July 18, 1967 S. E. ALLEN, JR 3,331,984

MAGNETIC FIELD SHAPING CYLINDER FOR CONFINED FLOW ELECTRON GUNS

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FIG. 1

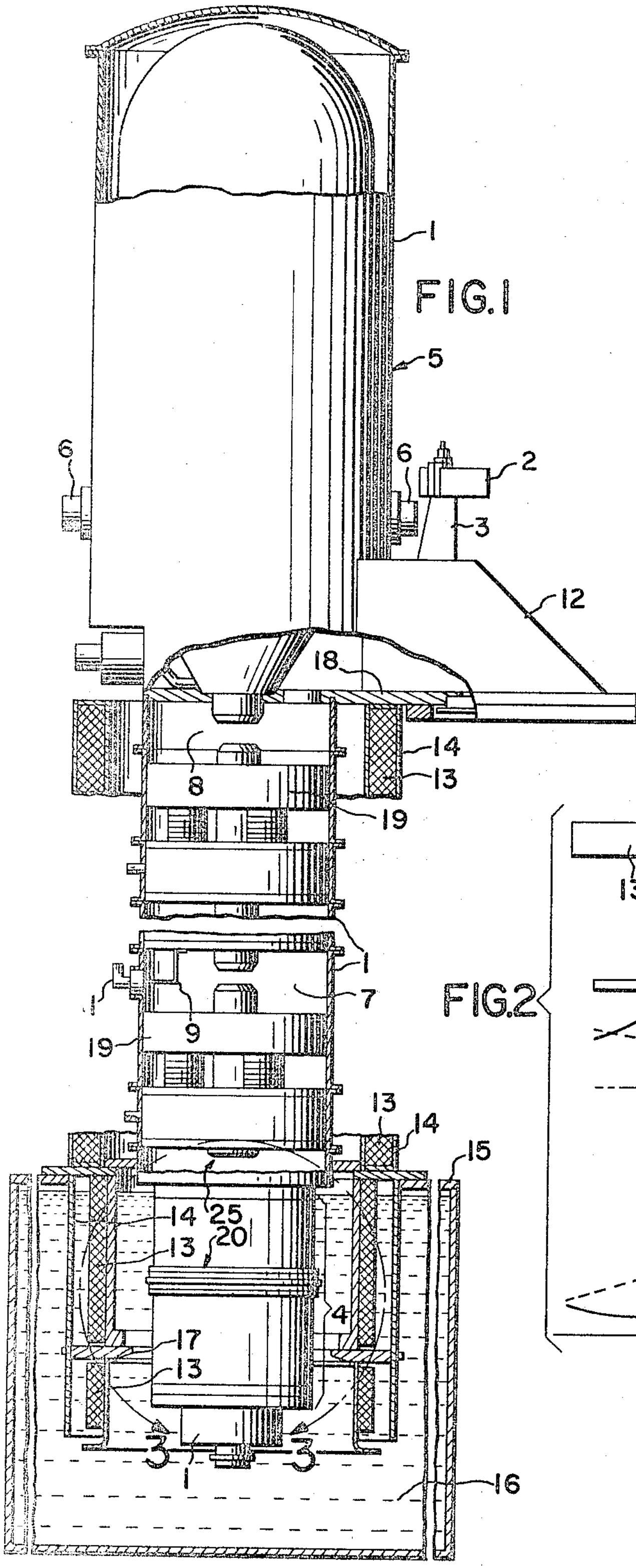
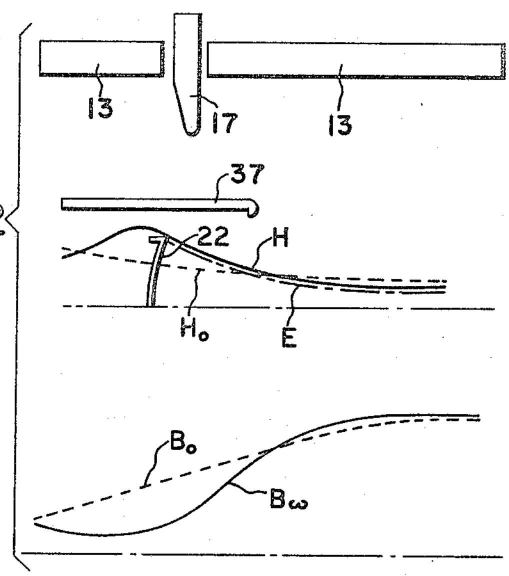


FIG. 2



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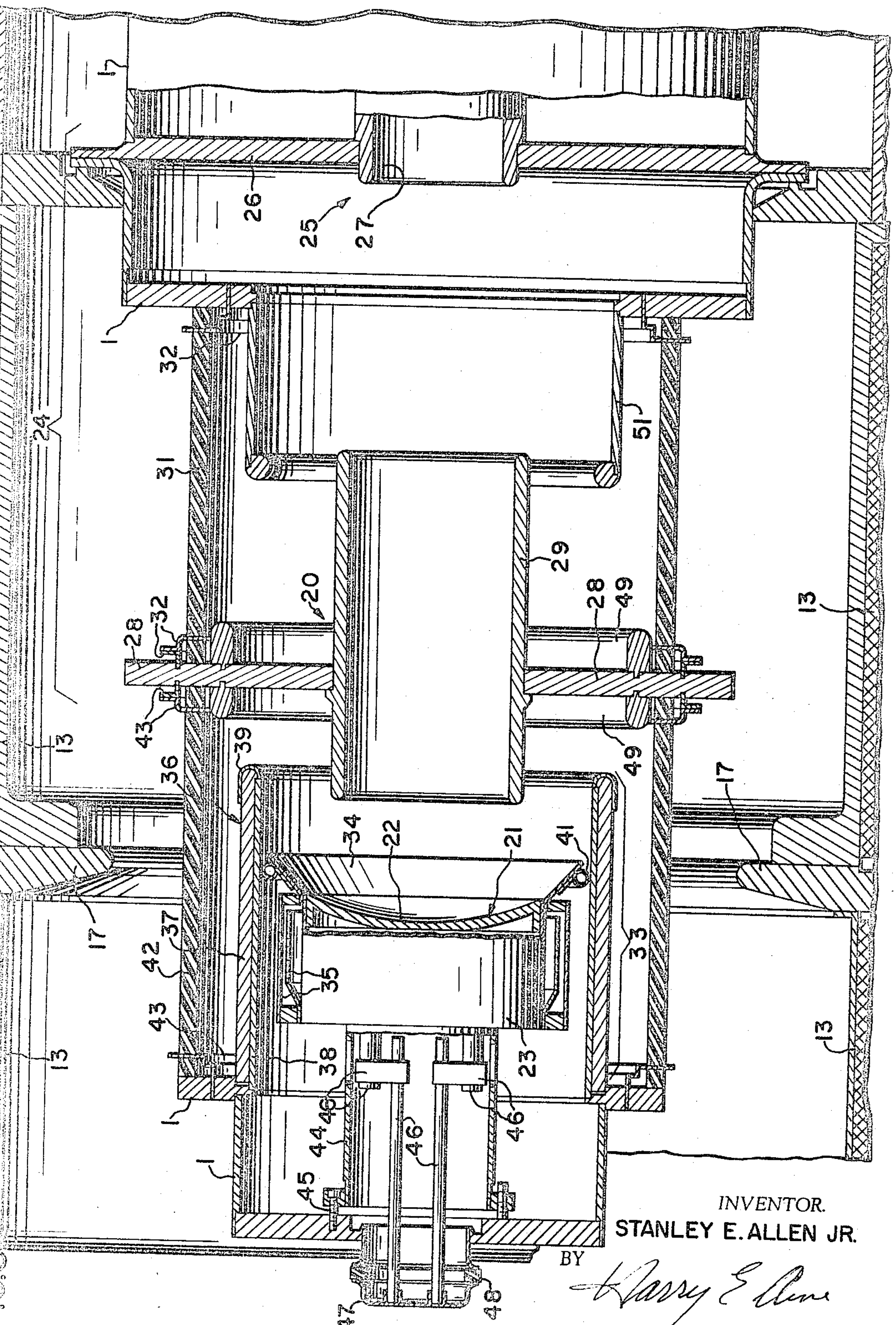

FIG. 3

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MAGNETIC FIELD SHAPING CYLINDER FOR CONFINED FLOW ELECTRON GUNS

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The present invention relates in general to high frequency electron tube apparatus and more particularly to an electron gun assembly for such tube apparatus, wherein the gun assembly employs magnetically confined convergent electron flow. Such gun assemblies are useful for super power multicavity klystron amplifiers, traveling wave tubes and the like.

Heretofore, high power high frequency tubes have employed one of two types of magnetic beam converging and focusing. A first type of magnetic focusing is a Brillouin flow and a second type is confined flow.

In Brillouin flow the cathode emitter is disposed in a magnetic field free region. Electrons are drawn from the cathode emitting surface in a magnetic field free region and converged by purely an electrostatic field until such time as the converging electron flow abruptly enters into a converging magnetic field in close proximity to an apertured anode structure. Generally, in Brillouin flow the anode structure forms a pole piece of the magnetic circuit. Brillouin focusing turns out to involve a critical balance between the velocity of the electrons, the magnetic field intensity and the space charge forces.

Brillouin flow does not lend itself to super power beams because slight deviations from the optimum electrical and magnetic design parameters of the tube disrupt the critical electric and magnetic balance required for Brillouin flow, thereby resulting in substantial unwanted perturbations of the beam and the accompanying interception of the beam. At super power levels even slight amounts of interception can be disastrous and therefore, Brillouin flow focusing is more commonly used at or below moderate beam power levels of 10's of kilowatts average. One advantage of Brillouin flow as opposed to confined flow is that Brillouin flow provides a more efficient use of a given magnetic field intensity such that the weight and size of the focus magnet may be minimized when utilizing Brillouin flow. Therefore, for some applications where size and weight of the magnet are critical such as in airborne missile applications, Brillouin flow is utilized.

In the confined flow focusing the cathode emitter is immersed in an axially directed convergent magnetic field with the electrostatic field lines of the gun conforming to the shape of the magnetic field lines passing through the cathode emitting surface. Confined flow focusing has the advantage of being less critical to slight deviations from the optimum magnetic and electric design parameters of the gun but requires a higher magnetic field intensity and, therefore, a larger magnetic generator than that required for Brillouin flow guns. Confined flow guns are preferred for super power applications where the average beam power is in the order of 100's of kilowatts or more since greater deviations in the magnetic and electric parameters of the tube may be permitted without resulting in excessive beam interception throughout the tube structure.

In the present invention a hollow cylindrical magnetic field shaping member is closely spaced surrounding the cathode emitter structure. In a preferred embodiment the magnetic field shaping member forms a portion of the cathode focus electrode structure of the gun. The cylindrical magnetic field shaping member functions to locally perturb the axially directed beam focusing magnetic field

in the region of the cathode emitter to increase the rate of convergence of the magnetic field lines passing through the emitting surface thereby increasing the rate of convergence of the beam over that obtained in the absence of the magnetic field shaping member.

Previously, it had been proposed, in Brillouin flow guns, to provide a cylindrical magnetic member closely surrounding the cathode emitter, see U.S. Patent 2,974,-246 issued Mar. 7, 1961, inventor A. H. W. Beck et al. However, the function of the cylindrical magnetic member in the Brillouin flow gun is completely different than that of the cylindrical field shaping member of the present invention. The magnetic member in the Brillouin flow gun serves the purpose of completely shielding the cathode emitter from the beam focusing magnetic field such that the cathode emitting surface will be disposed in a magnetic field free region. In the present invention the cylindrical magnetic field shaping member serves to perturb the beam focusing magnetic field passing through the cathode in such a manner as to increase its rate of convergence and thereby increase the rate of convergence of the beam in the gun. By increasing the rate of convergence the beam loading of the cathode emitter may be reduced thereby increasing the longevity of the cathode emitter and of the electron tube apparatus utilizing such emitter.

Also, it had previously been proposed, for confined flow guns, to provide a magnetic structure surrounding the cathode emitter, see U.S. Patent 2,905,847 issued 22 Sept. 1959, inventor Werner Klein et al. This prior magnetic structure included a cylindrical magnetic member open at one end but substantially closed off at its down stream end by a centrally apertured transverse magnetic wall member. This magnetic structure surrounded and included within its interior both the cathode and the anode. The cylindrical magnetic member and the end closing transverse wall were slightly spaced from each other to form a magnetic gap to produce a convergent magnetic field threading through the cathode emitting surface. It was not contemplated that either the cylindrical member nor the end wall should be used alone for the recited purpose. This two element magnetic structure does not lend itself to super power electron gun structures and especially such gun structures employing modulating anodes. One reason for this is that such magnetic structure, which encloses both with anode and cathode, must be closely spaced both to the cathode and anode structures and operated at anode potential. However, for super power tubes extremely high voltages as of 10's to 100's kv. are applied between anode and cathode structures. Close spacing of the cathode structure or modulating anode to the surrounding magnetic structure will lead to arc-overs during operation resulting in catastrophic destruction of the tube.

The cylindrical magnetic field shaping member of the present invention, which surrounds merely the cathode structure, permits such magnetic field shaping member to be closely spaced to the cathode such that it may be operated at or near cathode potential while performing the same function as the prior art two-element member which surrounded both the anode and cathode. Thus, in the present invention the single element cylindrical magnetic field shaping member is especially well suited to high power applications which were not conveniently accommodated by the prior art two magnetic element structure.

The principal object of the present invention is to provide an improved high power magnetically confined flow convergent electron gun especially useful for super power electron discharge devices.

One feature of the present invention is the provision of a magnetic field shaping member surrounding the cathode emitter of a magnetically confined flow gun, the magnetic field shaping member consisting essentially only of a hollow cylindrical magnetic member whereby the magnetic field shaping structure is simplified for increasing the rate of convergence of the magnetic field through the cathode emitter.

Another feature of the present invention is the same as the preceding feature wherein the magnetic field shaping member forms a portion of the cathode focus electrode structure.

Another feature of the present invention is the same as the preceding feature including the provision of a liner made of a material having a higher thermal conductivity than the magnetic field shaping member and disposed within the cylindrical magnetic field shaping member in abutting relationship to decrease the thermal impedance of the heat path from the magnetic field shaping member to the outside of the tube envelope structure for cooling of the field shaping member in use.

Another feature of the present invention is the same as the first feature wherein the beam confining magnetic field is generated by an electrical solenoid having an annular magnetic pole piece surrounding the gun external of the vacuum envelope, and said pole piece being disposed axially intermediate the length of the cylindrical magnetic field shaping member.

Other features and advantages of the present invention will become apparent upon a perusal of the specification taken in connection with the accompanying drawings wherein:

FIG. 1 is a longitudinal foreshortened view partly in section of a high frequency electron discharge device employing features of the present invention,

FIG. 2 is a longitudinal schematic cross-sectional diagram of an electron gun assembly showing the function of the structural features of the present invention, and

FIG. 3 is an enlarged cross-sectional view of that portion of the structure of FIG. 1 delineated by lines 3—3.

Referring now to FIG. 1, there is shown a high frequency electron discharge tube apparatus utilizing features of the present invention. More particularly, the tube comprises an evacuated tubular envelope **1** evacuated to a suitable low pressure as of, for example, 10^{-9} millimeters of mercury via the intermediary of an appendage ion pump **2** in gas communication with the interior of the tube envelope **1** via a suitable tubulation **3**.

An electron gun assembly **4**, more fully described below, is disposed at one end of the tube envelope **1** and serves to form and project a beam of electrons over a predetermined path directed axially and longitudinally of the tube envelope **1**. A beam collecting structure **5** is disposed at the terminating end of the elongated electron beam path for collecting the electron beam. A coolant as of, for example, water circulates through suitable ducts, not shown, in the collector structure **5**. Coolant is supplied to the collector via fluid fittings **6**.

A plurality of re-entrant cavity resonators **7** and **8** are arranged along the beam path in axially spaced relation for electromagnetic interaction with the electron beam passable therethrough. Input wave energy to be amplified is supplied to the input resonator **7** via the intermediary of an input loop **9** and coaxial line **11**. Amplified output wave energy is extracted in the conventional manner from the beam via output resonator **8** and propagated to a suitable load, not shown, via the intermediary of an output iris and output waveguide **12** sealed in a suitable vacuum tight manner via the intermediary of a wave permeable vacuum tight window.

An electric solenoid **13** coaxially surrounds the elongated vacuum envelope **1** and provides an axially directed beam focusing magnetic field as of, for example 500 gauss for confining the beam to its predetermined beam path. A hollow cylindrical magnetic shield **14** as of soft iron surrounds the outside of the solenoid **13** for minimizing leakage of the magnetic field. At the gun end of the tube

1 the shield **14** abuts an apertured plate **15** as of soft iron forming the top of an iron tank containing an oil bath **16** in which the gun end of the tube, including the solenoil **13**, is immersed. The iron of the tank forms a portion of the magnetic shield and the oil bath, having a higher dielectric strength than air, reduces the probability of an arc-over across the insulators of the gun **4**.

Annular magnetic pole pieces **17** and **18** operating at main anode potential, respectively, are carried substantially at the ends of the magnetic shield **14** for shaping the beam confining magnetic field within the solenoid **13**.

Axially moveable tuning structures **19** are disposed within the cavity resonators **7** and **8**, respectively, for tuning of the tube over the operating frequency range.

In operation, input signals are applied to the input resonator **7** via coaxial line **11**. The signals are amplified in successive resonators and the amplified output signal is derived from the tube **1** via the intermediary of output waveguide **12**. A modulating electrode structure **20** is disposed in the electron gun assembly **4**. The modulating anode **20** will be more fully described below but is of the non-intercepting type such that it may be pulsed from cathode potential positive with respect to the cathode to anode potential of 140 kv. for initiating beam current. Because the modulating anode draws negligible current during the time the beam is on, the modulating anode may be driven by a low current high voltage modulating supply, not shown.

A typical tube of the above described type utilizes a beam voltage of approximately 140 kv. having an average beam power in the order of megawatts to produce hundreds of kilowatts average and tens of megawatts peak UHF output power.

In such a super power tube, with average beam power of a megawatt or more, the electron beam focusing must be precise, for even small percentages of beam interception by the various tube elements, such as drift tubes, can result in extremely high power dissipation. For example, a 1% beam interception on the drift tube, for a 1 megawatt average beam, results in 10 kilowatts average power being dissipated at the point of beam interception.

In the present invention unwanted beam interception, without R.F. applied to the beam, has been controlled to a range of 0.25% over the entire beam path. Typically with R.F. power applied the interception, utilizing the features of the present invention, has been controlled to 0.5% throughout the entire length of the beam.

Referring now to FIG. 3 the novel electron gun structure of the present invention will be described in greater detail.

A cathode emitter body **21** as of impregnated tungsten is provided with a concave substantially spherical shaped emitting surface **22**. The cathode emitter body **21** is heated via a hot wire heater assembly **23** to its operating temperature of approximately 1050° C.

An anode structure **24** is axially spaced apart from the cathode emitter **21** in the direction of beam travel. The anode structure consists of a main anode **25** and a modulating anode **20**. The main anode **25** is formed by a circular transverse wall **26** as of stainless steel having a central aperture therethrough. An axially directed cylindrical tube **27** as of copper is carried substantially at one end thereof by the margin of the central aperture in the anode wall **26**. The main anode **25** is carried from the central portion of the tubular vacuum envelope structure **1** and is operated at the same potential as the central and collector portions of the tube envelope structure **1**.

The modulating anode structure **20** is disposed intermediate the cathode emitter **21** and the main anode **25**. The modulating anode structure **20** includes a circular transversely directed and centrally apertured modulating anode wall **28** as of copper. A tubular anode segment **29** as of copper is carried intermediate its length from the central aperture in the anode wall **28**. The modulating anode wall **28** is carried from the central portion of the tube vacuum envelope structure **1** via the intermediary of a tubular high voltage insulator **31** as of alumina ceramic. Flanged annular frame members **32** as of Kovar are brazed to the insulator **31**, modulating anode wall **28** and envelope structure **1**, respectively, to form a portion of the gas-tight tube envelope **1**.

A cathode focus electrode assembly **33** surrounds the cathode emitter **21** and is operated at or near cathode potential, where near means within 10% of the cathode potential. In a preferred embodiment the focus electrode assembly operates at cathode potential. The focus electrode assembly **33** includes an outwardly flared focus electrode **34**, as of 0.030" stainless steel, which closely surrounds the outer periphery of the cathode emitter **21** and projects axially of the tube in the direction of the modulating anode **20**. The focus electrode **34** is carried from the cathode emitter body **21** via the intermediary of cylindrical heat shields **35** as of 0.010" thick molybdenum.

A cylindrical magnetic field shaping structure **36** forms a portion of the focus electrode assembly **33**. Magnetic shaping structure **36** includes an outer hollow cylindrical magnetic field shaping member **37** as of iron ⅜" thick and 6.75" in length having an inside diameter of approximately 6.75". A cylindrical liner **38**, as of 3⁄16" thick copper, lines the inside of the cylindrical magnetic member **37** and is disposed in abutting relationship with the cylindrical magnetic field shaping member **37**. Liner **38** is preferably made of the good thermal and electrical conducting material as of, for example, copper.

The liner **38** serves the dual purpose of enhancing the thermal conductivity of the heat path from the magnetic field shaping member **37** to the wall of the tubular vacuum envelope structure, and provides a smooth electrical conducting surface on the inside surface of the focus electrode structure in the regions where said focus electrode structure is subjected to high electric fields. It has been found that a typical magnetic material such as, for example, iron has certain porosity and surface impurities which tend to initiate electrical breakdown between such elements and adjacent structure in the presence of high electric field gradients as will be encountered in high voltage super power tubes of the type above described. Likewise, a thin gauge annular copper channel **39** of J-shaped cross-section is fixed over the rounded free end of the magnetic shim member **37** to prevent electrical breakdown in use.

The cathode body **21** and focus electrode **34** are supported from the magnetic shaping structure **36** via the intermediary of a plurality of peripherally spaced thin wire spring members **41** as of 0.030" thick stainless steel which serve the purpose of supporting the focus electrode **34** and for centering the cathode structure with respect to the magnetic shaping structure **36**. In addition, the thin wires provide a high impedance thermal path to prevent excessive transfer of thermal energy from the cathode emitter **21** and focus electrode **34** to the magnetic field shaping structure **37** which might otherwise tend to impair the desired magnetic properties of the magnetic shaping structure.

A cylindrical high voltage insulator **42** as of alumina ceramic serves as a portion of the tubular vacuum envelope structure and also serves to hold off the high potential as of 142 kv. between cathode **21** and modulating anode structure **20** during the time the tube is drawing beam current. Annular frame members **43** as of Kovar are brazed to the high voltage insulator **42** and serve as portions of the vacuum envelope structure **1**.

The cathode emitter body **21** and the heater assembly **23** are also supported within the tube envelope structure **1** via the intermediary of a tubular axially directed support member **44** carried from the end closing wall of the vacuum envelope structure **1** via the intermediary of a plurality of screws **45**. Tubular support **44** also serves as the return heater head for the heater assembly **23**.

A pair of heater leads **46** are parallel connected and supply heating current to the heater assembly **23**. The heater leads **46** are connected to a terminal **47** insulated from the tube envelope structure **1** via the intermediary of an annular insulating member **48**.

A pair of axially directed rounded annular corona shields **49** as of copper are carried from the modulating anode wall **28** adjacent the annular insulator frame members **32** and **43**, respectively to eliminate electrical breakdown in the vicinity of the brazed frame members **32** and **43**. A cylindrical insulator sputter shield **51** as of copper extends axially of the high voltage insulator **31** internally thereof to prevent sputtering of anode material from the tubular anode member **27** onto the insulator **31** which would otherwise cause electrical breakdown across the high voltage insulator **31**.

By reference to FIG. 2 the mode of operation of the electron gun structure **4** of FIG. 3 can be more clearly seen. The upper half of the diagram of FIG. 2 schematically qualitatively shows the electrical and magnetic parameters of the gun structure. More specifically, when the tube is drawing beam current the electric field lines as produced by the modulating anode structure **20** and focus electrode structure **33** will produce an electric field leaving the cathode emitting surface **22** at the beam edge as shown by dashed line E. The electric field lines converge through the modulating tubular anode segments **29**. In the absence of the magnetic field shaping member **37** the solenoid **13** together with the pole piece **17** causes the magnetic field to pass through the cathode substantially as shown by the dotted line designated to H_O. For this case it can be seen that the magnetic field lines H_O do not converge as rapidly as the electric field lines leaving the surface of the cathode emitter **22** and therefore, do not conform to the shape of the electric field lines E. In such a case the electron beam would be unstable and would not have the desired degree of convergence resulting in unwanted beam interception throughout the length of the beam.

With the provision of the cylindrical magnetic shaping member **37** surrounding the cathode emitter surface **22** the magnetic field in the vicinity of the cathode emitter surface **22** is perturbed as shown by the solid line designated H. The perturbation produced in the magnetic field by the field shaping member **37** causes the magnetic field lines H to more rapidly converge and to conform essentially to the shape of the electric field lines leaving the cathode emitter surface **22**. In such a case the electron beam will be more rapidly converged and will have the requisite stability with a minimum of unwanted beam interception.

The lower half of the diagram of FIG. 2 shows the total magnetic field intensity with and without the magnetic field shaping member **37**. The dotted line designated B_O shows the axial magnetic field component intensity at the beam edge of the gun without the field shaping member **37** as a function of distance along the gun structure. The solid line designated B_W shows the intensity of the axial component of the magnetic field at the edge of the beam in the presence of the magnetic field shaping member **37**. The effect of the magnetic field shaping member is readily discernible and shows that it locally perturbs in the magnetic field intensity to cause the field intensity to increase more rapidly as the magnetic field lines pass through the surface of the cathode emitter taken in the direction toward the accelerating electrode or anode structure.

In a typical example the cylindrical magnetic field shaping member **37** of the present invention converges the beam diameter from the plane of the cathode to the plane of the main anode by as high a factor as 5 to 1 while maintaining beam interception percentages at 0.5% over the full length of the beam path with full R.F. power applied to the beam. This degree of convergence allows the cathode emitter body **21** to operate at relatively low current loading as of 1 ampere square centimeter leading to a long cathode life in the order of thousands of hours while delivering beam power in the order of megawatts average.

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

What is claimed is:

In an electron tube apparatus, a cathode emitter having an emitting surface of a given area, an anode structure spaced from said cathode emitting surface and having an aperture therein disposed in substantial alignment with said cathode structure, said aperture of said anode structure having an area smaller than the emitting surface area of said cathode emitter, said anode structure serving to draw and converge a stream of electrons from said cathode emitting surface through said apertured anode structure, a beam collector structure disposed at the terminal end of the electron stream for collecting the electrons, wave interaction structure disposed along the electron stream intermediate said cathode and said beam collector for electromagnetic interaction with the stream, an output means for extracting wave energy from the stream, solenoid means for producing a beam focusing magnetic field, said emitter and said anode structure being immersed in a convergent magnetic field portion of the beam focusing magnetic field threading through said cathode emitter and said anode aperture for confined flow

focusing of the beam of electrons, a magnetic field shaping member surrounding said cathode emitter with a projection extending into and terminating within the region between said anode structure and said cathode emitter, said field shaping member consisting solely of a hollow cylindrical magnetic member for perturbing the magnetic field in said cathode emitter region to increase the rate of convergence of said magnetic field lines passing through the emitting surface of said cathode emitter and to cause said magnetic field lines to approximately conform to the shape of the electric field lines in the region of the beam between said anode and cathode structures, said beam focusing solenoid means including a magnetic pole piece spaced from and surrounding said cylindrical magnetic field shaping member and disposed intermediate the length of said cylindrical field shaping member.

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