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INITIAL OPERATION OF A HIGH-POWER WHISPERING-GALLERY-MODE GYROTRON*

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ABSTRACT

Varian has begun the development of a high-power gyrotron based on a whispering-gallery-mode interaction circuit. The first experimental tube has been designed to generate pulsed output powers up to 1 MW at a frequency of 140 GHz. The tube was also designed for CW operation at power levels of several hundred kilowatts. The overall design of the tube is discussed. Fabrication of the tube is nearing completion and initial tests on the tube will be carried out in the near future.

INTRODUCTION

To meet the electron cyclotron resonance heating (ECRH) source requirements for future magnetic fusion experiments, Varian is currently developing gyrotrons at a frequency of 140 GHz that will ultimately be capable of generating power levels of 1 MW, CW. The approach being followed in this effort will incorporate much of the technology developed and employed by Varian in a wide range of lower power gyrotrons,^(1,2) in addition to several new design concepts. The major difference in the current effort is due to the choice of mode in the interaction cavity. While all previous Varian gyrotrons have employed interaction circuits based on TE_{0n1} modes, the 1 MW tube will utilize a whispering-gallery-mode cavity. This approach has been successfully demonstrated at high power levels in Soviet gyrotrons,⁽³⁾ and more recently at the Massachusetts Institute of Technology (MIT).⁽⁴⁾

In the following, we discuss the specific design elements of the first experimental tube in the current development effort. This tube has been designed to generate pulsed output powers of 1 MW and CW power levels of several hundred kilowatts at a frequency of 140 GHz. Subsequent tubes will be upgraded with the capability of operating at 1 MW CW.

1 MW GYROTRON DESIGN

Electron Gun

The magnetron injection electron gun design for the 1 MW tube is essentially the same as the one that was designed and built by Varian for the MIT experiments referenced above. The gun is designed for operation with a beam voltage of 80 kV and a beam current up to 50 A. The nominal radius of the beam in the interaction circuit coincides with the inner electric field maximum of the TE_{15,2,1} mode at 140 GHz. Computer simulations of the gun predict perpendicular velocity spreads of less than 5% for operation at a perpendicular to parallel velocity ratio of two.⁽⁵⁾

Interaction Cavity

The interaction cavity for the 1 MW tube consists of a simple, tapered, TE_{15,2,1} cavity, resonant at a frequency of 140 GHz. The loaded Q of the cavity is about 500. A plot of the calculated efficiency for the cavity design is shown in Figure 1. As indicated, efficiencies in excess of 50% are predicted for operation at 1 MW power levels. Wall loading due to ohmic losses in the cavity, including the effects of temperature and surface roughness, is

FIGURE 1. CALCULATED EFFICIENCY vs OUTPUT POWER FOR TE_{15,2,1} CAVITY DESIGN

D1465
F717

FIGURE 2. CAVITY WALL LOADING PROFILE FOR TE_{15,2,1} CAVITY DESIGN

D1466
F717

plotted as a function axial distance in Figure 2. A thermal analysis of the cavity, using the wall loading profile in Figure 2, predicts that the cooling design for the cavity is sufficient for operation up to power levels of 400 to 500 kW, CW and 1 MW for 10 to 20 ms pulses.

The cavity has been designed for minimal back-rl leakage toward the electron gun. The output mode purity of the cavity is quite high with more than 99.5% of the power in the desired TE_{15,2} mode.

*The 140 GHz gyrotron oscillator is being developed under contract with Lawrence Livermore National Laboratory, operated by the University of California for the U.S. Department of Energy, under Prime Contract W-7405-eng-48.

Output Coupler/Collector

The first experimental 1 MW tube will employ standard output coupling where the electron beam collector also serves as the output waveguide. A nonlinear up taper links the interaction cavity to the 5-inch diameter collector and a nonlinear down taper is incorporated between the collector and the 3.5-inch diameter window and output waveguide. The entire up taper/collector/down taper was designed to preserve the purity of the desired TE_{15,2} output mode. Calculations indicate that greater than 95% of the output power remains in the TE_{15,2} mode at the tube exit. The collector is designed to dissipate enough electron beam power to enable rf output powers of 300 to 400 kW CW to be achieved as well as 1 MW under 1 ms pulse conditions.

Output Window

The output window on the first tube will be a double-disc, face-cooled design similar to that used on the 100 kW, CW 140 GHz tube.⁽²⁾ The major difference in the 1 MW design is the larger size of the output waveguide (3.5 inches instead of 2.5 inches in diameter). A thermomechanical analysis of the 1 MW window design indicates that it is capable of withstanding CW operation at 400 kW power levels and 100 ms operation at power levels up to the full 1 MW, with an adequate margin of safety.

Gyrotion Magnet

Tests of the 1 MW tube will be carried out in the same superconducting magnet employed in testing the lower power 140 GHz tubes. The magnet provides a nominal field of 56 kG in the interaction region of the tube. The main magnetic field is supplied by two large coils, while two smaller coils are used to regulate the field strength in the gun region. Additional transverse magnet coils may be energized to optimize transmission of the electron beam through the tube.

CONCLUSIONS

Forthcoming tests on the first experimental 1 MW, 140 GHz gyrotion will provide valuable information concerning the peak and

CW power capabilities of whispering-gallery-mode gyrotions. To enable CW power levels of 1 MW to be achieved, future tubes will employ several modifications to the existing design. In the interaction circuit, improved cooling, operation in a higher order mode (i.e., TE_{15,3,4}), or decreasing the loaded Q of the cavity are three possible means of reaching 1 MW CW operation. Various ways of separating the electron beam from the rf output are being considered to enable the collector to be made large enough to accommodate the requisite beam power without affecting the mode purity of the output. This output coupling approach would also allow use of window geometries which are more capable of withstanding the thermomechanical stresses induced in operating at 1 MW CW. Implementation of these design techniques should lead to a demonstration of the required source for ECRH in reactor-relevant magnetic fusion experiments.

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