Development of a Wide-Band Window in $HE_{1,1}$ Guide for Gyrotrons

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***Abstract*—Calabazas Creek Research, Inc. is developing a broadband system to couple RF power from MW-class gyrotrons that eliminates the external matching optical unit. A critical component is a Brewster window in HE_{11} waveguide. This paper describes progress in fabricating and testing the window and the associated hardware.**

I. INTRODUCTION

A key technical issue for step tunable gyrotrons is transmission of the RF power from inside the tube to the external transmission system. Most current, high power gyrotrons use single disk, chemically vapor deposited (CVD) diamond for the vacuum window. The thickness corresponds to multiples of a half wavelength of the RF power. Consequently, the windows transmit power over extremely narrow bands that are widely separated in frequency.

Brewster angle windows offer a potential solution to this problem. Properly linearly polarized RF waves incident on a vacuum window at the Brewster angle are transmitted without reflection, independent of frequency. Low average power, prototype, step-tunable gyrotrons typically employ Brewster angle windows. This has allowed development of RF cavities and quasi-optical launchers to convert the various cavity modes into a Gaussian mode. The problem arises for high average power operation. A Brewster window for a Gaussian mode output requires an unusually large diamond disk. Researchers at Karlsruhe Institute of Technology (KIT) recently reported operation of a 1-MW, step-tunable gyrotron using a diamond Brewster angle window [1]. The dimensions of the elliptical diamond disk are 139 x 95 x 1.7 mm. This is significantly larger than typical diamondl gyrotron windows, which are approximately 106 mm in diameter. The large size presents significant fabrication issues as well as a significant increase in cost. Also, the current gyrotron development efforts are focused on 1.5 MW, long pulse gyrotrons, specifically for ITER. It is doubtful that a Gaussian mode, Brewster angle, diamond window could be practical at this power level.

To avoid the large size, increased cost, and power limitation, Calabazas Creek Research, Inc. (CCR) is developing a system that couples gyrotron power directly into 32 mm (1.25 inch) diameter, $HE_{1,1}$ corrugated waveguide inside the vacuum envelope [2]. The Brewster angle for diamond is 67.5°, requiring an elliptical disk with a major axis diameter of 102 mm with a clear aperture of 88 mm. This is slightly less than the 106 mm circular disks currently used for single mode gyrotrons. Analysis indicates this window can safely transmit more than 1.5 MW CW at 170 GHz.

Extraction of RF power from the gyrotron in HE_{11} corrugated waveguide provides a more important advantage in that it eliminates the Mirror Optical Units (MOU) currently required to couple Gaussian mode power into corrugated waveguide transmission systems. The total cost of MOU fabrication is approximately $100K, and it is estimated that approximately 3-5% of the RF power is lost [3].

This presentation will describe the coupler that converts whispering gallery mode power into HE_{11} power in corrugated waveguide and the Brewster angle diamond window that allows step tunable operation.

II. CONFIGURATION

Figure 1 shows a typical arrangement of the direct coupler and the Brewster angle window in a gyrotron. The RF power from the circuit is converted and focused into HE_{11} waveguide parallel to the axis of the tube. A miter bend directs the power perpendicular to the gyrotron where it passes through the Brewster angle diamond window. The transmission line is coupled to the output of the window using a Helicoflex seal. The window is designed to transfer mechanical stresses between the gyrotron and transmission line around the diamond window. This avoids breaking the window from misalignments, vibrations, or shocks.

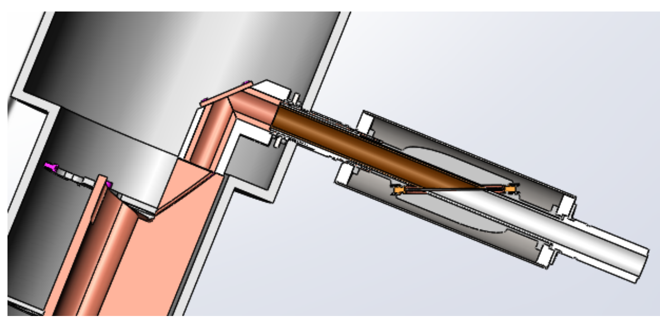

Figure 1. Configuration of direct coupler and Brewster angle window for typical gyrotron

III. ANALYSIS

Extensive thermal analysis indicates that the CCR design should be capable of transmitting in excess of 1.75 MW CW, depending on the loss tangent of the diamond disk. Figure 2 predicts that the CCR design should be capable of transmitting approximately 1.9 MW of RF power at 170 GHz if the diamond loss tangent is 4 x 10^{-5} or better. Measurements following the braze of the diamond to the seal rings indicated a loss tangent of approximately 2 x 10^{-5}, which would imply the window is capable of transmitting in excess of 2 MW CW.

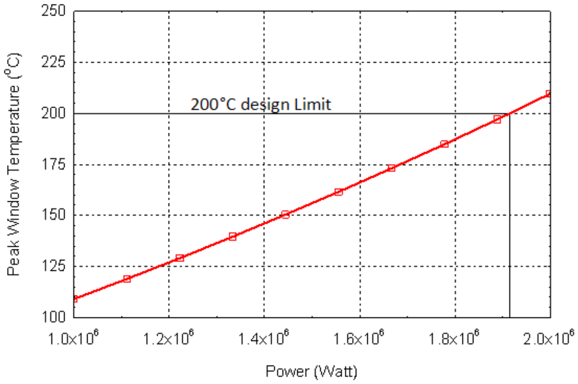

Figure 2. Power handling capability of Brewster angle diamond window with 88 mm clear aperture

IV. FABRICATION

Direct Coupler

The direct coupler was fabricated using Computer Numerically Controlled (CNC) machining as a single part that includes the launcher and focusing mirrors. The launcher design code *SURF3D* generated a numerical surface that was imported into SolidWorks to create the appropriate machining software. Because the coupler consists of a single part, there are no mirrors to adjust or align. The final component is a miter bend in corrugated waveguide to direct the RF power out of the gyrotron. Figure 3 shows a photograph of the direct coupler system.

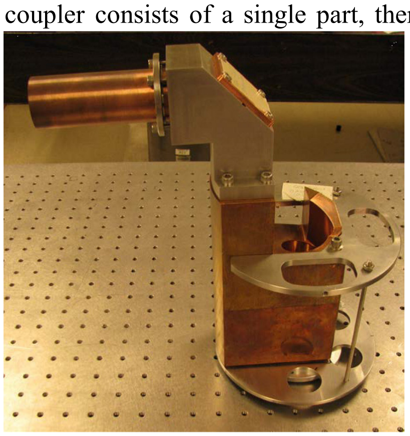

Figure 3. Direct coupler with corrugated waveguide

Brewster Window

All parts for the Brewster window were fabricated and assembly and subassembly machining are in progress. Figure 4 shows the component, including the diamond disk brazed to elliptical seal rings.

V. TESTING

Direct Coupler

The direct coupler was fabricated and tested at low power using facilities at Massachusetts Institute of Technology (MIT). These measurements indicated that approximately 98% of the RF power transmitted through the coupler and right angle bend was propagating in the HE_{11} mode. Recall that approximately 7% of gyrotron power is typically lost when converted to a Gaussian mode and subsequently converted to an HE_{11} mode using an MOU.

The coupler was subsequently installed in the MIT gyrotron and tested at high power. The output power was significantly reduced due to mode competition; which initially was attributed to reflections from the direct coupler system [4]. Subsequent measurements with the original Gaussian mode coupler incurred the same mode competition issues, indicating problems with the electron gun and/or gyrotron circuit. Additional high power tests of the coupler are scheduled for fall 2015, following repair of the gyrotron.

Brewster Window

The Brewster window will be tested at MIT at low and high power in conjunction with the direct coupler. Once those tests are completed, the window will be installed in the transmission line at General Atomics and tested at power levels exceeding 1 MW in long pulses. Available test results will be reported.

III. ACKNOWLEDGEMENT

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Figure 4. Components of the Brewster window assembly.