

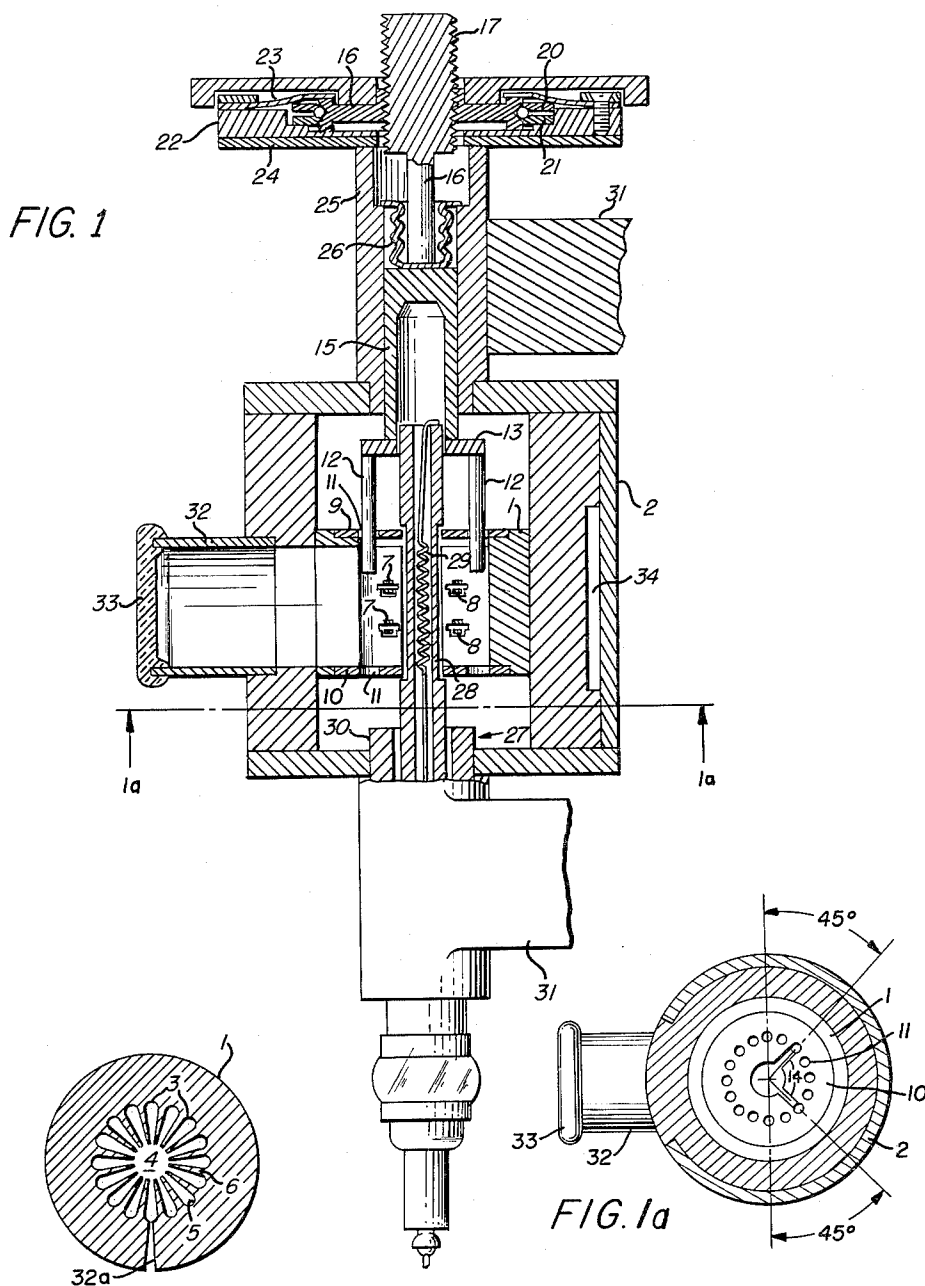
March 27, 1962

D. L. WINSOR
TUNABLE MAGNETRONS

3,027,488

Filed Nov. 3, 1958

2 Sheets-Sheet 1



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FIG. 4

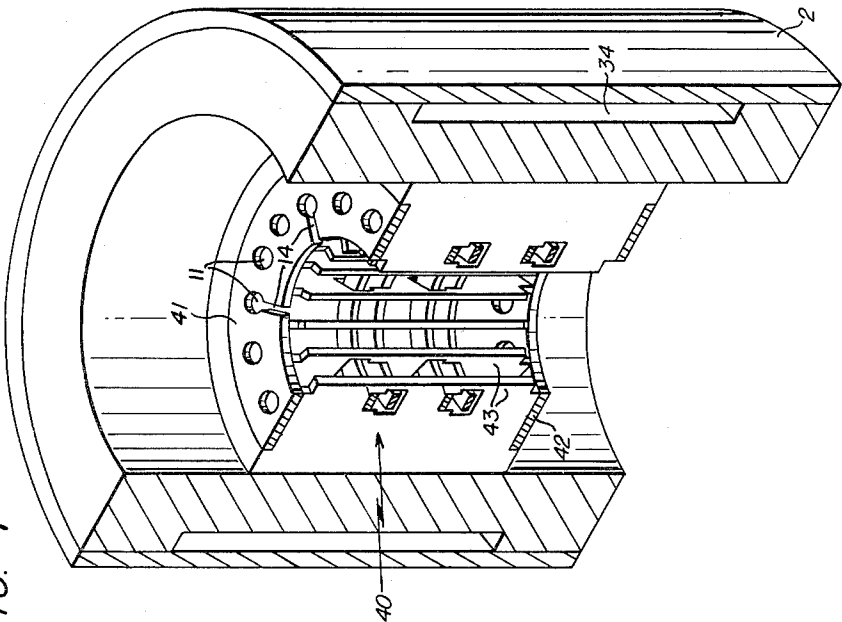
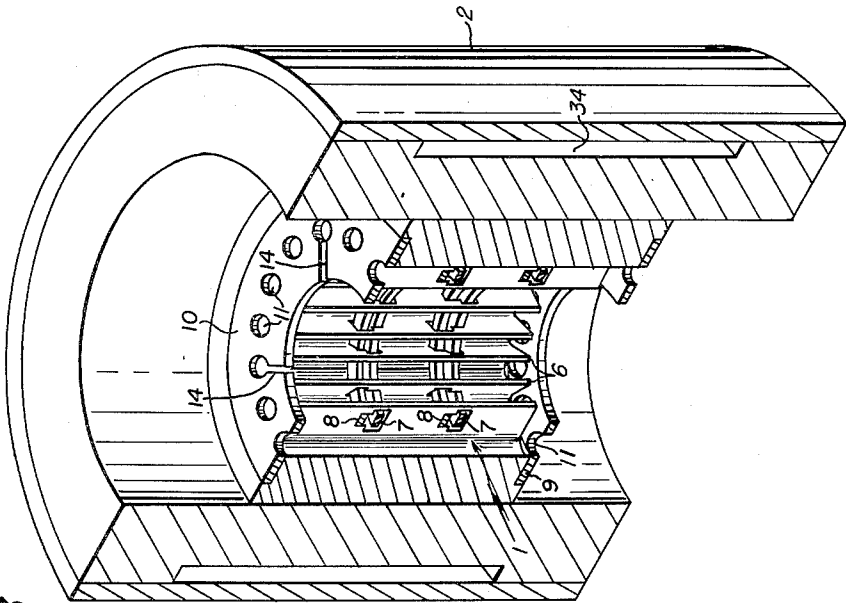


FIG. 3



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TUNABLE MAGNETRONS

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Filed Nov. 3, 1958, Ser. No. 772,648
10 Claims. (Cl. 315—39.61)

This invention relates to electron discharge devices of the magnetron type and more particularly pertains to a magnetron incorporating a frequency tuning mechanism.

Magnetrons are particularly useful for generating high frequency energy at extremely short wave length. A particular form of magnetron over which this invention is an improvement comprises an anode block constituted of copper or some other highly electrically conductive non-magnetic material shaped in the form of a right circular cylinder having planar ends perpendicular to the axis of the cylinder. A central axial cylindrical aperture is provided in the anode block which houses an axially disposed electron emissive cathode. A plurality of resonator cavities are provided in the anode block, the resonator cavities extending parallel to the axis of the cylinder and being arranged about a circle whose center lies on the axis of the cylinder. Each of the resonator cavities communicates with the central aperture through a radially extending slot. This construction is commonly known as a multi-cavity magnetron.

It is well known that conventional multi-cavity magnetrons in which the cavity resonators are all alike oscillate in any one of a number of different modes, each of the different modes of oscillation involving an instantaneous phase difference between the oscillations generated in adjacent cavities. It has been found that the most efficient and desirable mode of operation is that referred to as the " π -mode" in which the oscillations in any arbitrarily selected cavity of the magnetron is 180° (π radians) out of phase compared with the phase of the oscillations in the adjacent cavity. Another way of visualizing " π -mode" operation is to view the cavity resonators as comprising two sets, one set of cavity resonators consisting of any arbitrarily selected cavity and every alternate cavity, the other set consisting of the remaining cavities, and to consider all the cavities in each set to oscillate in phase with all the other cavities in that set so that when the oscillations in the cavities of one set are at maximum positive potential, the oscillations in the cavities of the other set are at maximum negative potential. In order to achieve π -mode operation in conventional multi-cavity magnetrons it is customary to electrically connect alternate anode elements by means of low impedance conductors or straps which effectively lock alternate cavities together in the same phase. One effect of these straps is to shift the oscillation frequencies of the various undesirable modes away from the π -mode without affecting the latter, thus facilitating the elimination of the undesirable modes by causing the electric and magnetic field conditions favoring the generation of the undesirable modes to be further removed from the conditions which favor π -mode operation.

It is also well known that the frequency of oscillation of a conventional magnetron is determined by the geometry of the cavity resonators and that the magnetron may be tuned in frequency by inserting devices in the cavities which alter their capacitance or inductance. As the trend in the electronic art has demanded generators capable of operating at higher and higher frequencies, the magnetron, in an effort to meet that demand, has been designed to generate such higher frequencies by scaling down the geometry of the cavity resonators. As a result of the diminution in the size of the cavity resonators closer tolerances are required, and the devices which are

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inserted into the cavities to effect tuning of the magnetron have become less massive and less rigid in a situation where more rigidity is necessary due to the very close spacing required. In addition, the tuning devices, because of their decreased mass, are less able to dissipate the heat generated within the magnetron so that deformation of the devices is likely to occur due to their overheating.

This invention discloses a magnetron construction permitting the largest possible cavity geometry for a desired resonant frequency and proposes affixing covers to the ends of the anode block to enclose the resonant cavities, at least one of those end covers having apertures circumferentially coincident with the profile of a portion of each cavity. In accordance with the invention, tuning pins, secured at one end to a movable plate, are arranged to project through the apertures in the end cover and penetrate into the cavities. Apparatus is provided for raising or lowering the movable plate, in order that the tuning pins may be advanced into or withdrawn from the cavities to cause a change in the resonant frequency of those cavities. By virtue of this novel construction, it has been found that increased effectiveness in changing the frequency of oscillation is obtained for a given penetration of the tuning pins. As a corollary to the increased effectiveness of the tuning pins, greater tuning ranges are achieved without any significant increase in the complexity of the tuning mechanism.

The invention further proposes that one or both of the anode end covers be provided with slots disposed to permit the propagation of energy of the adjacent mode (that is, the mode next adjacent the desired mode of oscillation) into the magnetron end space. By properly orienting such slots, it is possible to couple the adjacent mode to the magnetron end space to load it sufficiently to suppress oscillation in that mode.

The invention, together with its manner of construction and mode of operation, will be better understood by a perusal of the following description when considered in conjunction with the drawing wherein:

FIG. 1 is a vertical section through a magnetron constructed in accordance with the invention;

FIG. 1a is a horizontal section taken through said magnetron with cathode and tuning pins removed;

FIG. 2 is a cross-section through an anode block showing the configuration of the resonant cavities;

FIG. 3 depicts a segment of an anode having end covers; and

FIG. 4 depicts a modification of the structure shown in FIG. 3.

Referring now to FIG. 1 which depicts a longitudinal section through a magnetron constructed in accordance with the invention, there is shown an anode block 1 of copper or some other highly electrically conductive material enclosed within an evacuated chamber formed in part by a tubular body 2. As may be seen in FIG. 2 the anode has resonant cavities 3 therein which communicate with a central chamber 4, all the cavity resonators being alike in configuration. The cavities are "teardrop" in cross section, the rear wall 5 of each cavity being circular and the walls formed by the vanes 6 being tangent to that circular wall portion. FIG. 3 shows the anode block 1 in a position inverted to that depicted in FIG. 1. One set of alternate vanes 6 of the anode are interconnected by straps 7 and straps 8 interconnect the other set of alternate vanes. Those straps are provided for the purpose of achieving better mode separation in the magnetron in order to prevent oscillations in an undesired mode from occurring. In effect, the straps tend to insure π -mode operation of the magnetron by causing one set of alternate resonant cavities to oscillate in a phase which is

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π radians displaced from the phase of oscillations in the other set of resonant cavities. Secured to one end of the anode block 1 is an annular cover or plate 9, illustrated in both FIGS. 1 and 3. The plate 9 at its outer periphery is brazed or otherwise secured to the anode 1 and as best seen in FIG. 1, that plate does not rest upon the vanes 6 or close off the upper ends of the cavity resonators but is separated therefrom by a small space. This plate 9 is used to minimize the effects of tuner resonance. The other end of the anode has secured to it a cover or plate 10 which abuts the vanes and closes the resonant cavities at that end. Each of the covers 9 and 10 has circular apertures 11 therein, the number of such apertures in each cover corresponding to the number of cavity resonators in the anode. The diameter of the apertures 11 is identical with the diameter of the circular wall portion 5 of the resonant cavities and each aperture is arranged in relation to the adjacent resonant cavity so that a portion of the circular edge of the aperture is coincident with the periphery of the circular wall portion of the resonant cavity. Thus correspondingly positioned apertures in the covers 9 and 10 are aligned. Tuning pins 12, shown in FIG. 1, are supported from a carrier 13 and each pin is arranged to be inserted through an aperture in cover 9 into a resonant cavity. The tuning pins are circular in cross section and are of smaller diameter than the diameter of the apertures. It is important that each tuning pin be centrally disposed within its apertures and not in contact with either the cover 9 or the wall of the resonant cavity. To obtain the requisite alignment of the tuning pins during assembly of the magnetron an alignment jig may be inserted through the apertures in the oppositely disposed cover 10 to position the pins in the desired positions. Upon completion of the necessary manufacturing operations the alignment jig is removed. The effect of the cover 10 during operation of the tube is to cause the magnetic component of the fields in the resonant cavities to be displaced in the direction of the cover 9 so that the penetration of the tuning pins into the resonant cavities has an enhanced effect in altering the inductance of the resonant cavities and hence an increased effectiveness in tuning the frequency of the magnetron. That is, penetration of a tuning pin into a resonant cavity effects a volume displacement of the magnet field component in that cavity which changes the inductance of the resonant cavity and due to the presence of cover 10, the magnetic field component is more intense at the tuner end of the anode so that a given penetration of the tuning pin has a larger influence than it would have in the absence of the cover 10.

The employment of end covers 9 and 10 causes a considerable increase in the resonant frequency of the cavity resonators 3 so that for a given resonant frequency a larger cavity geometry is made possible. That is, in the absence of end covers the geometry of the cavity resonators must be of a certain size to cause resonance at a desired frequency; the addition of end covers, however, permits the same resonant frequency to be obtained with cavity resonators of the same configuration but of larger size. This effect of the end covers is significant where the magnetron is designed to operate at very high frequencies, for example, frequencies in the vicinity of 10,000 megacycles (X-band), because at such frequencies the size of the cavity resonators becomes very small and difficulties are encountered in adhering to mechanical tolerances. For manufacturing reasons, therefore, it is highly desirable that the geometry of the cavity resonators be as large as possible. The attainment of larger cavity geometry permits, as a corollary advantage, the use of tuning pins having the largest possible cross-sectional area. These larger tuning pins are more rigid than pins of smaller cross sectional area and are better able to dissipate the heat generated in the interior of the magnetron. The end covers also function to limit the fringing RF (radio

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frequency) fields at the ends of the anode block and thereby reduce the sensitivity of the magnetron to the geometry of the end spaces, viz., the spaces in the enclosed chamber at ends of the anodes. End covers also permit the use of long anode structures without trouble from inadequate separation between mode multiplets, mode multiplets being the families of modes having a given order of RF voltage variation along the length of the anode. As is understood by those familiar with magnetrons, the length of the anode is the distance between the planar ends of the anode block.

In order to suppress any tendency of the magnetron to oscillate in the

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mode (N being the number of cavity resonators) which is the mode next adjacent the π mode, radial slots 14 may be added in the end cover 10 and so oriented as to couple the adjacent mode into the end space where it is loaded sufficiently to prevent oscillation in that mode from building up to any significant extent. The best orientation of the slots for the suppression of the adjacent mode is attained by arranging the slots along radial lines which intersect at a 45° angle a diametral line passing through the cavity in the anode block from which the output of the magnetron is taken as shown in FIG. 1a.

Referring again to FIG. 1, there is shown a mechanism for raising and lowering the carrier 13 and its attached tuning pins. The carrier 13 is secured to a piston 15 at one end of a rod 16, the rod being provided with micrometer screw threads 17 at its other end which are engaged by a threaded plate 18 attached to a circular plate or wheel 19 provided at its periphery with means such as knurling so that it may be readily moved. The periphery of threaded plate 18 constitutes a ball-bearing race. Surrounding that race is a complementary race comprising two bevelled rigs 20 and 21, the ring 20 being seated upon a stationary disc 22, and the ring 21 being pressed into cooperation with ring 20 by an annular spring 23 affixed to disc 22. Ball bearings are positioned between the races to permit the wheel 19 to rotate easily. The disc 22 is secured to a flange 24 fastened to pole piece 25, this latter member functioning as a cylinder for piston 15. To insure a leak-proof connection between piston and cylinder, a Sylphon bellows 26 is provided having an outwardly extending rim at one end which is soldered to an internal shoulder of pole piece 25, the opposite end of the bellows 26 being bonded to the piston 15. The mechanism described above for raising and lowering the tuning pins is exemplary only and it is not intended that the invention be limited to the illustrated mechanism since, obviously, many other mechanisms are available for performing the same function.

Disposed in the central chamber of the anode block is a cathode structure 27 which includes a cathode sleeve 28, preferably of nickel, having a diametrically reduced portion substantially coextensive with the length of the anode block, the surface of the reduced portion being coated with an electron-emissive substance, for example, an alkaline earth metal oxide, which copiously emits electrons at elevated temperatures. Housed within the cathode sleeve 28 in a location best suited for the transfer of heat to the electron-emissive coating is a heater filament 29, one end of the filament being in electrical contact with the sleeve 28. The upper end of the cathode sleeve is disposed within the end space of the magnetron housing and piston 15 is constructed as a hollow shell so that when the piston is lowered the sleeve 28 is received within the hollow without contacting the walls of the piston. The lower end of cathode sleeve 28 is centrally disposed within another pole piece 30. The cathode sleeve, of course, is insulated from the pole piece 30. A magnetic field is established between the pole pieces 25 and 30 by

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connecting the pole pieces to the ends of a horseshoe magnet 31, the end portions only being illustrated. The magnetic field extends through the interaction region of the magnetron which is the space between the activated surface of the cathode and the inner ends of the vanes 6.

The output of the magnetron may be obtained in a conventional manner, as by inserting an antenna loop through an aperture in the wall of the magnetron into one of the cavity resonators and omitting the tuning pin normally positioned in that cavity. Where the magnetron is designed to generate frequencies in the shorter wavelength regions, however, such as at X-band, an antenna loop becomes impracticable and a waveguide output is commonly employed. FIG. 1 illustrates a magnetron having a waveguide output. A waveguide section 32 is secured to the housing of the magnetron and an aperture 32a is provided in the anode block 1 which permits electromagnetic energy in one of the cavity resonators to propagate into the waveguide. In order that the vacuum in the magnetron may be maintained, the outer end of the waveguide section 32 is sealed by a dielectric window 33.

In order to remove the heat generated by the magnetron, the tubular body 2 is provided with a passage 34 through which water or some other coolant may be circulated. Suitable inlet and outlet connections (not shown) must be provided through which the coolant may be introduced into and withdrawn from the passage. This means for cooling a magnetron is conventional and some other means of cooling the magnetron may well be employed, if desired.

FIG. 4 illustrates a modification of the invention and shows an anode block 40 in which end covers 41 and 42 are secured to the block and enclose the ends of the resonant cavities. For purposes of comparison, it will be noted that in the structure illustrated in FIG. 3 the end cover 9 does not abut the edge of the cavity vanes 6 but rather is spaced from the edge of the cavity vanes, whereas in the structure illustrated in FIG. 4, each end cover, 41 and 42, is bonded to and abuts the edge of vanes 43 along a larger extent of the edge of the vanes. In all other essential respects the structures shown in FIGS. 3 and 4 are identical. End covers 41 and 42 are provided with apertures in the same manner that end covers 9 and 10 are provided with apertures. The structure illustrated in FIG. 4 is advantageous in that by enclosing both ends of the resonant cavities the resonant frequency of the cavities is increased to a greater extent than is possible where only one end is enclosed, thereby permitting the largest attainable cavity geometry for a given resonant frequency. However, the symmetrical construction shown in FIG. 4 causes the magnetic field components in the cavity resonators to have a symmetrical distribution so that the magnetic field components are not shifted toward the tuner end of the anode, as they are in the structure of FIG. 3. Therefore, for a given depth of tuner penetration into a cavity resonator, the amount of frequency shift which is obtained with the construction of FIG. 4 is not as great as the amount of frequency shift obtained with the construction of FIG. 3.

While there have been illustrated only two embodiments of the invention, it will be apparent that the invention is not limited to the precise structures depicted in the drawings and that variations are apparent to those skilled in the magnetron tube art. For example, the end cover 10 shown in FIG. 3 and the end cover 42 in FIG. 4, which is opposite the tuner end, need not have alignment apertures therein, but may be imperforate annular discs. As further examples, the tuning pins need not be circular in cross-section but may be of a different configuration and the cavity resonators need not be "teardrop" in shape. Therefore, it is intended that the scope of the invention be construed in accordance with the appended claims.

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What is claimed is:

1. A frequency tunable electron discharge device of the magnetron type comprising a cylindrical anode block having a central chamber extending along the longitudinal axis thereof, said anode block having a plurality of anode segments partially defining resonant cavities therein communicating with said central chamber, a cathode situated in said central chamber, at least one end cover contacting an end face of said anode segments, each end of said anode block having a cover attached thereto, at least one of said covers having apertures therein permitting access to said resonant cavities, a portion of the edge configuration of each aperture being coincident with a portion of the profile of the adjacent resonant cavity, a plurality of tuning pins disposed at one end of said anode block, each of said tuning pins extending through a different one of the apertures in the adjacent end cover into one of said cavities, and means secured to said tuning pins for adjusting the depth of penetration of said pins in said resonant cavities.

2. A frequency tunable electron discharge device of the magnetron type comprising a cylindrical anode block having a central chamber extending along the longitudinal axis thereof, said anode block having a plurality of anode segments partially defining resonant cavities therein communicating with said central chamber, a cathode situated in said central chamber, at least one end cover contacting an end face of said anode segments, each end of said anode block having a cover attached thereto, at least one of said covers having apertures therein permitting access to said resonant cavities, a portion of the edge configuration of each aperture being coincident with a portion of the profile of the adjacent resonant cavity, at least one of said end covers having radial slots therein for coupling undesirable mode energy into an end space, a plurality of tuning pins disposed at one end of said anode block, each of said tuning pins extending through a different one of the apertures in the adjacent end cover into one of said cavities, and means secured to said tuning pins for adjusting the depth of penetration of said pins in said resonant cavities.

3. A frequency tunable electron discharge device of the magnetron type comprising a cylindrical anode block having a central chamber extending along the longitudinal axis thereof, said anode block having a plurality of anode segments partially defining resonant cavities therein communicating with said central chamber, a cathode situated in said central chamber, at least one end cover contacting an end face of said anode segments, each end of said anode block having a cover attached thereto, at least one of said covers having apertures therein permitting access to said resonant cavities, a portion of the edge configuration of each aperture being coincident with a portion of the profile of the adjacent resonant cavity, a plurality of tuning pins disposed at one end of said anode block, each of said tuning pins extending through a different one of the apertures in the adjacent end cover into one of said cavities, each of said tuning pins having a cross-sectional configuration identical with and of smaller size than the aperture through which it extends, and means secured to said tuning pins for adjusting the depth of penetration of said pins in said resonant cavities.

4. A frequency tunable magnetron comprising an evacuated housing, a cylindrical anode block disposed in said housing, a cathode, said anode block having a central chamber in which said cathode is situated, said anode block having a plurality of anode segments partially defining resonant cavities therein communicating with said central chamber, a first cover in said housing contacting one end face of said anode segments, a second cover in said housing secured to the other end face of said anode segments and enclosing said resonant cavities, said covers having apertures therein permitting access to said resonant cavities, a portion of the edge configuration of each aperture in said cover being coincident with a por-

tion of the profile of the adjacent resonant cavity, a plurality of tuning pins, each of said tuning pins extending through a different one of the apertures in said first cover into one of said cavities, and means secured to said tuning pins for concurrently adjusting the depth of penetration of said pins in said resonant cavities.

5. A frequency tunable magnetron comprising an evacuated housing, a cylindrical anode block disposed in said housing, a cathode, said anode block having a central chamber in which said cathode is situated, said anode block having a plurality of anode segments partially defining resonant cavities therein communicating with said central chamber, a first cover in said housing contacting one end face of each of said anode segments, a second cover in said housing secured to the other end face of said anode segments and enclosing said resonant cavities, said covers having apertures therein permitting access to said resonant cavities, a portion of the edge configuration of each aperture in said cover being coincident with a portion of the profile of the adjacent resonant cavity, said second cover being additionally provided with radial slots for coupling undesirable mode energy to the end space in said housing, a plurality of tuning pins, each of said tuning pins extending through a different one of the apertures in said first cover into one of said cavities, and means secured to said tuning pins for concurrently adjusting the depth of penetration of said pins in said resonant cavities.

6. A frequency tunable magnetron comprising an evacuated housing, a cylindrical anode disposed in said housing, a cathode, said anode having a central chamber in which said cathode is disposed, said anode having a plurality of anode segments partially defining resonant cavities therein communicating with said central chamber, a pair of end covers, said covers being secured to opposite end faces of said anode segments and enclosing said resonant cavities, at least one of said covers having apertures therein providing access to said resonant cavities, a portion of the edge configuration of each aperture being coincident with a portion of the profile of the adjacent resonant cavity, a plurality of tuning pins, each of said tuning pins extending through a different one of said apertures into a resonant cavity, and means secured to said tuning pins for concurrently adjusting the depth of penetration of said pins in said resonant cavities.

7. A frequency tunable magnetron comprising an evacuated housing, a cylindrical anode disposed in said housing, a cathode, said anode having a central chamber in which said cathode is disposed, said anode having a plurality of anode segments partially defining resonant cavities therein communicating with said central chamber, a pair of end covers, said covers being secured to opposite end faces of said anode segments and enclosing said resonant cavities, at least one of said covers having apertures therein providing access to said resonant cavities, a portion of the edge configuration of each aperture being coincident with a portion of the profile of the adjacent resonant cavity, at least one of said end covers having radial slots therein oriented to couple undesirable mode energy into an end space in said housing, a plurality of tuning pins, each of said tuning pins extending through

a different one of said apertures into a resonant cavity, and means secured to said tuning pins for concurrently adjusting the depth of penetration of said pins in said resonant cavities.

8. An electron discharge device of the magnetron type comprising a cylindrical anode block having a central chamber extending along the longitudinal axis thereof, said anode block having a plurality of anode segments partially defining resonant cavities therein communicating with said central chamber, a cathode situated in said central chamber, at least one end cover having one opening concentric with said cylinder and a plurality of smaller openings each aligned with one of said cavities and substantially smaller than the end of the cavity contacting an end face of said anode segments and radial slots extending from at least one of said smaller openings to said one opening.

9. An electron discharge device of the magnetron type comprising a cylindrical anode block having a central chamber extending along the longitudinal axis thereof, said anode block having a plurality of anode segments partially defining resonant cavities therein communicating with said central chamber, a cathode situated in said central chamber, at least one end cover having one opening concentric with said cylinder and a plurality of smaller openings each aligned with one of said cavities and substantially smaller than the end of the cavity contacting an end face of said anode segments, said end cover having a plurality of radial slots therein, said slots extending from different of said small openings to said one opening, the width of said slots being substantially smaller than the width of said cavities for coupling undesirable mode energy into an end space.

10. An electron discharge device of the magnetron type comprising a cylindrical anode block having a central chamber extending along the longitudinal axis thereof, said anode block having resonant cavities therein communicating with said central chamber, a cathode situated in said central chamber, at least one end cover having one opening concentric with said cylinder and a plurality of smaller openings each aligned with one of said cavities and substantially smaller than the end of the cavity attached to an end of said anode block, said end cover having a plurality of radial slots therein, said slots extending from different of said small openings to said one opening, the width of said slots being substantially smaller than the width of said cavities for coupling undesirable mode energy into an end space.

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