which with the addition of the auxiliary coil **34**, encompasses all of the cavity resonators. Thus, defocusing of the electron beam in the fourth cavity resonator **22** is avoided.

Both the solenoid **28** and the auxiliary coil **34** are designed and constructed in accordance with known techniques wherefore details of such construction need not be spelled out. However, in such design and construction, it is preferred that the auxiliary coil **34** be designed with a number of turns such that the requisite magnetic field is obtained with a current flow identical to that in the main solenoid **32** wherefore a single magnet power supply (not shown) can be used and the electrical circuit can constitute a series connection. Additionally, both the main solenoid **32** and the auxiliary coil **34** can be supplied with coolant from an identical source (not shown). Thus, the necessity for additional complexity in both the coolant supply and the power supply for the magnetic focusing structures is obviated.

The described beam focusing arrangement provides for a high percentage of beam transmission to the collector assembly **14** which is arranged to provide for highly efficient dissipation of the heat generated during beam collection. The aforementioned beam focusing arrangement is claimed in copending U.S. patent application, Serial No. 308,880 entitled "High Frequency Electron Discharge Device and Focusing Means Therefor" by Earl W. McCune and Louis T. Zitelli, filed Sept. 13, 1963, since abandoned in favor of continuation-in-part application U.S. Serial No. 327,369 filed Dec. 2, 1963, and assigned to the same assignee as the present invention. As best shown in FIGS. 2 and 3, the collector assembly **14** is mounted in axial alignment with the remainder of the klystron amplifier and includes a collector bucket **40** composed of a hollow cylindrical tube **42** closed at its remote base end by an internally tapered cup **44**, both elements being formed from a good thermal conducting material, such as copper. Additionally, the collector bucket **40** preferably includes, adjacent its open entrance end, an inwardly directed annular flange **46** which serves to minimize re-entry of secondary emission electrons from the collector bucket back into the interaction region of the tube.

The exterior surface of the hollow cylindrical collector tube **42** is milled to form a plurality of longitudinally extending, circumferentially spaced slots which are covered by a cylindrical copper partition **48** which is mounted in tightly pressed engagement over the slotted collector tube to thus form coolant channels **50**. At its one end, the cylindrical partition **48** is secured to the perimetral edge of an annular flange **52** spaced from the base of the collector bucket **40** as formed by the described cup **44**, the inner edge of the flange **52**, in turn, being secured to the extremity of a smaller cylindrical tube **54** that is axially aligned with the collector bucket **40** and is arranged to deliver coolant to the channels **50**, as will be explained in detail hereinafter.

At its other extremity, the cylindrical copper partition **48** terminates a short distance from an outwardly projecting portion **46***a* of the previously described annular flange **46** at the entrance end of the collector bucket **40**. In a manner somewhat similar to that of the cylindrical collector tube **42** itself, the cylindrical partition **48** is milled on its exterior surface to provide a plurality of longitudinally extending and circumferentially spaced slots and is tightly encompassed by a copper sleeve **55** which is secured at its opposite extremities respectively to the exterior edge of the annular flange **46***a* at the entrance end of the collector bucket **40** and to another annular flange **56** that is slightly spaced from the partition supporting flange **52**, thus forming return coolant channels **58**. The inner edge of this sleeve supporting flange **56** is internally secured to a tube **60** concentrically mounted about the described inlet tube **54** for coolant so as to provide an annular outlet passage for the coolant received from the return channels **58**. As illustrated by the arrows in FIG. 2, coolant, preferably in the form of distilled water supplied from the inner tube **54**, first moves radially outward adjacent the base of the collector bucket **40**, thence longitudinally through the channels **50** exterior to the collector tube **42** and thereafter through the return channels **58** and into the annular outlet passage in tube **60**.

It is to be expressly observed that the coolant flowing through the channels **50**, **58** in both directions is encompassed by copper elements all of which are in direct metallic contact with the collector tube **42** itself, as best shown in FIG. 4. Since it is well established that the greatest impediment to efficient heat transfer exists at an interface between liquid and solid surfaces, the described arrangement wherein only one such interface exists between all coolant channels and the meal (i.e. the collector tube **42**) from which heat is to be extracted, the efficiency of heat transfer is optimized.

At its entrance end, the collector assembly **14** is held in spaced, thermally and electrically isolated relation from the remainder of the tube by a ceramic ring **62** positioned between the collector flange **46** and a collector mounting flange **64** disposed adjacent the final cavity resonator **22**. At its remote end, the described collector bucket **40** and coolant structure is provided with an axially flexible connection, generally indicated at **66**, and which incorporates another ceramic ring **68**, for mounting to an encompassing cylindrical shield **70** which surrounds the entire collector structure and is brazed or otherwise secured to the exterior of the mounting flange **64** at the terminal end of the interaction region of the tube.

The flexible connection **66** allows axial motion which results because of the difference in thermal expansion between the copper collector and the steel shell **70**. The flexible connection does not allow radial motion and therefore, keeps the collector located concentrically within the steel shell **70**. The shell **70** is made of steel to provide a strong vacuum envelope and also to shield the collector region from undesirable magnetic fields. X-ray radiation is effectively stopped by the copper collector. Any small amount of radiation emanating from the copper collector would be further attenuated by the steel shell.

To facilitate ingress and egress of coolant to and from the collector assembly **14**, the mentioned inlet tube **54** projects beyond the encompassing outlet tube **60** and both tubes are provided with circular openings **54***a*, **60***a* in their side walls adjacent their extremities which are closed respectively by a circular cap **72** and an annular cap **74**. The stepped projecting tubular structure defined by the tubes **54**, **60** constitutes the male member arranged for pressed connection into the female stepped receptacle formed in a dual coolant manifold **76**. Such manifold **76** constitutes a generally cylindrical structure having a smaller bore **78** extending substantially half-way therethrough and arranged to encompass the projecting smaller inlet tube **54** and a larger bore **80** extending through the other half thereof and appropriately dimensioned to encompass the terminal portion of the larger foreshortened outlet tube **60**. Each of the bores **78**, **80** are centrally

enlarged at a position such that the respective openings **54***a*, **60***a* in the wall of the inlet and outlet tubes are encompassed to establish liquid communication through inlet and outlet stubs **82**, **84** which are arranged for appropriate connection to the coolant supply lines (not shown). To avoid leakage, circular O-rings **79**, **81** are supported in sealing relationship between the bores **78**, **80** and the encompassed tubes **54**, **60** on opposite sides of both the inlet and outlet openings **54***a*, **60***a*.

As can be readily visualized, the dual manifold **76** as illustrated, can be simply pressed over the projecting tubes **54**, **60** to establish connection to the coolant supply. Furthermore, the entire manifold **76** can be rotated about the axis defined by the tubes **54**, **60** to facilitate positional arrangement of the coolant connections. Once assembled, the manifold **76** can be held in position on the tubes by a washer **86** that is held in engagement with the manifold by a thumb bolt **88** arranged for threaded connection into the end cap **72** on the central tube **54**. In view of the fact that all coolant pressures existent within the manifold **76** and the associated inlet and outlet tubes **54**, **60** for the coolant are exerted radially, substantially no pressure tending to unseat the manifold **76** from its support on the tubes will exist.

By the way of example, a klystron amplifier substantially as illustrated and having an overall length of substantially three feet has been successfully operated at a frequency of approximately two gigacycles with a C.W. radio frequency output power of 100 kw. and a beam power of 300 kw. The described collector assembly **14** has effectively handled the heat generated under such continuous wave operation with a coolant flow of approximately 40 gal./min. The described focusing arrangement, supplying a magnetic field of approximately 2000 gauss, has substantially eliminated beam interception within the cavities, such result being clearly demonstrated by the fact that no observable differences in cavity dimensions between operation at 80 kw. and 100 kw. were found.

While the focusing and beam collection arrangement have been specifically described relative to a klystron amplifier wherein standing waves exist within resonant cavities, it will be apparent that the same heating problems would be encountered in traveling wave structures, such as for example, a disc loaded waveguide involving traveling wave interaction at high power levels.

Since many changes can 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. A high frequency tube which comprises an elongated, evacuated tubular envelope, means at one end of said envelope for producing and directing a beam of charged particles longitudinally through said envelope, means for establishing high frequency fields in interacting relation with said particle beam, a beam collecting bucket at the remote end of said envelope arranged to receive and collect the charged particles, means forming coolant channels for conducting fluid coolant in heat transferring relation with the exterior surface of said beam collecting bucket, a first coolant tube arranged to establish fluid communication with the ends of said channels at one end and having a lateral opening adjacent its remote end, a second foreshortened coolant tube surrounding the closed portion of said first coolant tube to form an annular passageway in communication with the remote ends of said channels and having a lateral opening therein, and means including a coolant manifold arranged to sealingly encompass both of said tubes for establishing flow of coolant through said tubes and said channels, said manifold being axially and circumferentially movable on said coolant tubes by being sealingly engaged to said cooling tubes via a plurality of axially spaced O-rings, said channel forming means including an exteriorly slotted partition closely encompassing said beam collecting bucket, said bucket being exteriorly slotted whereby reception of said partition thereover forms first coolant channels, a sleeve closely encompassing said slotted partition to form second coolant channels, said channels being in communication adjacent one end of said beam collecting bucket.

2. A high frequency electron discharge device including beam forming and projecting means disposed at the upstream end portion of said device and beam collector means disposed at the downstream end portion of said device, said beam collector means including a generally tubular collector bucket for receiving the electron beam, said collector bucket having a pair of coaxially disposed metal sleeves disposed thereabout and conductively interconnected to said collector bucket along the mutual axially coextensive portions thereof, said pair of sleeves forming bidirectional fluid flow passageways about the axial extent of said collector bucket, a pair of axially spaced ring members disposed at the downstream end portion of said collector bucket, said ring members being physically coupled at their exterior peripheral surfaces to the said coaxially disposed pair of sleeves at their respective downstream end portions to thereby form bidirectional fluid flow passageways having lateral flow directions with respect to the central axis of said collector bucket, a pair of radially spaced coaxial coolant tubes coupled to the respective internal diameters of said ring members to thereby form a pair of axially bidirectional fluid flow passageways coupled to said lateral bidirectional fluid flow passageways, each of said coolant tubes being provided with a plurality of circumferentially spaced apertures at axially offset regions with respect to each other, coolant manifold means disposed about said pair of coaxially disposed coolant tubes and forming a fluid tight seal thereabout, said manifold being fluid coupled to said respective coolant tubes via said plurality of circumferentially spaced apertures such that radial bidirectional fluid flow occurs therebetween.

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