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S. FRANKEL
ELECTRON DISCHARGE DEVICE

2,480,126

Filed Dec. 14, 1945

2 Sheets-Sheet 1

Fig. 1.

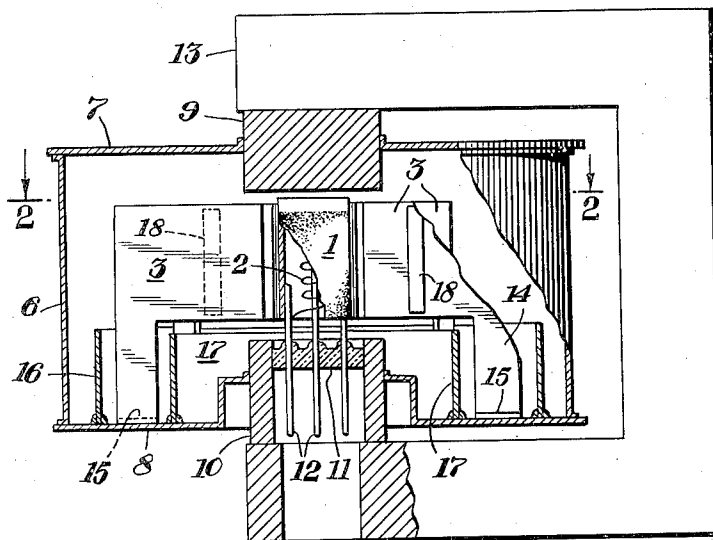
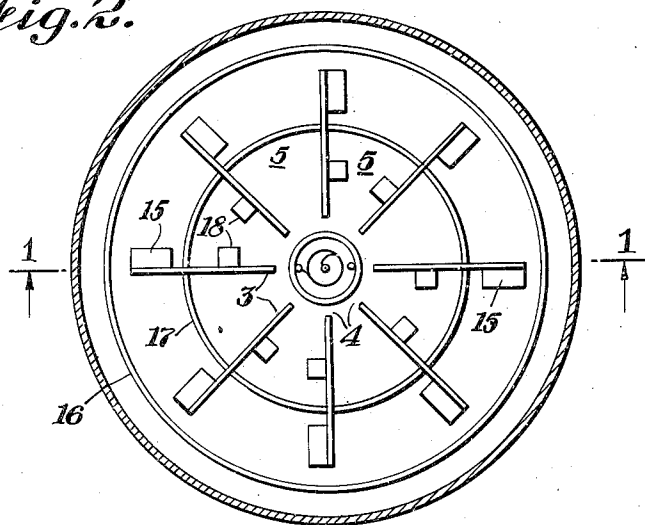


Fig. 2.



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2 Sheets-Sheet 2

Fig. 3.

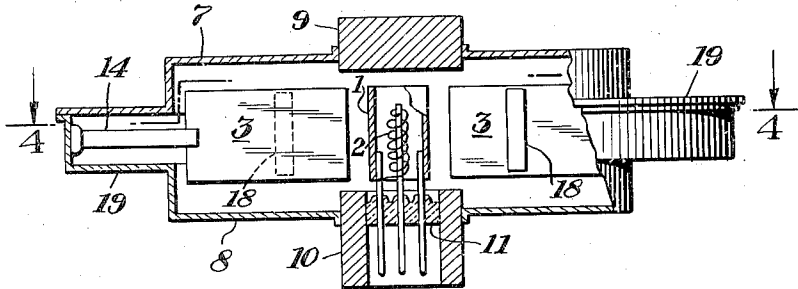


Fig. 4.

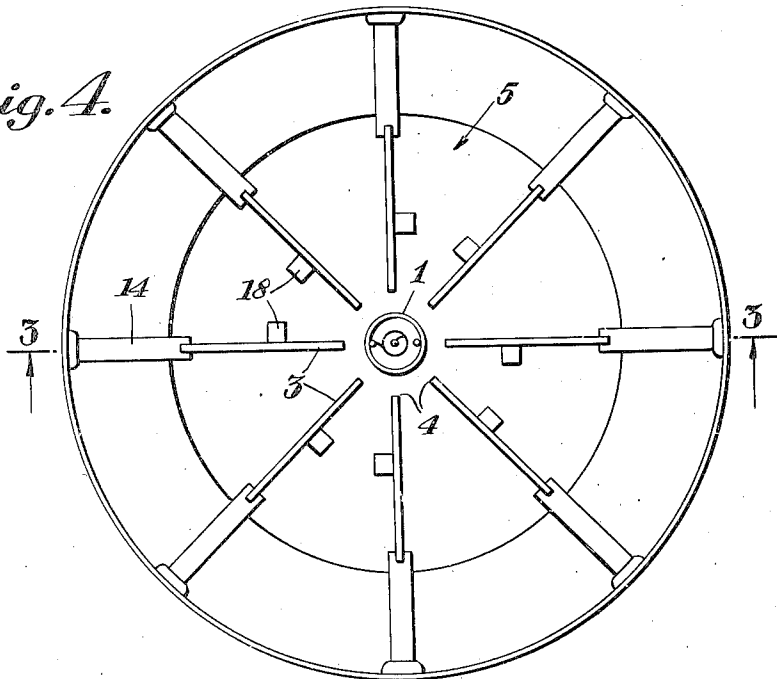
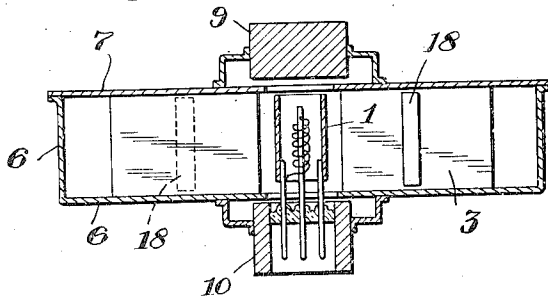


Fig. 5.



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ELECTRON DISCHARGE DEVICE

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11 Claims. (Cl. 250—27.5)

1

My invention relates to electron discharge devices, particularly to devices of the magnetron type.

Magnetrons have been proposed comprising a cathode, and an anode with a plurality of resonant cavities arranged around the cathode. Magnetic lines of force lengthwise of the cathode deflect the electrons into spiral paths around the cathode and successively past the cavity openings, which excite high frequency oscillations in the cavities. The preferred and most efficient operating mode, called the pi (π) mode, consists of excitation of alternate cavities in phase, this phase being opposite to that of the remaining cavities. When the cavities are not coupled to each other electrically, or are loosely coupled, several modes of operation in addition to the desired π mode are possible. Unfortunately, the operating conditions, such as anode-cathode voltage and magnetic field strength, of the desired and undesired modes are not widely separated. That is, slight variations in operating condition can easily cause a change in the mode of operation with consequent changes in efficiency, output and frequency. This property of the magnetron is known as "mode jumping."

If the modes can be widely separated as regards operating conditions, then the performance of the magnetron tube becomes much less critical, and in particular, if the π mode can be separated from the others, stable operation in the most efficient mode is insured. This separation of modes has in the past been attempted in various ways, including "straps" between alternate cavities to electrically tie the cavities in parallel and insure the alternate phasing. At the higher frequencies straps are mechanically impractical and furthermore they introduce heavy capacitance loading between cavity walls.

In addition to proper electrical coupling between cavities, the magnetron should have good electrical insulation between the parts carrying high frequency energy. When generating centimeter waves, for example, supports and electrode spacers of solid insulating material invariably introduce high frequency losses, shunting capacitances and the like.

An object of my invention is an improved electron discharge device of the magnetron type.

A further object of my invention is a magnetron that will operate in the most efficient mode, and yet will be stable in that mode.

More specifically, an object of my invention is a magnetron that will operate in one mode and will not easily change to a different mode.

2

A still further object of my invention is a magnetron with electrodes that are rigidly supported and spaced without the usual high frequency losses of solid insulation.

Embodiments for best illustrating the principles of my novel magnetron are described in the following specification and shown in the accompanying drawings in which

Fig. 1 is a vertical section, taken on line 1—1 of Fig. 2 of one magnetron tube embodying my invention,

Fig. 2 is a sectional view on line 2—2 of Fig. 1,

Fig. 3 is a vertical section, taken on line 3—3 of Fig. 4 of another embodiment of my novel magnetron,

Fig. 4 is a sectional view on line 4—4 of Fig. 3, and

Fig. 5 is a vertical half section of still another embodiment of my novel magnetron.

My novel magnetron comprises a tubular cathode sleeve 1 exteriorly coated with an electron emissive layer such as barium-strontium oxides and internally heated with coil 2. The sleeve is coaxial with an anode comprising a circle of vanes or fins 3, extending radially outward from the sleeve. The outer ends of the vanes terminate short of the envelope wall, and the inner ends are evenly spaced around the circle called the anode circle, with narrow slits or openings 4 between each pair of vanes. Through these openings, the electron stream induces oscillating voltage in the "cavities" 5 bounded by the vanes. The cathode and vanes are enclosed in the envelope, preferably of metal, the side wall 6 being cylindrical and coaxial with the electrodes, and being closed at the ends with round flat end plates 7 and 8. A metal or glass tubulation for exhausting and sealing the envelope may be connected at any desired point on the envelope. Magnetic pole pieces comprising round iron plugs 9 and 10 are set into and sealed centrally in the envelope end plates. The lower iron plug is tubular and internally accommodates a glass button-type header 11 through which are sealed the cathode and cathode heater leads 12. The ends of the yoke 13 of a permanent or electro-magnet fit snugly against the iron plugs and establish a strong magnetic field in the annular anode-cathode space with the magnetic lines of force substantially parallel to the cathode axis.

The vanes are each individually supported, in the embodiment of Fig. 1, on a metal stub or post 14 extending downward to the lower envelope and plate. Each vane 3 and its stub support 14

may conveniently, be stamped as a unit from relatively heavy gauge sheet metal, and the lower end of the support shaped into a right-angle foot 15 and brazed to the end plate. For electrical reasons, to be more fully described, the length of the stubs 14 is one quarter wave length at the operating frequency. Two cylinders 16 and 17 are coaxial with the circle of supports, are placed respectively inside and outside the circle and are attached to the lower end plate. Cylinder 17 is shorter in length than supports 14 so as to clear the lower edges of the vanes.

To operate, the necessary voltage is applied to the heating coil 2 to raise the sleeve to emitting temperature, and a high voltage, positive with respect to the cathode, is applied to the anode vanes. Preferably, the cathode is maintained at a high negative potential with respect to the anode so that the anode, and the connected envelope parts, may be grounded. Electrons which leave the face of the cathode are deflected by the axial magnetic field from the normal radial anode-cathode paths and are caused to spiral about the cathode. By judicious adjustment of the field strength and anode voltage, the average electron may be made to encircle the cathode several times before falling into the cathode or anode. As the electrons traverse the cavity openings 4, the electrons bunch and excite oscillations in the cavities, and in the preferred mode, the electron transit time past the openings is so regulated with respect to the resonance property of the cavities, that the high frequency voltage across each opening is in phase opposition to the voltage across the next adjacent opening. Opposite sides of each cavity may be considered as a transmission line, each line being coupled at the cathode end to an electromotive force with the electromotive forces of alternate lines in phase.

The end of each cavity remote from the voltage source is open physically and electrically, so that each cavity communicates with adjacent cavities around the ends of the vanes. Herein lies one of the important features of my invention. The open ended vanes insure close coupling, or "heavy" coupling, between adjacent cavities. The high frequency current flowing radially outward along one side of a vane must be equal to current flowing radially inward along the other side of the same vane. These two currents are actually and solidly connected in series around the outer end of the vane and must oscillate in exact phase opposition, independently of any interaction with the electron stream. Considerable variation may thus be tolerated in operating conditions, such as anode voltage and magnetic field, without disturbing this mode of operation. My method of insuring proper phasing is, essentially, to couple the cavities in series at the high current points, rather than, as usual, to couple the cavities in parallel at the high voltage points.

To insure the proper phase and voltage at the anode circle, for π mode of operation, alternate cavities contain impedance disturbing elements 18. These elements are small metal bars attached transversely across the sides of the vanes and function as lumped capacities shunted across the transmission line. When each cavity is considered as a transmission line of length θ (the length of the vane), with characteristic impedance Z_0 and when the disturbing element 18 introduces a capacitive reactance X_c in shunt with the line at a distance θ_2 from the anode circle or distance θ_1 from the outer end of the

vane, so that $\theta_1 = \theta - \theta_2$, then proper phasing and magnitude of the voltages is obtained if

$$\frac{\cos \theta + \cos (\theta_1 - \theta_2)}{2X_c} + \frac{2 \sin \theta}{Z_0} = 0$$

In a magnetron of known construction, the factors θ , and Z_0 are given directly and the necessary shunt reactance X_c for a given phase shift is determined by the high frequency properties of the line. Hence, the distance θ_1 or θ_2 may be solved from the above relation. Alternatively, an arbitrary value may be assigned to θ_1 , or θ_2 , and X_c solved for.

No electrical insulating material, except the single glass button 11 is necessary in my novel magnetron, yet the anode vanes are effectively isolated as to high frequency energy from all metal parts of the tube. The support stub for each anode vane is in effect the inner conductor of a resonant transmission line, the outer conductor of the line being the cylinders 16 and 17. The length of each stub is approximately one quarter wave length, and since the lower or envelope ends of the stubs and cylinders are short circuited, the opposite ends of the stubs present high impedance to the vanes. No inter-electrode spacers, nor envelope spacers are necessary, and since all insulating material has been removed from the high frequency fields of the tube, heating losses and undesirable reactances inside the tube are eliminated.

An alternative anode support arrangement is shown in Figs. 3 and 4. The quarter-wave stub supports 14 for the vanes, here, extend radially outward from the vanes and are attached to the outer extremity of a flattened radial extension 19 of the envelope. The sides of the envelope extension are offset toward the stubs to provide the necessary spacing for transmission-line resonance and a standing voltage wave on the stubs. With the outer end of the transmission line short circuited, the impedance at the vane-end is a maximum which, as before, permits operation of the vanes at high frequency without loss of energy to the supports.

The top and bottom end plates 7 and 8 of the envelope may, if desired, be moved into contact with the side edges of the vanes 3 as shown in Fig. 5. The outer ends of the vanes terminate short of the cylindrical envelope wall 6, and the inner ends lie in a circle close to and concentric with the cathode. The width of the openings between the inner ends of the vanes, and the distance from the cathode may be the same as in Fig. 1. The vanes and their cover plates can be enclosed in a separate envelope or may be hermetically sealed to and used as part of the envelope. The latter construction is shown. In operation, the spiraling electrons excite high frequency oscillation in the openings to the cavities, and the high frequency energy propagated lengthwise of one cavity is solidly coupled to the high frequency energy in the adjacent vanes through the openings at the outer ends of the vanes. The radial components of current in adjacent cavities are in exact phase opposition, as in Fig. 1, and the π mode is insured even during considerable variation in operating conditions. While the enclosed passages or cavities of Fig. 5 may be theoretically treated as wave guides, and the open-sided passages or cavities between vanes of Fig. 1 or 3 may be considered as transmission lines, the results are the same in that stable π mode of operation is insured with the close current coupling between cavities

at their outer ends, and the voltage excitation of alternate cavities in phase opposition, at their inner ends.

My novel magnetron is stable in operation and efficient. It will operate in the desired mode and will tolerate considerable variations in the parameters of the tube. It contains no power-absorbing straps or insulators. My magnetron is simple and rugged in construction, and is easy to manufacture and operate.

I claim:

1. A magnetron comprising an elongated cathode, a plurality of evenly spaced metal vanes extending radially outward from said cathode, the inner ends of said vanes being spaced from each other and from said cathode, the space between each pair of vanes being in open communication around the outer ends of the vanes with the spaces of adjacent pairs of vanes, a metal envelope enclosing said cathode and vanes and everywhere spaced from said vanes, separate elements supporting each of said vanes from said envelope, and additional elements operatively associated with said separate elements forming infinite impedances therewith, and a magnet with poles at the ends of the cathode.

2. A magnetron comprising an envelope, a cathode mounted centrally in said envelope, a plurality of sheet metal vanes extending radially outward from said cathode, the inner ends of said vanes being evenly spaced from each other and from said cathode, a support stub for each vane attached at one end to one of said vanes and attached at its other end to said envelope, said stubs each being approximately one quarter wave in length at the operating frequency.

3. A magnetron comprising an anode structure having a plurality of elongated circularly arranged walls forming cavities, said walls extending generally radially and each being open at its inner end and at its outer end, electronic means at the inner ends of said cavities for exciting oscillations in said cavities, a metal envelope enclosing said anode structure and said electronic means and everywhere spaced from said anode structure, separate elements supporting each of said anode walls from said envelope, and additional elements operatively associated with said separate elements forming infinite impedances therewith.

4. A magnetron oscillator comprising a tubular cathode, a plurality of sheet-metal vanes, one edge of each vane being parallel to and disposed in close spaced relation with the cathode, said vanes being uniformly spaced and extending radially outward from said cathode, an envelope enclosing said vanes and cathode, and everywhere spaced from said vanes, and separate elements supporting each of said vanes from said envelope and additional elements forming infinite impedances with said separate elements.

5. An electron discharge device comprising a cylindrical metal envelope, aligned iron plugs hermetically sealed centrally in the ends of said envelope, a tubular cathode between and coaxial with said plugs, a plurality of sheet-metal vanes in said envelope and circularly arranged in planes through the axis of said cathode, said vanes terminating at their outer ends short of the envelope wall, and separate elements supporting each of said vanes from said envelopes and additional elements forming infinite impedances with said separate elements.

6. An electron discharge device comprising a cylindrical envelope, round magnetic metal plugs

hermetically sealed centrally in the ends of said envelope, a cathode between and coaxial with said plugs, a plurality of evenly spaced sheet metal vanes in said envelope, said vanes extending radially outward from said cathode, said envelope having a flattened radial extension circumferential about the cylindrical side wall of the envelope, a support member attached to one of said vanes and to the bottom of said extension, the length of said support member within said envelope extension being about an odd number of quarter wave lengths at the operating frequency.

7. An electron discharge device comprising an anode having a plurality of circularly arranged resonators having bounding walls and cavities therebetween, each cavity being radially elongated and in open communication at both ends with the adjacent cavities, electronic means at the inner ends of said cavities for inducing oscillations in said resonators through the openings at one end of the cavities, impedance disturbing elements for interrupting the continuity, to traveling electric waves, arranged on the walls of alternate cavities to shift the phase of said waves at said one end with respect to the phase of the waves at said one end of the remaining cavities, a metal envelope enclosing said device and everywhere spaced from said bounding walls, separate elements supporting each of said bounding walls, and additional elements forming infinite impedances with said separate elements.

8. An electron discharge device comprising a metal structure containing a plurality of walls defining elongated cavities, each cavity having an opening adapted for the induction of exciting voltages into said cavities, metal members mounted transversely across the walls of alternate cavities for changing the electrical impedance of said alternate cavities with respect to the electrical impedance of the remaining cavities, a metal envelope enclosing said device and everywhere spaced from said defining walls, separate elements supporting each of said defining walls from said envelope, and additional elements forming infinite impedances with said separate elements.

9. An electron discharge device comprising a structure having a plurality of resonators having walls defining cavities, the cavities having openings successively arranged and adapted to receive exciting voltages, impedance disturbing elements on the walls of alternate cavities to adjust the phase and magnitude of voltage at the openings of said alternate cavities, said elements comprising metal protuberances on and transversely across the side walls of the cavities, a metal envelope enclosing said device and everywhere spaced from said defining walls, separate elements supporting each of said defining walls from said envelope, and additional elements forming infinite impedances with said separate elements.

10. A magnetron according to claim 1 in which each of said elements of infinite impedance comprises a quarter wave length stub attached between the one of said vanes and said envelope and a conductor attached adjacent said stub to said envelope and forming with said stub a quarter wave length transmission line short circuited by said envelope.

11. A magnetron according to claim 1 in which said elements of infinite impedance comprise a quarter wave length stub attached between each of said vanes and said envelope, said stubs being

arranged in a circle about said cathode, and two cylinders coaxial with said circularly arranged stubs and attached inside and outside said circle on said envelope, thus forming with said stubs quarter wave length transmission lines short circuited by said envelope.

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