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with an Internal Converter

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Design considerations for a 1 MW CW gyrotron with an internal converter

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ABSTRACT

Varian is carrying out the development of high-power, CW gyrotrons at frequencies ranging from 100-140 GHz. Recent experiments, carried out at a frequency of 110 GHz, resulted in the generation of output powers of 500 kW for 2.5-second pulses and 1 MW for 1 ms pulse durations.¹ The output mode of this tube was a whispering-gallery mode, based on the TE_{22,2} mode employed in the interaction cavity. Current design activity is aimed at producing a 1 MW CW gyrotron at the same frequency, but with a gaussian output mode structure. This type of output mode is desirable for low-loss transmission in a corrugated waveguide or mirror transmission line. In addition to the change in output coupling, the cavity mode will be changed to the TE_{22,6} mode. The higher order cavity mode is consistent with higher power or higher frequency requirements that will be addressed in subsequent development activities.

1. INTRODUCTION

Electron cyclotron resonance heating (ECRH) requirements for planned magnetic fusion experiments such as the International Thermonuclear Experimental Reactor (ITER) will require millimeter-wave sources capable of output powers of at least 1 MW CW at frequencies in the range, 100-200 GHz. Recent megawatt-level development work at Varian resulted in a gyrotron design that was tested to output powers of 1 MW for short pulses (~1 ms) and 500 kW for 2.5-s pulses at a frequency of 110 GHz.¹ The output mode of this tube was a whispering-gallery mode, based on the TE_{22,2} mode employed in the interaction cavity. Present design efforts are centered around the introduction of a mode converter, inside the tube, that transforms the waveguide output mode from the cavity to a gaussian beam, before the output power exits the tube. Other design activities are related to the thermal management problems that arise in operating under full CW conditions at output powers of 1 MW. The present development plan involves the construction of two tubes, each with several test iterations, with the ultimate goal of achieving 1 MW CW with a gaussian-like output mode.

Much of the design of the first experimental tube will be similar to the one employing the TE_{22,2} cavity mode, discussed above. The electron gun, collector and output window will be of nearly identical design, and the cavity will utilize the same TE_{22,n} class of modes. The major change will be in the output coupling portion of the tube. Below we summarize the design of the major elements of the first experimental tube with a gaussian or gaussian-like output mode.

2. DESIGN OF GYROTRON WITH INTERNAL CONVERTER

2.1 Electron gun

The first experimental tube, with a gaussian-like output mode, will make use of the same electron gun design employed on the earlier TE_{22,2}-mode design. The decision to utilize a cavity interaction employing the same TE_{22,n} class of modes at the same frequency, means that the desired electron beam parameters are essentially identical to that in the earlier design. This electron gun is a double-anode, magnetron-injection gun, that operates at a beam voltage of 80 kV and a nominal beam current of 35 A. In the cavity, the average radius of the hollow beam corresponds to the innermost radial maximum of the cavity electric field. Computer simulations of the electron gun predict a perpendicular velocity spread of $\pm 4\%$ for a perpendicular-to-parallel velocity ratio (α) of 2.0. In operation, it was found that the achievable value of α was somewhat lower at full operating current (limited by mirroring electrons), so the tube design will be optimized for a value of $\alpha = 1.5$.

2.2 Cavity

The decision has been made to use a TE_{22,6,1} mode in the cavity. As with the TE_{22,2,1} cavity, the electron beam will be situated on the innermost electric field maximum of the cavity mode. The increase in cavity size from the TE_{22,2,1} mode will make cavity-wall-loading problems much less severe and thus enable use of a significantly higher-Q cavity design. The higher Q should serve to stabilize operation in the desired mode more effectively than in the lower Q design employed with the TE_{22,2,1} mode, and thereby lead to higher efficiency operation. Initial designs being considered have a Q of about 1000 with peak wall-loading values of less than 1 kW/cm² for ideal copper cavity walls. Use of the TE_{22,6,1} mode is consistent with higher power or higher frequency requirements that will be the subject of subsequent development activities.

2.3 Output coupler

An internal converter, after the interaction cavity, will serve to transform the TE_{22,6} mode produced in the cavity to a gaussian-like beam that will exit the tube perpendicular to the tube axis. The converter design is similar to the one described by Denisov et al.² and consists of a section of waveguide with small perturbations to transform the output waveguide mode into a gaussian-like geometry, followed by a system of mirrors that provide further shaping of the output into a microwave beam, with the desired gaussian-mode parameters, and direct the resultant power to the output window. Initial designs have calculated efficiencies of greater than 95% in transforming the TE_{22,6} output mode from the cavity into a gaussian mode.

2.4 Collector

The electron beam collector will be quite similar to the one used in the earlier tube with the TE_{22,2} mode that employed radial extraction of the spent electron beam.¹ The electron beam will be collected after the microwave power has been transmitted through the output window. The diameter of the collector in the first tube will remain at 24 inches. Some changes in the magnetic environment have been made since there is no longer the need to direct the electron beam through a narrow slot in the output waveguide.

2.5 Output window

The output window for the first experimental tube with an internal converter will be quite similar to the 4-inch diameter, double-disk, sapphire design employed on the earlier TE_{22,2}-mode tube.¹ Face-cooling of the two sapphire discs is provided by a low-loss dielectric fluid. It will have the capability to transmit between 200-700 kW CW, depending on the exact parameters of the gaussian mode that results from the internal coupler system. For full 1 MW CW operation, alternate geometries and cooling methods are currently being studied.

3. SUMMARY

The demonstration of a full 1 MW CW tube with a gaussian output mode will provide an important tool for use in upcoming fusion experiments. The use of a gaussian output mode (as opposed to a waveguide output mode) should result in the most effective overall system design for such experiments. The first experimental tube in our effort to develop a gyrotron with these parameters will be an important step in achieving the ambitious goals.

4. ACKNOWLEDGMENTS

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5. REFERENCES

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