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AN IN-LINE POWER MONITOR FOR HE11 LOW LOSS TRANSMISSION LINES

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GENERAL ATOMICS

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ABSTRACT

A power monitor has been developed for the DIII–D 110 GHz EC transmission line, which allows for the measurement of power flowing in the transmission line before it reaches the launcher. The power monitor uses a small break in the transmission line to radiate power, which is then measured.

INTRODUCTION

High-power millimeter waves are used in fusion research to locally probe, heat, and drive current in thermonuclear plasmas. For most applications, the fusion researcher needs to have a reasonable estimate of the power delivered to the plasma in order to develop scaling laws, especially to identify the critical power density, that may trigger a transition-of-state within the plasma [1]. The simplest method of measuring the power is to divert a small quantity of power through small sampling holes milled into one of the miter bends used in the transmission line, rectifying the intercepted power and produces a signal proportional to power [2]. Nominally, the first miter bend located downstream from the gyrotron is used for this purpose. However, there are two serious problems with this process. First, the power coupled through the holes is extremely sensitive to both polarization and mode content. Second, the first miter bend is sometimes 100 m from the launcher with ten or more bends randomly placed throughout the transmission line, with each bend producing a limited but unknown quantity of mode conversion that may or may not propagate to the launcher. In other words, there is no simple relationship between the power signal measured at the first miter bend and the power launched into the plasma.

Placing a power monitor at the last miter bend before the launcher results in a more accurate measurement but suffers from the polarization hyper-sensitivity found in this type of power monitor. And since the polarization can be changed from experiment to experiment, there would still be no consistent relationship between the signal measured and the power launched into the plasma. With this in mind, the DIII–D EC program has developed an in-line power monitor that can be placed arbitrarily close to the launcher. (It is not limited to the location of the last miter bend, which could be six or more meters from the launcher.)

IN-LINE POWER MONITOR

Rather than use a series of holes in a mirror to produce a pick-off signal, the in-line power monitor uses the condition that when the HE_{11} mode travels through a corrugated waveguide the wall currents are low to nonexistent and thus can tolerate a break in the transmission line. Even if the gap is larger than several wavelengths, the power leak is relatively low. By surrounding the gap with a stainless steel cylinder, the rf leakage is effectively trapped while the vacuum envelope of the waveguide is maintained. A narrow ring of TiO_2 is applied to the inside of the stainless cylinder, which successfully absorbs the rf leaking out of the gap. Four resistive thermal detectors (RTDs) are placed around the outside of the stainless steel cylinder over the TiO_2 absorption zone, and a fifth RTD is placed at the end of the cylinder to act as a background monitor. The radiated signal fraction is given by $F = 0.55(\lambda G/D^2)^{3/2}$, where G is the waveguide gap length, D is the waveguide diameter, and λ is the free space wavelength. For G = 2.5 mm and D = 31.75 mm, F = 0.03%, or 300 W for 1 MW transmitted rf power. Figure 1 shows the configuration of the in-line power monitor developed for DIII–D.

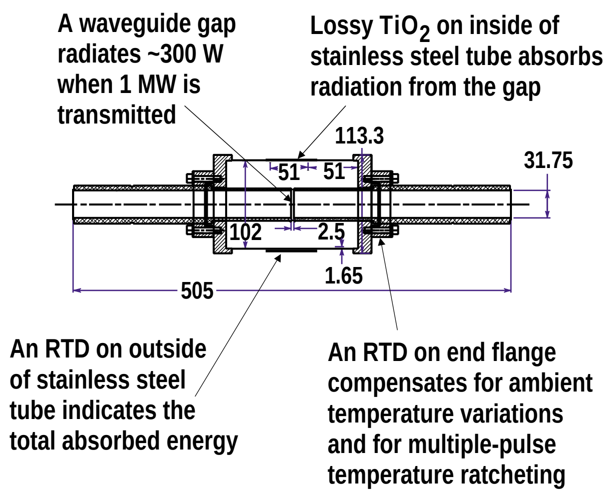

Fig. 1. Cross-sectional view of the in-line power monitor developed for the DIII–D EC system.

The thermal transit time from the TiO_2 band through the stainless steel cylinder is less than 1 s, whereas the transit time through the stainless to the end flanges is 730 s. Thus, the simple measurement of the temperature over the band minus the base line temperature should give a signal linearly proportional to the power throughput. Figure 2 illustrates a typical differential temperature measurement from one of the RTD signals for a 1 s pulse at a power level of 550 kW. Note the strong signal-to-noise level and the fast rise in temperature during the pulse.

In order to validate and calibrate the in-line power monitor, a long line of waveguide was set up in the gyrotron vault at DIII–D. The length of the line was similar to the ~80 m used between the gyrotrons and the DIII–D tokamak and contained 15 miter bends similar to that used in the most extreme DIII–D EC transmission line. Two of the miter bends house polarizers so that the polarity of the rf power passing through the in-line power monitor could be swept over a range of 0 to 90 deg. The test transmission line was terminated into a dummy load from which total injected power could be measured.

By measuring the temperature response of four RTDs placed equally around the outside of the stainless steel cylinder (every 90 deg), it was found that there was a nonuniform heating of the cylinder and that the nonuniformity changed as the polarization changed. Figure 3 shows the results of the measurements of the four RTDs (after the background is subtracted) as the polarization is rotated from 0 to 90 deg in 10-deg steps. Also included is a line representing the average of the four RTDs for each polarity (signified as SUM/4 on the figure) and a straight line representing the average temperature rise of all 40 measurements (line labeled AVE).

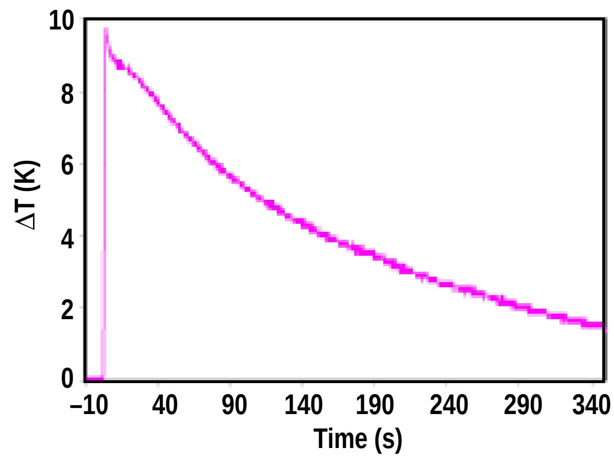

Fig. 2. Typical Δt response for one of the RTDs on the in-line power monitor for a 1 s pulse at a power level of 550 kW.

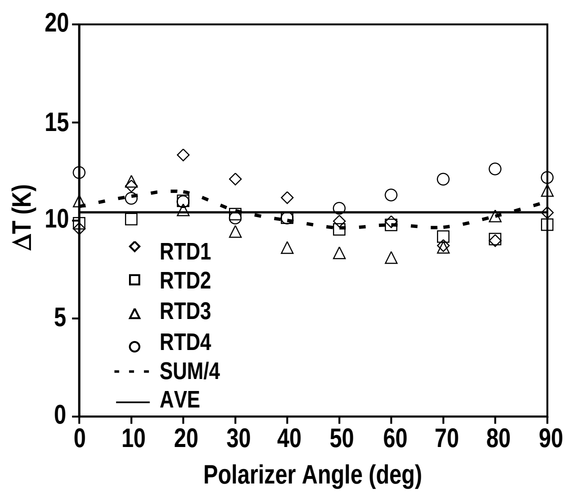

Fig. 3. Rise in temperature measured on the four RTDs mounted on the outside of the in-line power monitor, for 1 s pulses at 550 kW as the polarization is rotated over 90 deg. Also shown is the average for each polarization, SUM/4, and the average of all 40 measurements, AVE.

It is obvious that no single RTD can be used to represent the power level of the rf passing through the power monitor. There could be an error as large as 25% if the polarity is unfavorable. Even the sum of all four signals has a 10% variation as the polarization is varied. Because not all miter bends have their mirror located in the same plane it was expected there would be some variation in the polarization sweep. This is the result of rf wave with a less desirable orientation (resulting in higher losses and mode conversion) on some miter bends and more favorable on others. Consequently, the ratio would change as the polarization was swept. However, it was believed that this would be a 5% effect at most. To achieve reasonable accuracy, each power monitor will be calibrated in situ. And since the polarization sweep anticipated is on the order of 13 deg, the error bars on the signal should be small.

SUMMARY

The DIII–D EC program has developed an in-line power monitor based on the concept that a small but consistent amount of rf power will leak out of a gap in a corrugated waveguide transmission line carrying the HE_{11} mode. The magnitude of the power can be measured by detecting the temperature rise of a band of TiO_2 located over the gap. The design of the power monitor is such that for short pulses (<20 s) the increase in temperature is linear with power and pulse length, which makes it ideal for the DIII–D program. However, the power monitor was found to be more sensitive to polarization rotation than expected. As a result, each power monitor will have to be calibrated in situ and limited to the small range of polarization (±6 deg) used for DIII–D experiments.

ACKNOWLEDGMENT

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