May 21, 1968 H. M. OLSON, JR 3,384,783

MODE SUPPRESSION IN COAXIAL MAGNETRONS HAVING DIVERSE SIZE ANODE RESONATOR

Filed Dec. 16, 1965 2 Sheets-Sheet 1

FIG. 1

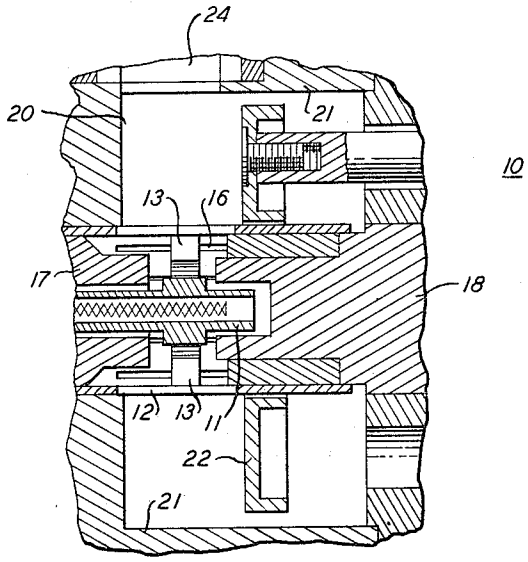
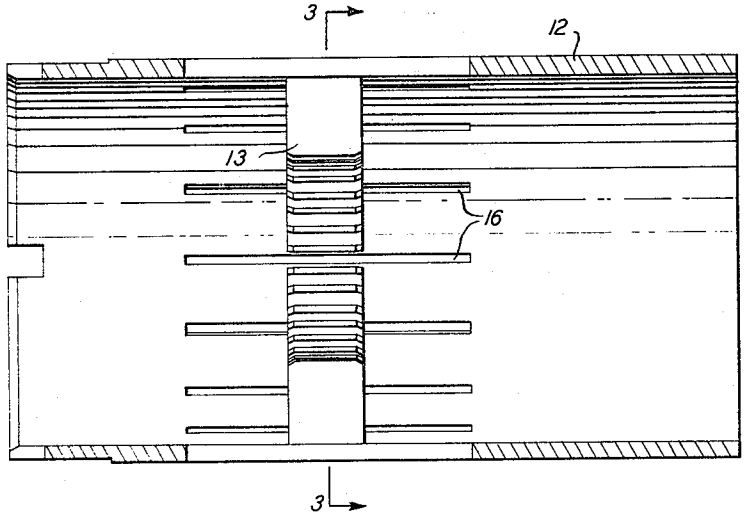



FIG. 2




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FIG. 3

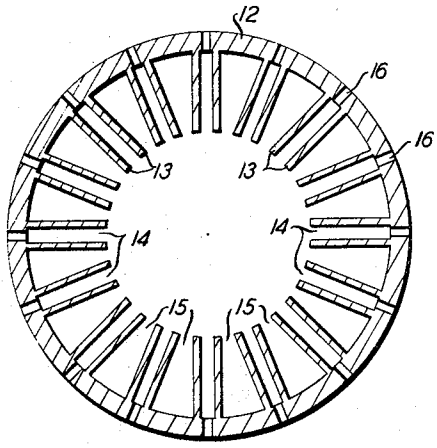



FIG. 4

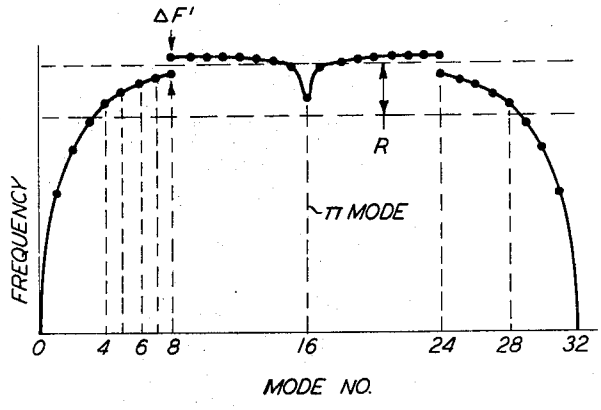
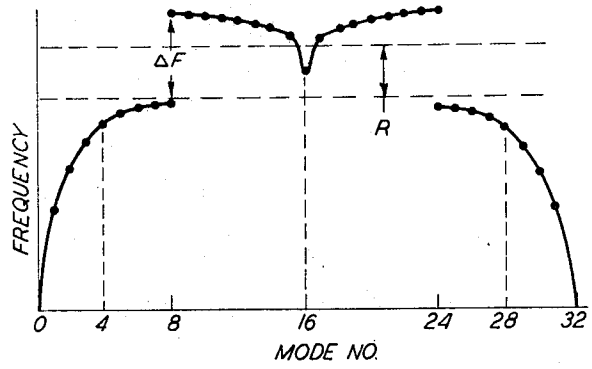



FIG. 5



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# MODE SUPPRESSION IN COAXIAL MAGNETRONS HAVING DIVERSE SIZE ANODE RESONATOR

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6 Claims. (Cl. 315—39.77)

This relates to magnetrons, and more particularly to coaxial cavity magnetrons.

A magnetron is a device for generating high radio frequency or microwave oscillations through excitation of a resonant structure by a crossed-field focused electron stream. As is pointed out, for example, in the patent of Drexler, 3,034,014, issued May 8, 1962, an advantageous configuration known as the coaxial cavity magnetron comprises a cylindrical cathode surrounded by a cylindrical anode having an array of vanes radially extending toward the cathode, which in turn is surrounded by an annular outer resonator. A magnetic field together with an electric field between the cathode and anode forces emitted electrons to follow a more or less circular path between the cathode and the anode vanes. Successive vanes define anode resonators in which energy oscillates at a characteristic frequency in response to field excitation by the electron stream. Predominant oscillation takes place in the $\pi$ mode, which is characterized by opposite electric polarities at adjacent vane tips at any given instant. Alternate anode resonators are coupled to the $TE_{011}$ oscillatory mode of the outer resonator by slots extending through the cylindrical anode wall. A movable tuning ring in the outer resonator adjusts the frequency of output oscillations from the outer resonator over a frequency band that roughly corresponds with the $\pi$ mode frequency.

Because of many competing modes of oscillation other than those described, the device tends to be unstable; the output microwave power is not always a predictable function of input power. Substantial efforts have been made to damp out and suppress spurious oscillations that take place, for example, in the array of coupling slots and around the tuning ring. While various modifications of the annular resonant structure have improved device stability, problems of competing oscillatory modes at discrete frequencies within the tuning range still persist. I have found that at these frequencies the desired operating mode is damped because of coupling to modes which originate in the anode resonant structure. If these effects are to be suppressed, the competing anode modes should be restricted to characteristic frequencies which are outside the tuning range of the magnetron.

The various anode oscillatory modes can be identified by the number of spatial cycles of the mode around the anode structure at one instant of time. For example, if a given mode of oscillation defines six spatial cycles around the anode structure at a given instant, it will be referred to as a No. 6 mode. With a 32-vane resonator, the $\pi$ mode would be defined as the No. 16 mode because alternate polarities on adjacent vanes would give 16 spatial cycles around the 32-vane anode structure.

As will be explained more fully later, I have found that the $\pi$ mode tends to couple with certain lower numbered and higher numbered modes, and as a result, $\pi$ mode energy is coupled into and dissipated by these other modes. For example, in a 32-vane magnetron the desired $\pi$ mode or No. 16 mode tends to couple with the Nos. 4, 5, 6, 7, 8, and Nos. 24, 25, 26, 27, and 28 modes. If these interfering anode modes could be displaced from the frequency band of magnetron operation, they could be prevented from coupling to the desired $\pi$ mode and thereby from unnecessarily loading the $\pi$ mode and disrupting the buildup of oscillations in the $\pi$ mode.



In accordance with the invention, alternate anode resonators are made small with respect to the remaining resonators. The anode vanes on opposite sides of an anode coupling slot are spaced closer together so that the alternate anode resonators that are coupled to the outer resonator are smaller and have a higher resonant frequency than the remaining anode resonators. On the other hand, the spacing of adjacent vane tips should be as uniform as possible to maintain the proper field configuration in the interaction region between the cathode and anode. Preferably, the uncoupled resonant frequency of each of the small resonators is higher than the frequency tuning range of the outer resonator and the resonant frequency of each of the large resonators is lower than the outer resonator frequency tuning range.

My anode structure has the effect of shifting the frequency of the interfering mode numbers so that they lie outside the tuning range of the magnetron. They are sufficiently far removed in terms of frequency from the $\pi$ mode as to avoid or reduce coupling with the $\pi$ mode and therefore with the $TE_{011}$ mode of the outer resonator. The result is a more stable and dependable operation of the coaxial cavity magnetron.

These and other features and advantages of the invention will be better appreciated from a consideration of the following detailed description, taken in conjunction with the accompanying drawing, in which:

FIG. 1 is a fragmentary view of a coaxial cavity magnetron in accordance with the invention;

FIG. 2 is a sectional view of the anode structure of the magnetron of FIG. 1;

FIG. 3 is a section taken along lines 3—3 of FIG. 2;

FIG. 4 is a graph of frequency versus mode number in a conventional coaxial cavity magnetron; and

FIG. 5 is a graph of frequency versus mode number in a coaxial cavity magnetron in acordance with the invention.

Referring now to FIG. 1, there is shown a fragmentary sectional view of a coaxial cavity magnetron **10** having a cylindrical cathode **11** surrounded by a cylindrical anode **12**. As is best shown in FIGS. 2 and 3, the anode **12** includes a plurality of anode vanes **13** which define therebetween a plurality of anode resonators **14** and **15**. In accordance with the invention, the alternate resonators **14** are smaller than the remaining resonators **15**. A plurality of coupling slots **16** extend through the anode **12** along the major portion of its length and parallel to its axis to communicate with the smaller anode resonators **14**. Extending into opposite ends of the cylindrical anode **12** are magnetic pole pieces **17** and **18** that are of opposite magnetic polarity. Encompassing anode **12** is an outer cavity resonator **20** which is defined between the anode and an outer cylindrical wall **21**.

When the cathode **11** is heated, electrons are emitted in a stream that flows between the cathode and the anode vanes **13**. An electric field between the anode and cathode coacts with the magnetic field between pole pieces **17** and **18** to constrain the stream to flow around the periphery of the cylindrical cathode. The fields of the electron stream excite oscillatory wave energy in the anode resonators **14** and **15** which is coupled to the outer cavity resonator **20** by way of coupling slots **16** where it oscillates predominately in the $TE_{011}$ mode, as is known in the art. The resonant frequency of the outer resonator **20** can be adjusted by moving a tuning ring **22** axially within the outer resonator. Output wave energy is coupled out of the device by an output waveguide section **24** which transmits it to an appropriate useful circuit.

The conventional coaxial cavity magnetron has anode resonators of uniform size rather than the alternately

small and large resonators **14** and **15** shown in FIG. 3. It is customary to design coaxial cavity magnetrons so that the primary mode of oscillation within the anode resonant structure is characterized by opposite instantaneous electrical fields between adjacent tips of the anode vanes **13**, or more precisely, a 180 degree phase difference between adjacent vane tips. The anode resonators are designed so that this mode, known as the $\pi$ mode, is of approximately the same frequency as the resonant frequency of the outer resonator **20**.

As mentioned before, the oscillatory mode components in the anode resonant structure are identified by the number of spatial cycles around the anode which occur at one instant in time. For example, if a given mode of oscillation defines six spatial cycles around the anode structure a given instant, it is referred to as the No. 6 mode. With the 32-vane resonator as shown in FIG. 3, the $\pi$ mode is defined as No. 16 mode because 180 degree phase differences between successive vanes give sixteen spatial cycles around the 32-vane structure.

It is the practice to design the anode of a conventional 32-vane coaxial cavity magnetron so that the frequency of the $\pi$ mode or No. 16 mode is placed just above the frequency tuning range of the outer resonator. When the $\pi$ mode is coupled to the $TE_{011}$ mode of the outer resonator the resonant frequency of the coupled pair of modes is approximately that of the $TE_{011}$ mode alone, because energy storage is primarily in the $TE_{011}$ mode. The frequency of the $\pi$-$TE_{011}$ mode combination can be tuned over a range of frequencies by moving the tuner in the outer resonator. FIG. 4 shows a graph of relative frequency vs. mode number in a conventional 32-vane coaxial cavity magnetron, viz, a coaxial magnetron having anode resonators of uniform size. Because of the strong coupling of the $\pi$ mode to the $TE_{011}$ mode the $\pi$ mode or No. 16 mode is shifted to a lower frequency than the No. 15 or the No. 17 mode.

I have found that one of the causes of instability in the conventional magnetron results from coupling of the lower numbered modes with the $\pi$ mode. As is shown in the typical characteristic appearing in FIG. 4, most of the lower numbered modes, that is, modes number 1 through 3 and 9 through 15, lie outside the frequency range R of the magnetron and therefore do not tend to couple to the $\pi$ mode. The modes numbered 5 through 8 lie within the frequency range R and therefore tend to couple to the desired $\pi$-$TE_{011}$ mode and to damp it as described before. My analysis has indicated that if the frequencies of the interfering lower numbered modes could be shifted outside the tuning range R, these effects could be reduced or substantially eliminated.

I have further found that the structure shown in FIG. 3 separates the lower numbered modes into two sets of modes with a frequency difference $\Delta F$ between the two sets as shown in the graph of FIG. 5. The anode structure of FIG. 3 is designed so that the anode resonators **14** have higher resonant frequencies than the alternate resonators **15**. As the frequency difference $\Delta F$ becomes more pronounced, the modes numbered 4 through 8 will be shifted outside the range of tuning frequencies R as shown in FIG. 5. As a result, the frequency of mode No. 16 is so far removed from that of the other anode mode numbers as to reduce or substantially eliminate any coupling of the No. 16 mode with the other anode resonator modes. Because the No. 16 mode is not damped by these other anode resonator modes, the buildup of oscillations in the No. 16 mode is not impeded by the other modes, and the magnetron operates with more stability. It should be noted that the conventional magnetron has a relatively small separation $\Delta F'$ between the frequencies of the intermediate mode number and the higher and lower mode numbers, as shown in FIG. 4. This is a result of small resonant frequency differences of the slotted and unslotted resonators. My magnetron essentially exaggerates the differences of the slotted and unslotted resonators to give an exaggerated frequency difference $\Delta F$.

Consider next the design of a coaxial cavity magnetron in accordance with the invention having an anode structure as shown in FIG. 3. As a typical example, assume that the magnetron to be built is to have a tuning range of 15.5 to 17.5 kilomegacycles per second. The anode of FIG. 3 should be designed such that the uncoupled self-resonant frequencies of the small resonators **14** are just above the tuning range R, while the self-resonant frequencies of the large resonators **15** are just below the tuning range. For example, the resonator frequencies of resonators **14** should be made approximately 17.8 kilomegacycles per second and the frequencies of resonators **15** should be made approximately 15.2 kilomegacycles. When the anode resonator is coupled to the outer resonator, the frequency of the No. 16 mode will be reduced to fall within the operating range, while the lower numbered modes will remain outside the operating range as shown in FIG. 5.

Depending on the other characteristics of the magnetron and the frequencies which are being used, this method of design may be somewhat inaccurate since it ignores the coupling between resonators. A greater accuracy can be achieved by computing the mode spectrum of the slotted group of resonators **14** while assuming the other group to be filled with metal, and then computing a mode spectrum of the unslotted resonators **15** while assuming the resonators **14** to be filled with metal. These spectra can be combined into a mode spectrum for the two groups of resonators as described in the book "Microwave Magnetrons" by Collins, McGraw-Hill, Chapter 3. However, the increased complexity of this method of design may not be justified by the improved accuracy of the results. Experimental adjustment of the mode spectrum may prove to be simpler.

In designing the magnetron, the distance between adjacent anode vane tips should be made as uniform as possible for optimum $\pi$ mode formation. I have found that one can design the anode structure by first designing a conventional structure with a resonant frequency just above the tuning range, as for example, 17.6 kilomegacycles. The design of such an anode can be obtained experimentally or approximated by using the information in the aforementioned Collins book. Next, the vanes are shifted circumferentially at their bases so as to reduce the size of the slotted resonators at the same time increasing the size of the unslotted resonators. In practice, the width of the coupling slots **16** limits the extent of shift of the anode vanes. If the tips of the anode vanes are maintained in their original positions, this design practice will usually give a sufficiently high frequency difference $\Delta F$ as shown in FIG. 5 to accommodate a reasonably wide tuning range R in accordance with the invention.

The embodiment described is intended to be merely illustrative of the principles of the invention. Various other modifications and embodiments may be made by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

**1.** In a coaxial cavity magnetron of the type having a substantially cylindrical cathode, a cylindrical anode wall surrounding the cathode, an outer annular resonator surrounding the cathode, a plurality of anode vanes extending from the anode wall toward the cathode, and a plurality of slots in the anode wall for coupling energy to the outer annular resonator, the improvement comprising:

anode resonators defined between adjacent anode vanes which are alternately small and large, whereby the oscillatory modes of the anode resonators are separated into a lower frequency set and a higher frequency set;

and means for tuning the outer resonator to a frequency that is intermediate the characteristic frequencies of the lower and higher frequency sets of anode resonator modes.

2. The improvement of claim 1 wherein:
the self-resonant frequency of each of the small resonators is higher than the resonant frequency of the outer resonator, and the self-resonant frequency of each of the large resonators is lower than the resonant frequency tof the outer resonator.

3. The improvement of claim 2 wherein:
all of the anode vanes are substantially the same length;
the distances between adjacent free ends of the vanes are substantially uniform;
and the distances between the bases of adjacent vanes are alternately relatively large and relatively small.

4. The improvement of claim 1 wherein:
the anode wall slots interconnect each of the small resonators with the outer resonator.

5. The improvement of claim 3 wherein:
the anode wall slots interconnect only each of the small resonators with the outer resonator.



6. The improvement of claim 2 wherein:
the tuning means includes means for changing the resonant frequency of the outer resonator over a range;
the self-resonant frequency of each of the small resonators is higher than any frequency in said range and the self-resonant frequency of each of the large resonators in lower than any frequency in said range.

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