INFRARED MONITORING OF GYROTRON WINDOWS*

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CONF-831257--1

DE84 004442

ABSTRACT

A technique for monitoring the gyrotron output window surface temperature with an infrared camera while the gyrotron is in operation has been developed. The IR camera views the window through a perforated waveguide wall, and serves both as a guide for the safe operation at high average power of the tube, as well as an aid in the analysis of new window designs. Window temperatures were studied as a function of a number of parameters, including gun anode voltage, beam current, magnetic field, coolant flow, and load matching. The IR technique is applicable to many types of high average power microwave and millimeter wave tubes. Successful operation of the Varian 60 GHz gyrotron to 214 kW CW was guided by the infrared camera. Analyses on 28, 56 and 60 GHz gyrotrons have led to a number of design changes. A comparison with computer calculations is also presented.

INTRODUCTION

Windows for the transmission of high average power microwave and millimeter wave tubes such as the gyrotron are a key limitation in practical tube development. Thermal stresses can be calculated by computer modeling, but a number of conditions are often assumed, such as the power density profile, the electromagnetic wave attenuation constant of the window material, the heat transfer coefficient at the window and load matching. Uncertainties with overmoded waveguide, ghost modes, cooling fluid profiles, etc. reduce the accuracy of the calculations. To determine the actual window conditions, a technique for monitoring the temperature distribution over the window surface with an IR camera while the gyrotron is in operation has been developed. This technique is quite useful in analyzing window designs as well as guiding the tube to safe operating parameters. The ability to observe small hot spots due to tiny metallic specks on the window surface is also of great value in quality control and window failure

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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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prevention. The gyrotrons available for examination at Varian include 28 GHz to 60 GHz tubes at 200 kW pulsed and CW. The output power of these tubes is in the TE₀₂ mode through a window in 2.5" diameter waveguide.

SYSTEM DESIGN

The technique uses an infrared camera (AGA-780) with an indium antimonide detector (3-5 μm). The air side of the window is observed through a pattern (grid) of tiny holes (cutoff for 180 GHz) in the output waveguide wall as illustrated in Figure 1. The thermal emissivity of the alumina window, which is a measure of the blackbody-like behavior at 3-5 μm , is $E_w \approx 0.95$, so the IR measurement of the window is very much like a blackbody. This also implies that the measurement yields only the surface temperature of the window. A test to observe a 330°C object behind a sample window at room temperature confirmed the validity of the measurement. Reflections from the window are negligible due to the high emissivity. Reflections of the window from the internal waveguide walls occur at angles which appear external to the window edge, and thus can be neglected. To minimize the problem of external waveguide wall reflections, the outside waveguide wall is painted black. However, in order to reduce the thermal emission of the painted waveguide wall, a cool waveguide is required; room temperature is sufficient.

The system presently views only about half of the window surface. Rotation of the camera about the waveguide axis permits a view of the entire window.

The IR camera scans the window area and measures the photon flux. This flux, I_a , is a function of the window temperature at each point, the grid transmittance, t_g , and the grid reflection r_g , along the optical path. The operational equation is:

$$I_a = I_w E_w + I_g (1 - t_g - r_g) + I_{amb} r_g$$

Where I_w , I_g , I_{amb} are the blackbody equivalent intensities of the window, grid and ambient "background", respectively. A determination of the grid transmission function is achieved by calibrating with a "blackbody" radiator of known

temperature. Calibrating at two different temperatures helps to eliminate the reflection term in determining the transmission function.

The temperature resolution of the system depends on the relative temperature difference between the waveguide and window as well as the grid transmission coefficient. For a waveguide at room temperature, the temperature resolution near the center of the window is about 1°C for a window temperature of 70°C . It improves as the window temperature increases. Spatial resolution is better than 2 mm and hot spots <1 mm are easily observed.

RESULTS

Measurements were first performed on 28 and 56 GHz CW gyrotrons. Temperature profiles show peaks near the window center (see Figure 2). Peak temperature as a function of output power is shown in Figure 3. A linear least squares fit appears to fit quite well. Similar results were obtained on other gyrotrons at different frequencies. A naive extrapolation of the peak window temperature at 200 kW output appears to be well below the boiling point of the FC-75 coolant ($\sim 130^{\circ}\text{C}$ at 30 psi). The variation of the peak window temperature for several operating parameters was checked. In particular, at 56 GHz, the FC-75 window coolant flow rate was found to be a crucial parameter (but not at 28 GHz). Figure 4 shows the variation of the peak window temperature as a function of the FC-75 flow rate for a number of output powers. The conservatively extrapolated curve at 130 kW shows that at 4 GPM, the temperature of the window can exceed the FC-75 boiling point. This was probably the cause of a previous window failure on the X-5 60 GHz gyrotron. Cooling the FC-75 was also found to reduce the peak window temperature. This would increase the safety margin at 200 kW operation for preventing boiling of the FC-75.

The X-6 60 GHz gyrotron was safely guided to operation at 214 kW CW by monitoring the window temperature with the IR system. Due to the wider dynamic range in the operational parameter space and higher operating temperatures on the X6 than on previous gyrotrons, changes in the temperature profile were easily discernable. Figure 5 illustrates the range of the peak window temperature (for constant output power) as a function of the magnetic field. This suggests mode conversion is occurring. The window temperature variation

appears to be due to a change in the phase of the modes at the window and not due to a change in mode content. Ghost modes in the window might also cause this phenomenon. The concurrent use of mode samples will provide additional information on this.

CONCLUSION

The IR monitoring method described above has proved to be invaluable to the development of the 60 GHz, 200 kW CW gyrotron. It is particularly useful in evaluating window designs and revealing tiny metallic specks that may have fallen onto the window surface. The technique is presently being simplified for use with both development and production testing. Integration into a test set is planned for further gyrotron development work.

* 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.

FIGURE 1. GRID DESIGN

FIGURE 2. RADIAL TEMPERATURE PROFILE

FIGURE 3. TEMPERATURE vs OUTPUT POWER

FIGURE 4. TEMPERATURE vs FC-75 FLOW

FIGURE 5. PEAK WINDOW TEMPERATURE vs MAIN
MAGNET #1 CURRENT

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5