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A Brief Review on Operation of Gyrotron- A Microwave Device

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Abstract – Microwave vacuum tubes are devices used for generation or amplification of the microwaves. Microwaves cover a large part of the electromagnetic spectrum, and at the same time there are only a few kinds of devices operating in this frequency band. This group includes amplifying devices, such as traveling-wave tubes (TWT), klystrons, gyro-TWTs, gyro-klystrons and other. The generators are magnetrons, back-ward wave tubes (BWO), gyrotrons and other. Currently, the microwave vacuum devices are almost exclusively de-signed for amplification and generation of large and very large RF signals. Another advantage of vacuum tubes over semiconductor equipment is the high efficiency, as yet unavailable for semiconductors.

***Keywords* –** Gyrotron, Fast wave device, Travelling Wave Tube, Radio Frequency , Cyclic Resonance Measure

I. INTRODUCTION

History of the microwave tubes is more than a century, but in the Second World War, its role has become important. Magnetrons and klystrons along with the traveling-wave tube were applied mainly in military and communication systems.

Due to the development of semiconductor technology the development of microwave tubes slowed down. In 70s it was assumed that vacuum tubes may be completely replaced by solid-state devices. But in 90's, the TWT tubes has replaced the semiconductor devices mainly in satellite communication. This TWT tubes were having an important property that is the interaction of electromagnetic wave and electron beam. An additional advantage the TWT was carrying is high efficiency, which compared to the previous experiments. In the years 1970–1980 a significant progress was made, both in the theoretical and experimental field. There were more work has been carried out in order to improve both the efficiency and the output RF power. The multimode wave was converted into a Gaussian distribution mode after the development of helical output launcher developed in 1975. The countries such as Australia, Germany, Brazil, Korea, France and Japan also started to work on gyrotrons. The development of terahertz and coaxial gyrotrons was carried out upto 2000 . Production and Extensive research work were carried out in USA, Japan and Russia. Now a days in India and China, has developed their own labs to work on gyrotrons [1-2]. The range of frequencies for Microwaves which are electromagnetic waves is approximately 1 - 300 GHz. In the microwave family, microwave tubes as klystrons, traveling wave tubes (TWTs), and backward wave oscillators (BWOs), all catagorized into slow-wave devices (figure no.2). The structure of the interaction area scales down with increasing frequency of operation; due to this these devices has limitations in the microwave range as of high power levels [3-5].

In case of vacuum devices, due to high mobility of electrons, size is not a restriction at high frequencies and the vacuum devices can operate up to very high frequencies with very good power handling capability of microwave vacuum tubes in which radiation is generated by the high accelerated electrons. For coherent radiation electrons gathered in the micro bunches and this phenomenon is called bunching [6-7]. For interaction in the gyrotron a simple cylindrical resonator is used for beam interaction. The RF is bounded in the form of a particular mode [6-8].

A very basic schematic view of gyrotron is shown in fig. 1. The helical moving electron beam, generated by the Magnetron Injection Gun interacts with the RF in the resonant cavity which is a simple cylindrical structure and finally the spent beam is collected at the wall of collector. Several kind of interaction cavity like simple cylindrical, co axial, complex etc. has been used for the gyrotrons for the beam wave interaction in the gyrotron. The simple cylindrical cavity with the input and output tapering is the most widely used for the gyrotrons roughly operates at 1.5MW or below output power. The coaxial cavity resonators are very useful for high power gyrotrons due to its advantage in the reduction of ohmic wall loss and beam voltage depression [5, 9-10].

The gyrotrons has various potential applications in the field of basic sciences to advance technologies like molecular characterization, plasma research, research on ceramic material growth, security, communication atmospheric science etc. Rather than these applications various new fields are also under exploration at the various institutes around the globe for the use of gyrotrons [11-13].

Gyrotrons in the range of 20 to 35 GHz are used in the industrial applications. The activity related to development of the megawatt gyrotron is highly accelerated by the International Thermonuclear Experimental Reactor (ITER) project. It is also used in the development of medium power gyrotrons in the frequency range of 24-84 GHz for industrial and heating applications [13-14].

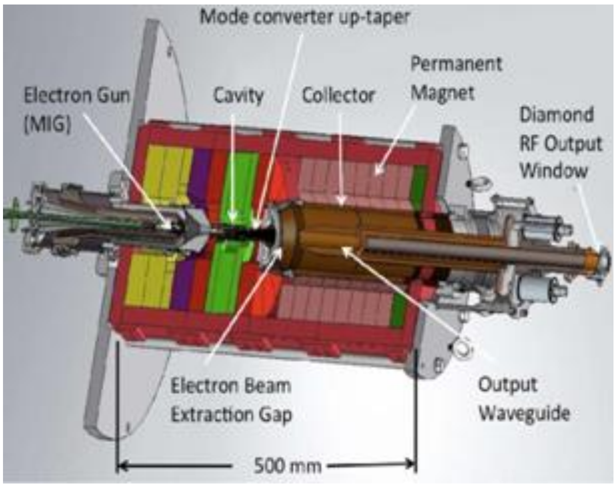

Figure. 1 Schematic diagram of a gyrotron

The gyrotron is a source of high power coherent radiation and are the most powerful radiation source in the millimeter and sub millimeter wave region. The device has been used as an effective source of the electromagnetic radiation in plasma fusion. The annular electron beam generated by a magnetron injection gun is focused into an open cavity resonator with the axial magnetic field, which are generated by superconducting magnet. Interaction between the RF field with the cyclotron motion of the electrons took place in the cavity, this interaction results the transverse kinetic energy converted into an RF beam which finally converted into a Gaussian beam. The spent electron beam then collected at the collector after propagating in cavity. To produce high average powers at millimeter wavelengths these are the most preferred vacuum electronic devices [15-16].

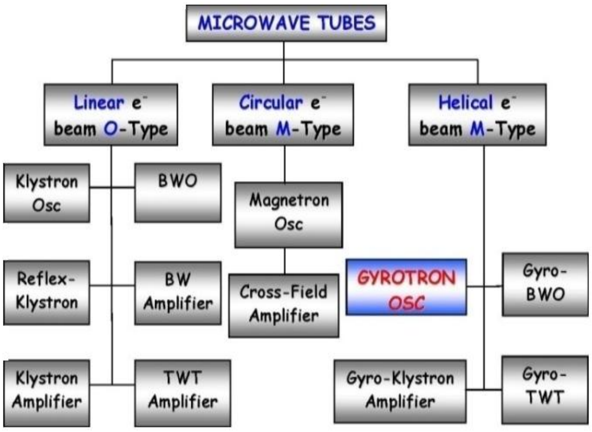

Figure 2: General Classifications of Microwave Tubes[25]

II. DESCRIPTION OF OPERATION OF GYROTRON

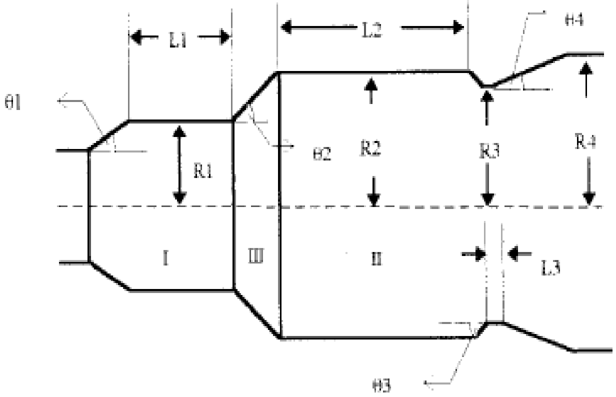

Figure 3: Complex cavity *[3]*

In the Gyrotrons , from cathode the emission of an electron beam took place and travels along through a single cavity or series of cavities in a helical path in the presence of the magnetic field (Figure 2) . This electron beam consists of many electrons gyrating around and in the magnetic field into a small helical path with a cyclotron frequency near the operating frequency of the device [17-20].

In case of Gyrotrons for small orbit device the Larmor orbits of the electrons should be smaller than the guiding centre radius . While for large orbit device Larmor radius should be greater than or equal to the guiding centre radius. With the use of Magnetron Injection Gun (MIG)A small orbit beam can be generated . To generate a large orbit beam a kick is imparted to a linear beam by either a magnetic cusp. Energy extracted is achived by the relativistic cyclotron resonance maser (CRM) in Gyrotron. In the relativistic cyclotron resonance maser (CRM) instability the electrons are phase bunched in the azimuthal direction due the RF fields, these electron bunches grow along the beam. Further when if the operating frequency is slightly higher than the cyclotron frequency of the electrons, the bunches end up in the decelerating phase of the microwave field and give up it energy to it. Only the transverse energy is extracted from the electron beam during a CRM fast wave interaction and hence an electron beam with significant transverse energy is chosen in a gyrotron device. Finally, the electron beam after transferring its energy it is collected by a thermally cooled collector. The energy from the RF fields from tube are extracted and sent through waveguides to the desired application [21-25].

From the equation of motion of beam the brillouin diagram is a resultant. As shown in figure 4 the blue section indicates the cavity structure and the red lines shows the electron beam lines. The cross-sectional view of Gyrotron structure is taken as shown in Figure 5.

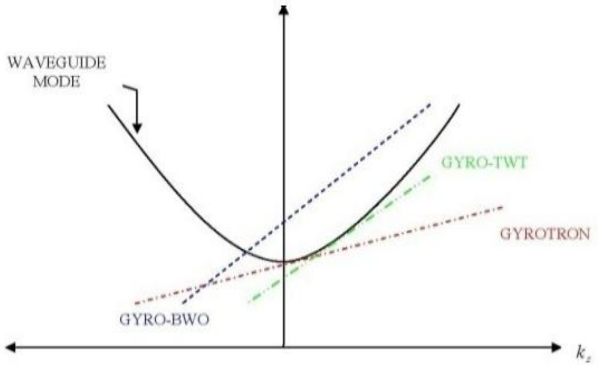

Figure 4: Brillouin diagram for different gyro-devices.

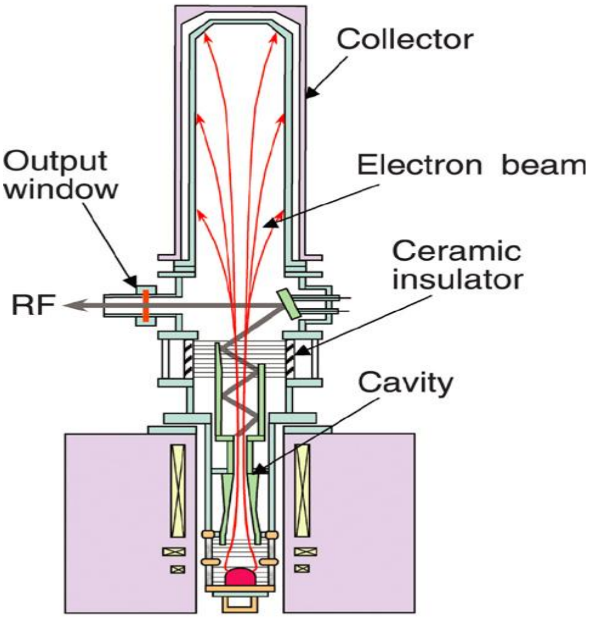

Figure 5: Cross-sectional view of a gyrotron cavity[3]

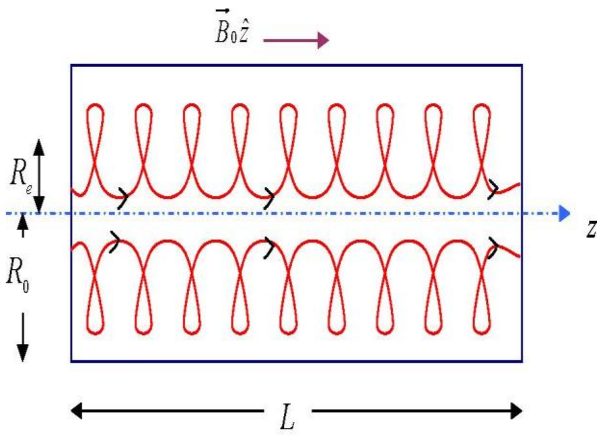

Figure6: Side view of single cavity gyrotron

Fig 6 Describes the single cavity gyrotron oscillator for analysis[2,3].

Where R_0 is the waveguide radius; R_e is the average beam radius, whereas ψ is slow varying part of gyrophase. A fixed axial magnetic field $\vec{B} = \vec{B}_0 \hat{z}$ is applied to this circular interaction structure. An annular electron beam is injected into an open-end cavity from the left hand side and propagates to the right, under the guidance of an applied magnetic field $\vec{B}_0$ Figure 2. Helically moving electrons have substantial part of their kinetic energy in the form of transverse motion. When electron beam interacts with the electromagnetic (EM) field inside the cavity, it will give up a portion of its energy to EM field. A steady state would be established, if the average power lost by the beam equals the wave power diffracted out of the cavity.

Electron bunching, which is of central importance in gyrotrons, is caused by the relativistic mass increase of the electrons. Therefore, a purely classical description could not be used to describe gyrotron interaction.

III. CONCLUSION

In the present analysis the status of gyrotron research and development has stressed on average power achievements. Average Power will be the relevant parameter for plasma heating as Magnetic fusion experiments advance toward electric power production. For the coherent radar application, average power determines the system capability even though a pulsed format is usually desired with duty factor typically 10%. The achievement of gyrotron oscillator developers in achieving high average power at frequencies as high as in GHz is quite remarkable and surpasses the capability Of other power tubes at this frequency by many orders of magnitude. If the magnetic fusion program requires them, gyrotron oscillators with megawatt average power rating would be possible with further development. Gyrotrons for the material processing application have been developed at 10-kW average power level in several countries; here the stress on reducing system cost, size, and complexity is well placed, and further efforts along these lines would be beneficial.

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