ANALYSIS OF THE OUTPUT MODE
FROM 60 GHz, 200 kW PULSED AND CW GYROTRONS

CONF-831245--2

DE84 004586

K. Felch, R. Bier, L. Fox, H. Huey,
H. Jory, J. Manca, J. Shively, S. Spang

Varian Associates, Inc.
611 Hansen Way
Palo Alto, CA 94022

C. Moeller

GA Technologies
P.O. Box 85608
San Diego, CA 92138

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ABSTRACT

A Varian 60 GHz, CW gyrotron has recently been operated at power levels up to 200 kW CW. The tube employs a TE₀₁₁/TE₀₂₁ complex interaction cavity which inhibits mode competition by the TE₂₂₁ mode with the desired TE₀₂₁ mode. The output mode of the cavity is nominally in the TE₀₂ circular waveguide mode in overmoded waveguide. Since the output waveguide also serves as the gyrotron collector, mode conversion occurs in the taper sections and gaps incorporated into the collector. Measurements of the mode conversion on a 60 GHz, 200 kW, 100 ms pulse tube, have been made and compared with similar measurements on the 60 GHz, 200 kW, CW gyrotron. These measurements indicated that the CW tube had significantly more conversion of the TE₀₂ mode into other TE_{0n} modes than did the pulse tube. Current design work is aimed at reducing the mode conversion of the CW design to the same levels as the pulse design ($\leq 10\%$ mode conversion).

INTRODUCTION

The Varian 60 GHz gyrotron is being developed for use in electron cyclotron resonance heating (ECRH) in magnetic confinement fusion devices. Several 200 kW, 100 ms pulse versions of the 60 GHz tube, as well as similar tubes at 53.2 GHz, have already been employed in various fusion experiments. However, for fusion reactors where steady-state or quasi-steady-state operation is necessary, gyrotrons with CW capabilities are required. The recent operation of a 60 GHz gyrotron at power levels up to 200 kW CW represents an important step in providing fusion experiments with the high

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Research sponsored by the Office of Fusion Energy, U.S. Department of Energy, under contract W-7405-eng-26 with the Union Carbide Corporation.

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frequency, high average power sources required to verify the ECRH concept in a reactor relevant regime.

An additional requirement for many ECRH experiments is the necessity to inject the microwave power in a specific mode with a given polarization. This need implies that the output mode of the gyrotron must be pure so that efficient conversion into the proper injection mode can be carried out. For the present 60 GHz gyrotron in which the electron beam collector also serves as the output waveguide for the microwaves, the mode purity requirement places severe restraints on the size and geometry of the collector. The collector must be capable of dissipating the entire CW beam power, up to 640 kW in the present tubes, while at the same time transmit the rf to the output of the tube without disturbing the purity of the mode.

The original 60 GHz CW design incorporates a 5-inch diameter collector which is the same diameter as the Varian 28 GHz, 200 kW CW design. The choice of 5 inches for the collector diameter was made primarily to insure that the collector could withstand the power deposited by the impinging electron beam, while mode purity concerns in this first design were of secondary importance. Since the heat dissipation requirements in the collector are much less stringent for pulse operation, the 60 GHz, 200 kw, 100 ms pulse gyrotron employs a collector diameter of 2.5 inches, so that the problem of mode conversion is greatly reduced.

Following is a discussion of the important features of the 60 GHz 100 ms pulse and CW gyrotrons and the results of measurements of the mode content in the output of the two tube designs.

EXPERIMENTAL RESULTS

A schematic diagram of the 60 GHz CW gyrotron is shown in Figure 1. The design of the 60 GHz, 100 ms pulse tube is identical to the CW design except that the collector is only 2.5 inches in diameter (no down-taper is required) and the output window consists of a single ceramic disc, edge-cooled with water rather than the double-disc CW design which is face-cooled with a dielectric fluid. In addition, no collector magnet is required in the collector region.

The specific pulse and CW tubes on which mode measurements were made both employed TE_{011}/TE_{021} complex interaction cavities. In the initial tests of the tubes, both exhibited excellent stability properties and were capable of operating over a much wider range of parameter space than had previous pulse and CW tubes employing a standard TE_{021} cavity. Mode interference by the competing TE_{221} mode was virtually eliminated, in contrast to the mode competition present in previous 60 GHz tubes. Both tubes were capable of generating 100 ms pulse power levels of 230 - 250 kW with efficiencies of 35 - 40%. When tested under CW conditions, the CW tube reached power levels in excess of 200 kW, the principal goal of the current gyrotron development program.

Several methods were employed to make qualitative and quantitative measurements of the mode content of the microwave output from the two tube designs. Initial tests were made by placing thermal sensitive paper in the 2.5 inch output waveguide of the tubes. The patterns from the pulse tube indicated that the output was predominantly in the TE_{02} mode, with only minute traces of other TE_{0n} modes. Identical measurements on the CW tube revealed patterns which could be attributed to the TE_{01} and TE_{03} modes as well as the TE_{02} mode. Unfortunately, actual quantitative measurements were not practical using this technique because of the limited gray scale of the thermal paper (limited "shades of gray").

To gain further quantitative information on the mode content of the two designs, measurements were made using mode selective directional couplers which were constructed to couple to different TE_{0n} modes(1,2). Relative calibrations of the couplers were obtained by analyzing the calculable output of a step transition and absolute calibrations were made using phase velocity transducers to the fundamental rectangular waveguide mode.

In Figure 2, we show a schematic diagram of the experimental set-up employed to measure the mode content using the couplers. The tapers and waveguide bend convert less than 3% of the incident mode. Measurements on the pulse tube indicated that most of the output (~ 94%) was in the TE_{02} mode while the TE_{01} and TE_{03} modes made up only about 6% of the mode output and the TE_{04} less than 0.1%. To verify these results a second method, employing only the TE_{01} coupler and a $TE_{01} \rightarrow TE_{02}$ converter(1), was used on the pulse tube. The TE_{01} content was measured before and after the converter. The converter is capable of converting at least 99% of the TE_{01} mode to the TE_{02} mode and

vice versa. This latter technique ignores the presence of the TE_{03} mode, but avoids dependence on the relative calibrations of different couplers. This method obtained values of about 90% and 10% for the TE_{02} and TE_{01} modes, respectively. Both techniques used on the pulse tube agree with cold test measurements employing a small waveguide probe to analyze the mode content in the output waveguide(3). These measurements indicated that about $89 \pm 5\%$ of the microwave output was in the TE_{02} mode.

Initial measurements on the CW tube indicate significantly larger amounts of mode conversion than on the pulse tube. Work on the CW tube is still in progress using the directional coupler technique.

CONCLUSION

The results of these measurements indicate that the 60 GHz pulse gyrotron has good output mode purity (90-95% pure TE_{02}). The CW design appears to have significantly more mode conversion than the pulse tube. Work is continuing on the CW tube measurements.

ACKNOWLEDGEMENT

The 60 GHz gyrotron oscillator is being developed under contract with Oak Ridge National Laboratory operated by Union Carbide Corporation for the U.S. Department of Energy under prime contract W-7405-eng-26., Office of Fusion Energy.

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1. MAIN MAGNET COILS	6. BEAM COLLECTOR AREA
2. GUN MAGNET COIL	7. COLLECTOR MAGNET COILS
3. ELECTRON GUN	8. OUTPUT GUIDE UP-TRANSITION
4. CAVITY	9. OUTPUT GUIDE DOWN-TRANSITION
5. OUTPUT WAVEGUIDE AND WINDOW	10. DEWAR

FIGURE 1. SCHEMATIC DIAGRAM OF THE VARIAN 60 GHz CW GYROTRON. THE 100 ms - PULSE TUBE IS SIMILAR EXCEPT THAT NO COLLECTOR COIL IS USED AND COLLECTOR DIAMETER IS THE SAME AS THAT OF THE OUTPUT WAVEGUIDE (2.5") SO THAT NO DOWN-TRANSITION IS NECESSARY.

FIGURE 2. SCHEMATIC OF EXPERIMENTAL SET-UP FOR MODE CONTENT MEASUREMENTS ON 60 GHz PULSE AND CW GYROTRONS USING MODE SELECTIVE DIRECTIONAL COUPLERS