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USE OF A CONVERTED MAGNETRON FOR MAKING AN ELECTRIC GENERATORS WITH RADIOISOTOPES OR A CONVERTING CELL OF THE FISSION NUCLEAR ENERGY

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Abstract: In this paper the working principle of a magnetron is examined from the standpoint of the accomplishing of the necessary transformation of this device. The working is explained of the electric generator with radioisotopes as well as of the converting cell of the fission nuclear energy by using a modified magnetron. Both the electric generator with radioisotopes and the converting cell of the fission nuclear energy represent energy sources supplied in the form of micro-wave - the main power source - and of direct current - the secondary reduced power source.

1. Introduction

The first electronic tube to make a high power source of micro-waves was the magnetron that uses two electromagnetic fields - one constant and the other oscillant - superposed on one another. In both these electromagnetic fields, the magnetic field and the electric field are in quadrature. The constant magnetic field is parallel with the oscillant magnetic field.

The magnetron is one of the most elaborate oscillators in the microwave field / 1, 2, 3, 4, 5, 6/. There are many laborious studies describing this electronic device. Hereafter, the

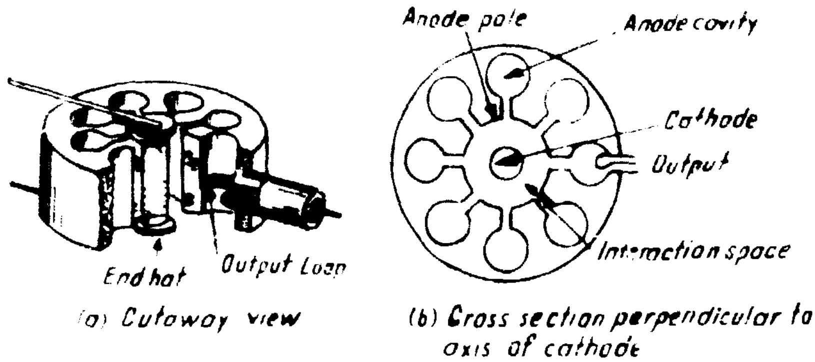

Fig. 1

Diagrams showing principal physical features of the cavity magnetron oscillator /3 /.

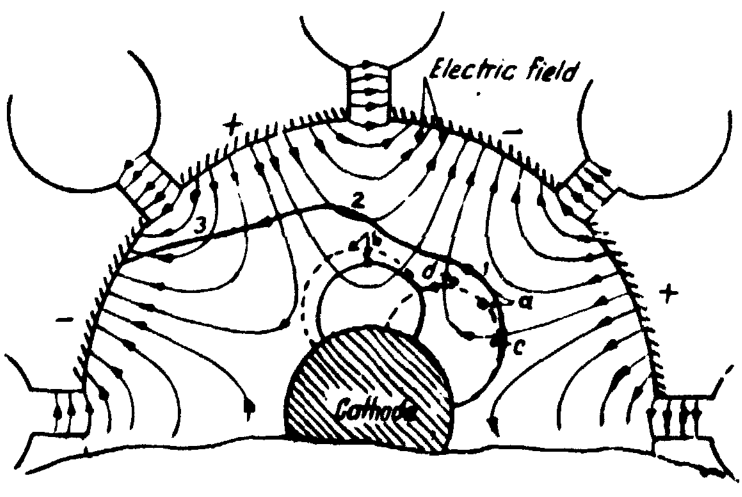

Fig. 2

Paths traversed by various electrons in a magnetron under oscillating conditions /3 /

working principle of the magnetron is explained from a less usual standpoint, that offers however the advantage of better emphasizing the applications of this vacuum valve to the energy conversion.

Figure 1 represents a cross-section of a magnetron. Figure 2 represents the rough distribution of the oscillating electric field at a certain time. Figure 3 offers only the tangential component of the oscillating electric field at a certain time. The radial component of the oscillating electric field is superposed on the component of the constant electric field which has a high value. The high value of the constant electric field diminishes the role of the radial component of the oscillating electric field. This radial component gives the electrons an additional acceleration with regard to the direct current component of the electric field (electron c fig. 2) or decelerates them (electron d fig.2) and consequently focusses them arround the electron beam (elec - tron a fig. 2) which are yielding the best part of their energy to the electromagnetic wave.

The electrons yield energy to the electromagnetic wave through the agency of the tangential component of the latter. In leaving the cathode by thermoionic emission, the electrons possess a low kinetic energy that undergoes a strong dispersion. The radial electric field due to the direct current begins to accelerate them at their very coming out of the cathode and after a short enough acceleration travel the electron dispersion diminishes appreciatively. When the kinetic energy, i.e. the electron velocity increases, the action of the axial magnetic field of the magnetron grows stronger. Under the combined action of the axial magnetic field and of the radial accelerating electric field (both stationary fields), the electron undergoes a beginning of an open spiral motion. Following its spiral course, this motion becomes approxi - mately tangential to the magnetron geometry (fig. 3). When meeting the tangential component of the oscillating electric field - in a situation favouring its acceleration, the electron is still more accelerated by the energy borrowed from the electromagnetic wave.

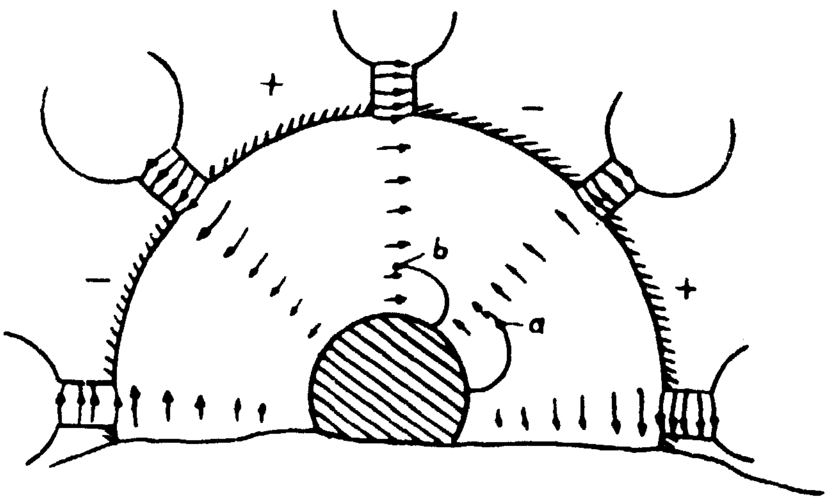

Fig. 3

Tangential component of the oscillating electric field at a certain time.

As a result of this additional acceleration, the spiral described by the electrons is closed owing to the stronger action of the magnetic field due to a non-zero velocity of the electrons, elec - tron b (fig. 2). These electrons are thus turned back toward the cathode . They are now in the oscillating electric field possessed of an unfavourable phase for the upkeeping of the electromagnetic oscillation and as such they represent only consumers of the electromagnetic wave power.

If the tangential component of the oscillating electric field is met by the electrons when their movement is parallel to this component - in a situation of deceleration - they yield energy to the electromagnetic wave continuity to move but along an opering spiral until they reach the anode (electron a, fig. 2) Theoretically the energy increase of these electrons within the constant radial electric field is almost integrally yielded to the electromagnetic wave and the electrons reach the anode with a diminished energy. This behaviour explains the rather high efficiency - 30-60% of the magnetron. The energy consumed by the out-of-phase electrons falling on the cathode is about 5% of the energy consumed by the magnetron. The above-mentioned behaviour both of the electrons yielding energy to the electromagnetic wave and of these borrowing energy from the electromagnetic wave is valid for the electrons that, in the absence of the electromagnetic oscillations, come back on the cathode under the influence of the axial magnetic field. In the absence of the oscillations, the relation between the axial magnetic field and the applied anode voltage is such that the current in the tube is null. At a given anode voltage the magnetic field that cuts the anode current takes the name of cut-off magnetic field. In normal oscillating operating conditions, the magnetic field of the magnetron has a higher value than that of cutt-off magnetic field.

2. Converting a magnetron so as to make it work as an electric generator with radioisotopes

So as to give a simpler explanation of the transformations to the imposed on a magnetron to make it an electric generator with radioisotopes it is necessary to emphasise the character of rotating field of the oscillating electric field of a magnetron.

Both radial component E_r and tangential component E_t of the oscillating electric field can be considered as rotating electric fields

$$E_r = E_{or} \sin (\omega t - \alpha_r)$$
$$E_t = E_{ot} \sin (\omega t - \alpha_t) \qquad (1)$$

where

$$\alpha = \alpha_o + \frac{\omega}{2p} t$$

2p - is the number of pairs of poles of the magnetron.

The angular rotation velocity of these fields is

$$\Omega = \frac{\omega}{2p}$$

In a magnetron, the electrons the tangential velocity of which is at such a phase with regard to the tangential electric field that they yield energy to this field, rotate concomitantly with it. The rotation, cophasal with the tangential electric field is achieved by keeping constant the angular velocity of the electrons i.e. the same as that of the tangential electric field Ω . This constant angular velocity Ω is obtained by means of the energy these electrons borrow from the radial of direct current electric field and by the influence of the constant axial magnetic field that produces the rotation of the electrons, i.e. the direction of the radial velocity.

So as to realize an electric generator with radioisotopes by means of a magnetron, its cathode is replaced by a cylinder the lateral surface of which is covered by a thin layer of an α or β

radioactive substance. The thermoionic emission is so replaced by the α or β radiation. If a single radioactive substance is used, the energetic dispersion of the radiation is relatively small and depends on the thickness of the substance layer.

As compared with the working of the ordinary magnetron the working of the magnetron converted into an electric generator with radioisotopes offers two different characteristics :

a) In the ordinary magnetron the electrons leaving the cathode possess a small energy and are accelerated by the cons - tant radial electric field. In the electric generator with radio-isotopes the α or β particles leave the cathode of their highest energy and there is no more radial field of acceleration.

b) In the ordinary magnetron the electrons which do not fulfill the "space" condition with regard to the oscillating field are back-reflected on the cathode by the axial magnetic field in a neighbouring zone of the cathode before they could acquire too high a velocity. In the electric generator with radioisotopes this process is impossible since the particles leaving the cathode have already reached their highest velocity.

The subsequent transformations of the magnetron are based on these differences.

In the electric generator with radioisotopes obtained from the converted magnetron, the axial magnetic field should be equal to the cut-off magnetic field or smaller than it. So as to show the working manner of this device, figure 4, 5 and 6 represent three working cases where the axial magnetic field is larger than the cut-off magnetic field. Figure 4 represents this working in the case of a constant axial magnetic field. Figure 5 represents this

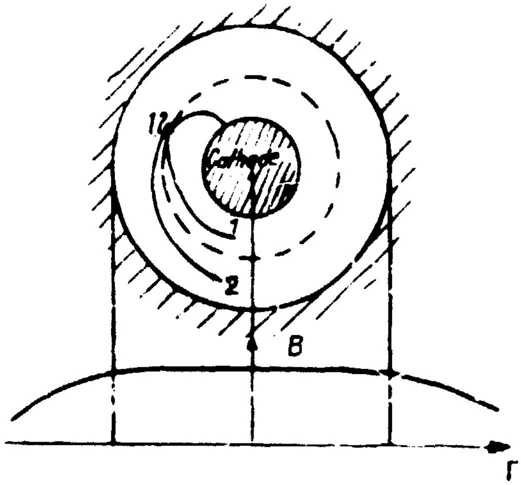

Fig. 4

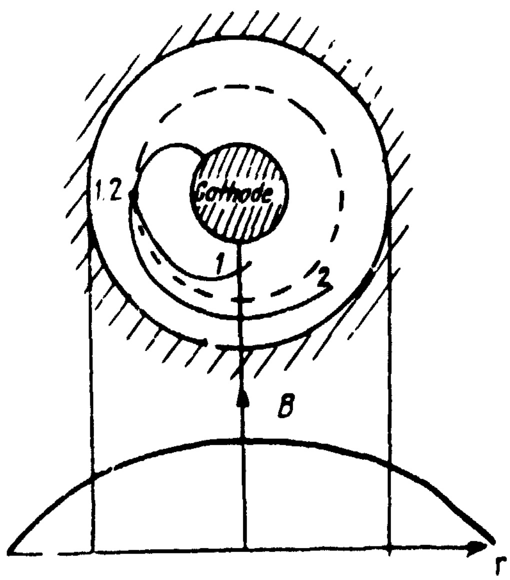

Fig. 5

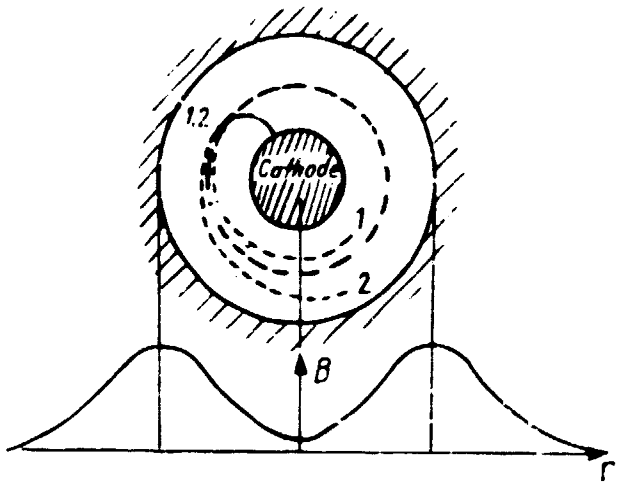

Fig. 6

working when the axial magnetic field is decreasing from the cathode to the anode while figure 6 shows it in the case of an axial magnetic field growing on towards the anode.

In all three cases, after leaving the cathode an orbit is initially formed for the emitted particles which they reach by a shorter or longer way according to the configuration of the axial magnetic field through which they travel. This orbit radius R_o is

$$R_o = \frac{m\, v_o}{q\, B_o} \qquad (2)$$

where

m - is the particle mass

v_o - is the emission velocity from the cathode

q - is the particle charge

B_o - is the magnetic field on the orbit.

When the energy dispersion is large the cathode-anode space can be full of this kind of initial orbites.

Hereafter we shall assume that the energy that particles α or β can yield to or borrow from the electromagnetic wave, in an enough short time interval, is realized as small percentages in comparison with the particle energy.

If particle (1), on reaching the orbit finds a "co - phasal" tangential electric field, it will yield energy to the electromagnetic wave and its velocity will thus diminish. The velocity decrease leads to the decrease of the orbit radius more or less rapidly according to the configuration of the axial magnetic field adjacent to the initial orbit. As a result of the radius diminution, the particle maintains its initial angular velocity Ω and consequently remains cophasal with the tangential electric field (for well choosen values of the magnetic field B in each cases). Remaining cophasal with the tangential electric field, the particle will continue to yield energy to the electromagnatic wave until it comes upon the cathode or at least very close to it.

If on arriving on the orbit, particle finds an "out-of-phase" tangential electric field, it will borrow energy from the electromagnetic wave and its velocity will increase. The velocity increase will result in the orbit radius increase which depends on the configuration of the axial magnetic field*) On the other,hand, owing to the radius increase, the angular velocity Ω will remain constant and therefore the particle will

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*) In the case of a non-uniform axial magnetic field the most adventageous are those for which $\frac{v_o}{B_o} = \frac{v}{B}$.

continue to borrow energy from the electromagnetic wave until it will come on the anode.

The energy acquired by particles (2) from the electromagnetic wave is higher than the energy yielded by the electromagnetic wave to particles (1) because the path of particles (2) is longer while being at the same time nearer to the anode cavities where the electric field is stronger *). Consequently, an electric generator with radioisotopes working within an axial magnetic field stronger than the cut-off magnetic field will not oscillate. It if receives microwave energy from without, this system will work as a particle accelerator.

The working of an electric generator with radioisotopes derived from a converted magnetron is obtained by an axial magnetic field equal to the cut-off magnetic field or smaller than it. By using such an axial magnetic field there will always be, on the particle trajectory from the anode to the cathode a radial component of the velocity similar to the radial component created by constant radial electric field in the ordinary magnetron. This radial component constitutes a velocity reserve for the particles yielding energy to the electromagnetic wave. Along the trajectory the radial component of the velocity is transformed with the help of the magnetic field in a tangential component of the velocity.

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*) It is possible that by a more through analysis a magnetic field configuration could be determined that could aliminate earlier from the electromagnetic wave zone the (2) particles enabling thus such a working. The two exhausting conditions imposed in this case on the magnetic field render however more difficult the contruction of such an electric generator with radioisotopes. For instance, the achieving of the magnetic field configuration from figure 6 is difficult if a completely axial magnetic field is wanted.

Figure 7 shows the working of an electric generator with radioisotopes made from a converted magnetron. The full line represents the paths of particles (1) and (2) in the absence of the oscillating regime. In the case of the oscillating operating conditions , particles (1) will be slowed down and yield energy to the electromagnetic wave, contingently travelling with this electromagnetic wave until its fall on the cathode. The initial yielding of energy on the first part of the trajectory along the electromagnetic wave prevents the falling of these particles on the anode. The configuration of the magnetic field should be such that particles (1) could maintain along the longest possible part of the trajectory possible until they fall on the cathode , a constant angular velocity equal to that of the rotating oscillating electric field. Particles (2) will, from the very time they leave the cathode , be accelerated by the field of the electromagnetic wave. The small velocity increase these particles underg between the cathode and the anode is sufficient to produce the increase of their radius R_0 so as to make them fall on the anode. The energy yielded to the electromagnetic wave by particles (1) is much larger than the energy borrowed from the electromagnetic wave by particles (2). The oscillations will be kept going and the generator will supply power in the form of mi-

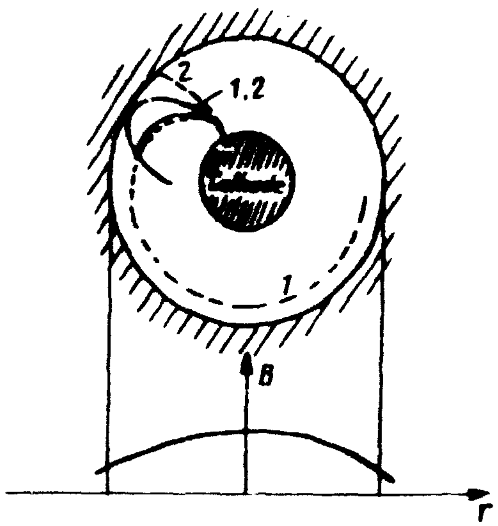

Fig. 7

crowaves.

The fall of the particles possessed of an electric charge on the anode results in a charge accumulation on this electrode. Consequently a voltage will appear between cathode and anode. The sign (+ or -) of this voltage will depend on the nature of the charge of the radioisotopes used. The electric field produced between anode and cathode by this voltage acts in a contrary way upon the working of the electric generator with radioisotopes. The direct current electric source concomitantly created in this device has a small power and can be used. The condition of utilization of this additional source is that its operating conditions should be near those of the short-circuit operating conditions. Under these operating conditions, the electric field between anode and cathode has a small value. - so that it cannot influence unfavourably the working as a microwave power generator of this electric generator with radioisotopes.

The voltage value of the direct current source, i.e., the value of the radial electric field can be used for controlling the microwave power.

3. Use of the converted magnetron for achieving a converting cell of the fission nuclear energy

In order to achieve a converting cell of the fission nuclear energy, the lateral surface of the cathode should be lined with a thin layer of fissionable material. The cell must work in a neutron flow within a nuclear reactor, in the neutron beam of a neutron generator or contingently in a set of a large number of cells brought to the condition of criticality. Since the mean density of the fisfionable material within a cell volume is small , if a nuclear reactor is to be achieved rods of solid nuclear fuel should be introduced between the cells. In this nuclear reactor, one part of the energy is transformed in microwave power by means of converting cells with a high efficiency (50%) while the other part should be used by the classical methods.

Characteristic of the converting cell of the fission nuclear energy as compared with the electric generator with radioisotopes are the great energy dispersion of the fission fragments and of the β disintegration. The axial magnetic field should fulfill the cut-off condition of the fission fragments offering the highest energy density. This converting cell will have particles possessing initial orbites as, in figure 4 and hindering the working and therefore the efficiency of the device.

So as to improve the efficiency, the converting cell should be excited by all the oscillation "modes" ; the energy dispersion of the fission products favours this kind of working. In comparison with the electric generator with radioisotopes the cell of which works on a single "mode", the converting cell should possess a great number of resonant cavities which increases the number of working "modes" so as to cover the whole energy field of the fission products with the best density.

REFERENCES

/ 1 / H.D.Hagstrum, Proc. IRE, 35 548 (1947).

/ 2 / J.B.Fisk, H.D.Hagstrum and P.L.Hartman, Bell System Tech.J., 25, 1, 1946.

/ 3 / F.E.Terman, "Electronic and radio engineering", McGraw-Hill Book Company, Inc., New York, Toronto London, 1955.

/ 4 / J.A.Bradshaw, Proceedings of the symposium on electronic waveguides", New York, April, 1958.

/ 5 / L.Brillouin, Phys.Rev. 6o, 385 (1941)

/ 6 / H.Nedderman, J.Appl.Phys. 26, 142o, 1955.