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THE DIII–D GYROTRON INSTALLATION

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The DIII-D Gyrotron Installation

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Abstract. The DIII-D ECH system was upgraded to six 110 GHz gyrotrons in 2003. It includes three fully articulating dual launchers with both toroidal and poloidal scans. Three of these systems include chemical vapor deposition (CVD) diamond rf output windows. Infrared observations of diamond windows will be presented.

Introduction

A powerful microwave system operating at the second harmonic of the electron cyclotron frequency on the DIII-D tokamak consists of six assemblies. Three Gycom gyrotrons nominally generate about 750 kW for 2 s pulses, with the pulse length limit resulting from the peak temperature allowed on the boron nitride rf output window. Three CPI (Communications and Power Industries) gyrotrons with diamond windows have been installed and rated at 0.9-1.0 MW for 5 s pulses.

Overview

Each gyrotron assembly comprises a superconducting magnet, a gyrotron/magnet supporting tank, compact and main dummy loads, a low loss evacuated transmission line, and associated controls and instrumentation (Fig. 1).

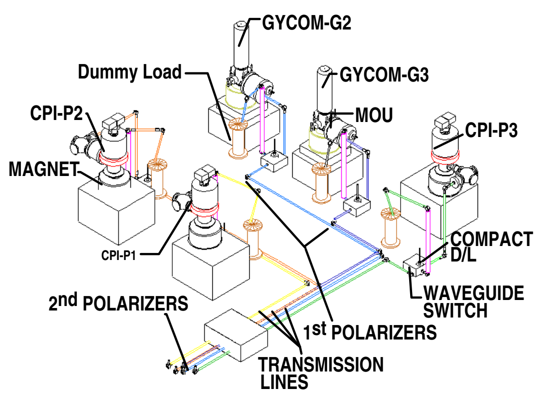


Fig. 1. Layout of the DIII–D ECH system.

The launchers, which inject from the tokamak low field side, can be scanned poloidally in the tokamak from the center to the outer edge of the plasma and can be also be scanned approximately ±20 deg toroidally providing both co- and counter-current drive. The sixth gyrotron, Gycom-G1, is not shown.

CVD Diamond Window

Artificial Chemical Vapor Deposition (CVD) diamond has become the material of choice for gyrotron windows. Three CPI 110 GHz gyrotrons with diamond windows are installed and operating at General Atomics (GA). The low dielectric loss tangent ($\tan\sigma \approx 2 \times 10^{-5}$) and the excellent thermal conductivity (four times that of copper) of diamond makes it possible to use such windows in gyrotrons with 1 MW output power in a Gaussian profile. Figure 2 shows the infrared emission profiles from windows on the three CPI gyrotrons installed at GA.

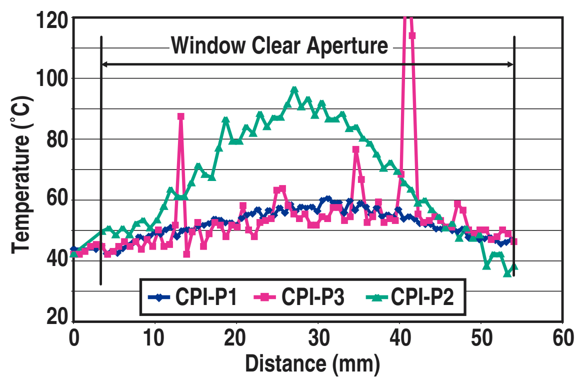
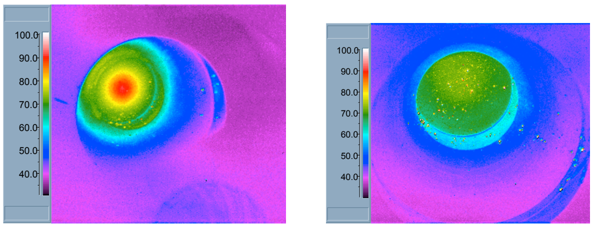


Fig. 2. Temperature profiles of diamond windows.

The emission profiles are quite different, which cannot be explained only by differences in thickness. All three diamond windows had slightly different histories of braze and cleaning procedures. CPI-P2 may have a graphite film contamination on its inside surface. A distinguishing characteristic of all diamond gyrotron windows is a presence of hot spots observed in infrared signals during the rf pulse, Fig. 3.



(a) CPI-P2 **(b) CPI-P3**

Fig. 3. IR images of diamond window of CPI-P2 and CPI-P3 gyrotrons.

The low absorption characteristic of diamond, which makes it ideal for use as a window, also makes the IR temperature determination a difficult measurement, requiring empirical calibration of the setup. The waveguide transmission line and coupling system are evacuated, so the window must be viewed off-axis through a sapphire viewport in the Matching Optics Unit (MOU). The diamond window is partly transparent for IR radiation from inside the gyrotron. Radiation from this source also will contribute to the final IR image and will bias the temperature determination.

The infrared measurement can be calibrated for the transparency of the diamond. Using the measured calibration, the time evolution of diamond the window temperature is in good agreement with theoretical calculations. The peak temperature, as seen in Fig. 3, comes into thermal equilibrium in about 3 s. If the interior temperature of the gyrotron remains constant the empirical calibration remains valid.

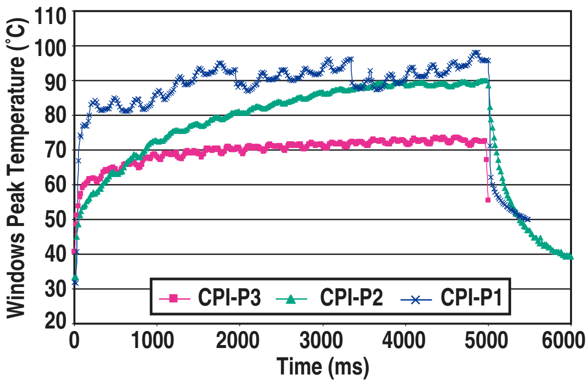


Fig. 4. Temperature evolution of the diamond window during 5 s rf pulse.

The rapid fluctuations in apparent window temperatures seen in Fig. 4 indicate the measurement error introduced by radiation passing through the window. Apart from the oscillations at 4 Hz, which is the frequency of the collector sweep coil, the CPI-P1 signal has a few sharp changes in the IR radiation amplitude. These changes are correlated with the rf signal. Figure 5 shows IR and rf signals for the same gyrotron shot, which indicate the errors, ~20%, in the measurement from changes in the radiation passing through the window.

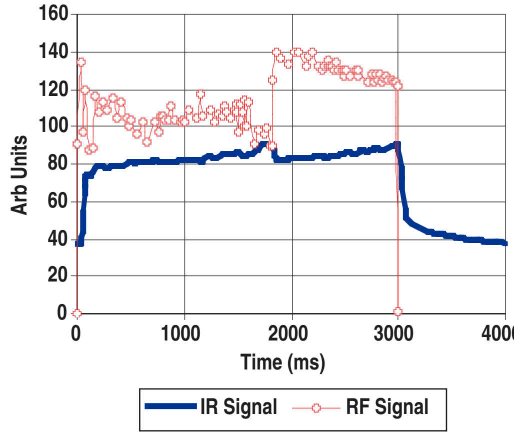


Fig. 5. Correlation between IR and rf signals on CPI-P1. The IR signal drops when the rf signal increases, indicating that perhaps up to a 20% error in the window temperature measurement can be introduced due to transmitted radiation.

Hardware Development

Reliable and simple devices for measurement of the rf power injected into the tokamak have been developed. Initial test results show that the units are compatible with full power operation at pulse lengths up to 5.0 sec. Some azimuthal asymmetry in the heating of the monitors has been noted and in under investigation. The design is given in Fig. 6.

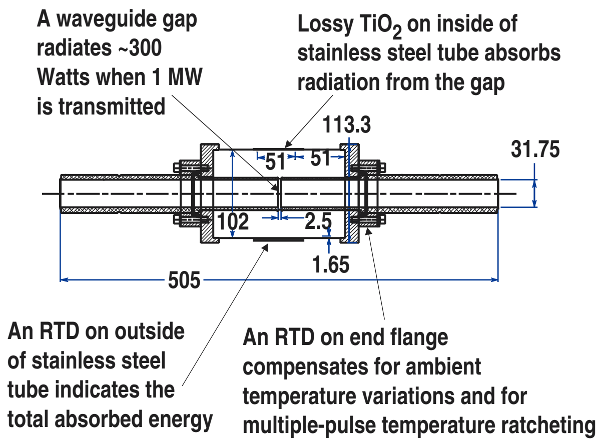


Fig. 6. An in line power monitor on an ECH transmission line, dimensions in mm.

Conclusions

The DIII–D ECH system consists of six gyrotrons available to support many different tokamak experiments. IR monitoring, that originally was used to prevent diamond window failures, yields useful information for understanding and developing technology of 1 MW class gyrotrons.

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