May 10, 1927. 1,628,466

A. W. HULL

ELECTRON DEVICE AND METHOD OF OPERATING

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Fig. 1.

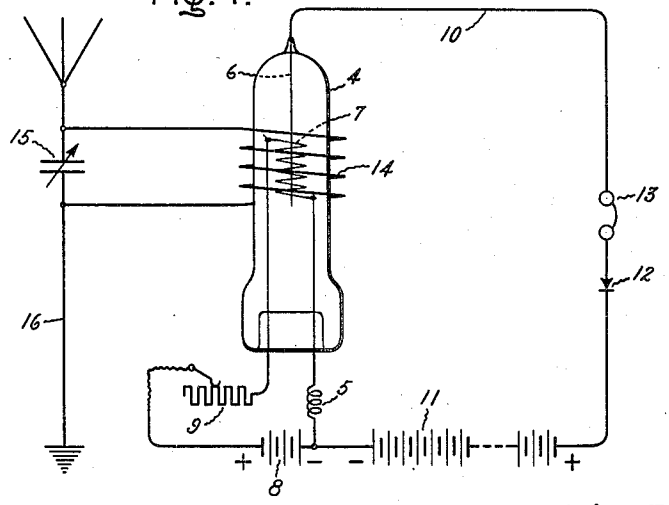


Fig. 2.

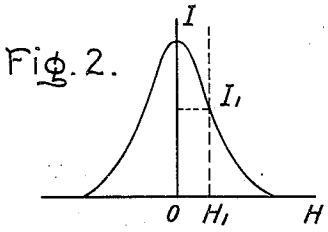
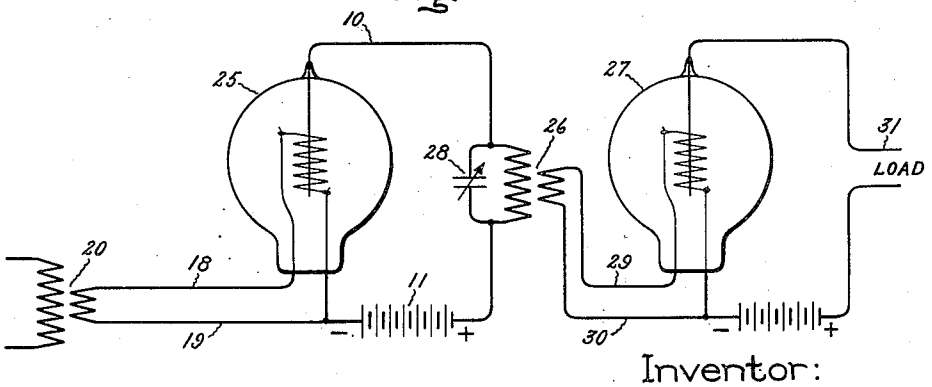


Fig. 3.

Fig. 4



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Fig. 5.

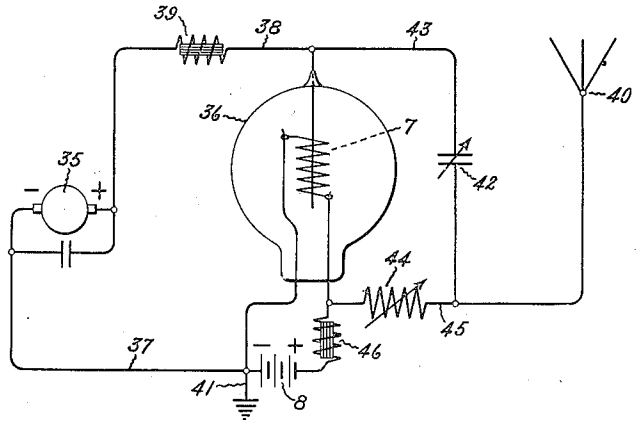
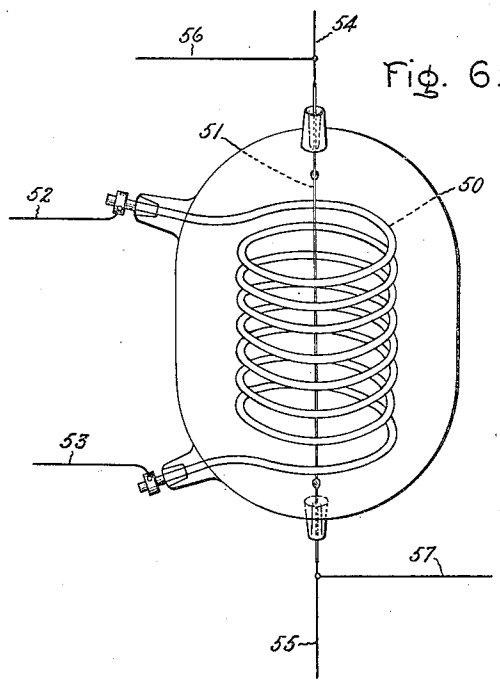


Fig. 6.



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UNITED STATES PATENT OFFICE.

ALBERT W. HULL, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ELECTRON DEVICE AND METHOD OF OPERATING.

Application filed November 15, 1921. Serial No. 515,409.

The present invention relates to devices in which an electron discharge is controlled by a magnetic field.

The present improvement relates particularly to the class of devices known as magnetrons which are described in my prior United States Patent No. 1,523,776 issued January 20, 1925, and also in the Transactions of the American Institute of Electrical Engineers for September, 1921, and in which an electron current is controlled by a magneto-strictive effect. I have described on page 718 of this article a magnetron having a helical cathode surrounding an anode which consists of a linear conductor. A magnetic field generated by an external winding, or windings, controls the electron discharge between the electrodes, for example, one winding may furnish a polarizing field and another winding may furnish a variable field which varies the electron current.

In accordance with my present invention one or all of the external magnetic windings are omitted and the magnetic flux formerly generated by the external winding is furnished by a current flowing through the thermionic cathode.

In the accompanying drawings, Figs. 1 and 5 diagrammatically illustrate respective radio receiving and sending apparatus embodying my invention; Fig. 2 is a graph showing the operating characteristic of my new device; Figs. 3 and 4 illustrate electric amplifying systems containing a magnetron operated and constructed in accordance with my invention, and Fig. 6 illustrates a magnetron in which the magnetic field parallel to the cathode is generated by a helically coiled anode.

Fig. 1 shows a magnetron 4 having an anode 6 and a helical cathode 7 surrounding the anode. The cathode is connected to a source of current represented by a battery 8 in series with an adjustable resistance 9, and a choke coil 5. The circuit 10 in series with the electrode 6, 7, contains a suitable source of direct current, as for example, the battery 11, a suitable detector, as for example, the crystal 12, and a telephone receiver 13. An external magnetic winding 14 is connected across the terminals of an adjustable condenser 15 forming part of the grounded antenna 16.

The cathode 7 may consist of a suitable refractory metal, for example, tungsten, and is proportioned to conduct a heating current in sufficient magnitude to generate a magnetic field which will materially reduce the current carrying capacity of the magnetron by magneto-striction as shown symbolically in Fig. 2. Fig. 2 illustrates the relation between magnetic field and current through the device with a given voltage, the ordinates representing current and abscissæ the magnetic field. It will be observed that the electron current is greatest when the magnetic field is zero, for example, when the magnetic field generated by the filament 7 is neutralized by the magnetic field generated by the coil 14. When the magnetic field exceeds a critical value current flow is substantially prevented. Ordinarily the device is so proportioned and the size of the cathode is so chosen that when a heating current is used which is suitable for the desired electron emission, the magnetic field will materially reduce effective electron emission from the cathode 7, or space current flow with a given applied external voltage, but will not entirely prevent the flow of current between the cathode and the anode. For example, as shown in Fig. 2, the magnetic field generated by the filament 7 may be equal to H_1, the current I_1, which is transmitted being approximately half of the value of the maximum current. When radio signals are received by the antenna 16 the alternating magnetic field generated by the winding 14 will be superimposed upon the polarizing field generated by the cathode current so that the current will vary above and below the value I_1. In this system the magnetron 4 acts as an amplifier, producing a current in the output circuit 10 which may be received in any desired manner, as for example, by the crystal and telephone receiver indicated in the drawing.

In the system shown in Fig. 3 both the polarizing field and the variable magnetic fields are generated by current flowing in the cathode of the magnetron. The input circuit 18, 19 is connected to the secondary of a transformer 20 the primary of which may receive current from any source, as for example, current from a telephone system or from a radio antenna. The conductors 18, 19 are connected to the terminals of a helical

cathode 7. The heating current for the cathode is furnished by a battery 21 which is connected in series with a choke coil 22 to prevent short circuiting the alternating current in the circuit 18, 19. The current source 21 is adapted to generate a polarizing magnetic field in the coiled cathode 7. The variable current received from the input circuit 18, 19 is superimposed upon this heating current, thereby generating a resultant field which controls the electron current through the magnetron, and therefore the amplified current in the external circuit 10, the potential of the source 11 being suitably chosen with respect to this resultant magnetic control field. A telephone receiver has been indicated in the output circuit 10, but of course any suitable translating device may be used.

In Fig. 4 the cathode is heated to incandescence entirely by the alternating or variable current to be amplified. The output circuit 10 of the magnetron 25, containing a current source 11, has been shown as connected to the primary of a transformer 26, the secondary of which is connected to the terminals of the cathode of a second magnetron 27. If desired an adjustable tuning condenser 28 may be provided in shunt with the primary winding of the transformer 26, particularly when the system is to be used for amplifying high frequency currents. The input circuit 29, 30 of the magnetron 27 receives amplified current from the output circuit 10 of the magnetron 25 through the transformer 26. In case the current in the circuit 18, 19 is alternating-current, for example, when as shown, this circuit is supplied by a transformer, then the frequency of the amplified current in the output circuit 10 is double the frequency of the current in the circuit 18, 19. The frequency is again doubled by the magnetron 27 so that in the output circuit 31 the frequency is four times the original frequency.

Due to the action of the magnetic field in reducing the current carrying capacity of the device by the deflection of electrons in their passage from cathode to anode, an increase of current in the cathode circuit will be accompanied by a decrease, or even an entire cessation of space current between the cathode and the anode, even though the electron emitting capacity of the cathode is increased by an increase of temperature. Therefore, a slight variation of cathode temperature by the variability of the current in the input circuit has no effect upon the operation of the device providing that the cathode temperature is high enough at all times to furnish electrons in sufficient numbers to carry the current as governed by the other conditions, such as the voltage applied between the cathode and anode, and magnetic field conditions. Current in the output circuit 31 may be utilized for any desired purpose.

In the radio sending apparatus shown in Fig. 5, the coiled cathode 7 functions as an inductive reactance, as well as generating the entire controlling field parallel to the axis of electrodes. Power is derived from a direct current generator 35 which is connected to the cathode and the anode of the magnetron 36 respectively by the conductor 37, and a conductor 38 containing a choke coil 39. The antenna 40 is connected to the grounded conductor 41 in series with the inductive cathode 7. An adjustable tuning condenser 42 is provided in a circuit 43 in shunt to the cathode and anode circuits. A small adjustable inductance 44 may be included in the circuit 45 which is common to both the circuits 40 and 43 but this inductance may be omitted, as the inductance of the cathode 7 will suffice for most purposes.

An oscillatory current is generated in the circuit 40 when properly tuned, by the cooperation of the capacity of the antenna to ground, the inductance of the cathode, and the control of the electron current in the tube by the magnetic field of the cathode current. A choke coil 46 keeps oscillatory current out of the cathode heating circuit.

In the magnetron shown in Fig. 6, a helically coiled anode 50 surrounds the linear cathode 51. The anode 50 may consist of copper tubing, so that a stream of cooling fluid may be conducted therethrough. An input circuit 52, 53 is connected to the anode to conduct a current to generate therein a field substantially parallel to the cathode. In some cases the circuit 52 may be omitted and instead of a separate magnetizing current the electron current which flows from the cathode through the space to the anode and thence through the turns of the anode coil may be used to generate a magnetic control field parallel to the cathode. This field may function as a polarizing field in conjunction with a field furnished by an external winding (not shown) as in the case of the device shown in Fig. 1, or it may generate a magnetic field having a variable component as in the case of the devices shown in Figs. 3 and 4 so that external field coils are unnecessary. The cathode heating circuit 54, 55 and the output circuit 56, 57 have been indicated but as the operation of a magnetron embodying my invention has been described in connection with Figs. 1, 3, 4 and 5 a complete system has not been shown.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. An electron discharge device having an electron-emitting cathode and an anode, one of said electrodes being helically arranged with respect to the other electrode and hav-

ing an electrical conductivity sufficiently high to conduct a current of sufficient magnitude to generate a field parallel to the axis of said cathode capable of effectively decreasing by magneto-striction an electron discharge between said electrodes.

2. An electron discharge device having an anode, a helical cathode surrounding said anode, said cathode having an electrical conductivity so related to electron emissivity that when said cathode is heated by current conducted therethrough to a temperature at which electrons are produced, then the magnetic field generated by said heating current will be capable of controlling by magneto-striction an electron discharge between said electrodes at a given operating voltage.

3. An electron discharge device comprising electrodes disposed in circular symmetry with respect to each other, one of said electrodes comprising a cathode, the conductivity of which is high enough to convey a current of sufficient magnitude to heat the same to incandescence and to generate a magnetic field substantially parallel to the axis of said cathode capable of materially suppressing current flow between said electrodes at a given voltage impressed between said electrodes.

4. An electron discharge device comprising an anode and a cathode helically arranged about said anode and being adapted to be heated to incandescence by passage of current, the conductivity of said cathode being high enough to permit the same to conduct a heating current having a magnetic field capable of effectively suppressing electronic conduction between said electrodes below a critical voltage and means for varying the current conducted by said cathode.

5. A magnetron having an anode, a helical cathode arranged with respect to said anode that a current conducted through said cathode will generate a field substantially perpendicular to an electron discharge between said electrodes, said cathode having sufficient current carrying capacity to conduct a current, the magnetic field of which is capable of reducing the current carrying capacity of said magnetron while being heated at the same time to incandescence, and means for varying said field to control the current conducted by said magnetron.

6. An electron discharge apparatus comprising a helical cathode having sufficiently high conductivity to conduct a current whereby a magnetic field substantially parallel to the longitudinal axis of said cathode may be generated which is capable of controlling effective electron emission from said cathode, and an external magnetic winding for said magnetron.

7. An electrical discharge apparatus having cooperating electrodes, one of which is coiled about the other in such relation that a magnetic field generated by current conducted through said coiled electrode will be substantially normal to an electron discharge between said electrodes and the conductivity of said electrode being sufficiently great to permit carrying a current which will exert a magneto-strictive effect upon said electron discharge at an effective working voltage impressed between said electrodes.

8. An electron discharge apparatus comprising electrodes arranged in circular symmetry with respect to each other separated by an evacuated space, one of said electrodes being arranged to enable a current therethrough to produce a field parallel to the axis of said electrode, an output circuit connected to said electrodes, the conductivity of said field-producing electrode being sufficient to permit operation with a current producing a magnetic field of sufficient magnitude to prevent electron conduction between said electrodes at the operating voltage of said output circuit, an input circuit connected to the terminals of said field-producing electrode, and means in said circuit for supplying a current which varies periodically between a value low enough to permit flow of electrons between said electrodes and a higher value at which the flow of electrons is prevented.

9. The method of operating a magnetron having an electrode coiled about the main axis of the discharge path which consists in conducting through said electrode a current of sufficient magnitude to produce a magnetic field substantially parallel to said axis and being capable of reducing the current-carrying capacity of said device.

10. An electron discharge apparatus comprising a supply circuit, a discharge tube having electrodes connected to said supply circuit, one of said electrodes being helically coiled about the other electrode and having a current-carrying capacity sufficiently high to conduct a current the magnetic field of which will control a current in said circuit, and means for varying said field.

11. An electron discharge device comprising an evacuated container, two electrodes only in said container, means for producing electrons at one of said electrodes, one of said electrodes being arranged in helical relation to the other electrode, and having sufficiently high current carrying capacity to conduct a current capable of exerting a magneto-strictive effect on the current between said electrodes.

12. The method of operating a magnetron containing electrodes, one of which is helically arranged with respect to the other which consists in transmitting a space current between said electrodes, conducting through said helical electrode a current of sufficient magnitude to produce a magnetic field whereby said space current may be

controlled and varying said field to produce desired variations in the value of said space current.

13. The method of operating an electrical discharge device having a rod-like anode and a helical cathode coiled about said anode which consists in conducting through said cathode current sufficient both to heat said cathode to an electron-emitting temperature and to exert an effective magneto-strictive effect upon an electron current between said electrodes at a given voltage.

14. The method of operating an electrical discharge device having a rod-like anode and a helical cathode coiled about said anode which consists in conducting through said cathode a substantially constant current sufficient both to heat said cathode to an electron-emitting temperature and to exert an effective magneto-strictive effect upon an electron current between said electrodes at a given voltage and superimposing upon said constant heating current a variable current whereby the electron current conducted at the given voltage will be varied.

15. A current controlling apparatus comprising the combination of an electron discharge device having a thermionic cathode and an anode one of said electrodes being coiled about the other, means for conducting through said coiled electrode a current of sufficient magnitude to generate a magnetic field capable of materially reducing said discharge, means for varying said field, an output circuit connected to said electrodes, a source of energy in said output circuit, a load device in said output circuit and means for the passage of variable current from said output circuit to the circuit of said coiled electrode.

In witness whereof, I have hereunto set my hand this 14th day of November, 1921.

ALBERT W. HULL.