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DESIGN AND HIGH POWER TESTING OF ITER ECH&CD TRANSMISSION LINE COMPONENTS

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GENERAL ATOMICS

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ABSTRACT

The ITER Electron Cyclotron Heating and Current Drive (ECH&CD) transmission line components will need to be suitable for 1-2 MW cw operation. The high heat loads compared to existing transmission lines will require enhanced cooling and, for some components, new or modified designs. Testing at representative ITER conditions of key components has been carried out at the JAEA 170 GHz gyrotron test stand at Naka. Preliminary test results and a discussion of new ITER-relevant components are presented.

I. INTRODUCTION AND BACKGROUND

The critical issue for ITER Electron Cyclotron Heating and Current Drive (ECH&CD) transmission line components is to assure that they will perform with high transmission efficiency over the ITER lifetime when used for 1 (or possibly 2) MW cw operation at 170 GHz. Most experience with megawatt-level ECH evacuated waveguide transmission lines has been obtained with transmitted power less than 1 MW and with pulse lengths less than 10 s. Over the last several years, development of 170 GHz gyrotrons for ITER has yielded gyrotrons with both high power and long pulse length capability. In particular, the 170 GHz gyrotron at the JAEA gyrotron test stand has generated 0.8MW/1h and 1 MW/800 s. This capability has enabled the possibility of testing prototypical ITER ECH transmission line components at representative ITER conditions. The US Department of Energy and JAEA have established a collaboration to test prototypical components at the JAEA test stand.

The high ITER heat loads resulting from 1-2 MW cw operation will require enhanced cooling and, for some components, new or modified designs. The components must also be designed to have very low losses in order to meet the ITER transmission line efficiency requirements.

II. RESULTS OF COMPONENT TESTS AT JAEA

Testing at representative ITER conditions of some components (waveguide switch, waveguides, miter bends, and gate valve) was carried out at the JAEA 170 GHz gyrotron test stand at Naka, Japan late in 2006 [1]. Additional components provided by GA were tested during August–December 2008, and more tests are planned in 2009. Testing plans were presented previously [2]. These GA components include polarizer miter bends, very low diffraction loss miter bends, dc break, waveguide switch, and waveguide water-cooling bars. The waveguide switch and cooling bars have not yet been tested at the JAEA test stand.

The layout of the JAEA transmission line prior to the test component section is shown in Fig. 1. A typical layout of the test section is shown in Fig. 2. For this layout, two polarizer miter bends with a 2-m length of waveguide between them were tested. On the downstream side of the polarizers, an additional 2-m section of waveguide followed by a dc break were tested. The rf power passing through the test components was absorbed in a JAEA pre-load and a Calabazas Creek Research calorimetric load. Similarly, a pair of low diffraction loss miter bends (LDLMBs) (Fig. 3) were tested with a 1-m section of waveguide between them. For HE_{11} mode transmission in the ITER transmission lines, the use of LDLMBs would greatly reduce one of the main sources of power losses and waveguide heating. By converting the HE_{11} mode to a gaussian mode in an up-taper to a slightly curved mirror in an 88.9 mm housing and then tapering back down to 63.5 mm waveguide, the calculated mode conversion is less than 0.1% and higher order modes near cutoff are not generated. In comparison, calculated mode conversion in regular miter bends is 0.25%, with half of this power in higher order modes which get rapidly absorbed in the waveguide.

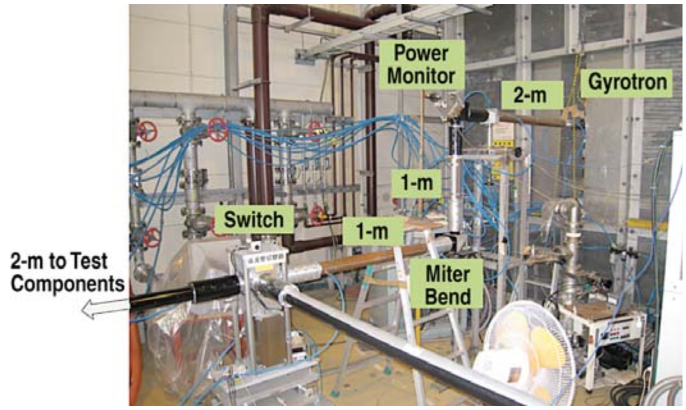

Fig. 1. Layout of the JAEA transmission line before the test section.

Fig. 2. Configuration for testing the fast rotation polarizer miter bends and dc break.

Fig. 3. Pair of low diffraction loss miter bends tested at JAEA test stand. Black tape on surfaces facilitated IR temperature measurements.

Numerous shots of approximately 600 kW for 240 s were injected into the transmission line. Calorimetric measurements of the heat dissipated in miter bend mirrors were made, and IR and RTD measurements were made of waveguide temperatures during the pulses. A critical issue in interpreting the results is to understand the mode purity of the transmitted beam. Ideally, power is transmitted in the HE_{11} mode, since that is the lowest loss mode that propagates in the corrugated waveguide, and the beam emitted at the end of the waveguide has the gaussian profile desired for injection into the plasma. The HE_{11} mode purity of the millimeter-wave beam in the JAEA transmission line has been estimated by analyzing the field patterns radiated from the waveguide output [3]. JAEA measurements show that the beam was tilted by $\sim 1°$ at the exit of the waveguide where the test components were connected, indicating misalignment of the beam into the waveguide and consequent generation of higher order modes. GA analyses show that a $0.7°$ misalignment of a gaussian beam at the waveguide input will generate 10% HE_{21} and 10% TE_{01} mode, with the rest of the power in the HE_{11} mode. JAEA is in the process of developing techniques for improving the alignment of the beam from the MOU into the waveguide.

Measurements of the dc break showed that the temperature increase of the outer surface of the ceramic insulator was about 8°C vs a safe operating limit of about 50°C. This was equivalent to 27°C for 2 MW transmission. Because of the presence of higher order modes, this increase was larger than would have been the case with pure HE_{11} transmission. For pure HE_{11}, the calculated temperature increase is about 10°C for 2 MW cw transmission when the adjacent waveguide stubs are water-cooled. The radiated rf power measured at 50 cm was found to be equivalent to 0.7 mW/cm^2 at 2 MW, well within the 5 mW/cm^2 safety standard.

The polarizer mirrors exhibited higher losses than predicted from theory. The losses in both the polarization rotator and circular polarizer showed the theoretically predicted variation with perpendicular H-field, but the magnitude of the losses varied from 1.7 to 2.9 times the theoretical losses at room temperature. This relatively high loss is attributed to a resistive recast layer on the surface of the copper grooves created during the wire-EDM machining process. The polarizers have been returned to GA so that the mirror surfaces can be re-machined using conventional NC machining, and the mirrors will be retested at the JAEA facility. Even with the resistive surface layer, finite element thermal and stress analyses show that the polarizers are suitable for 1 MW cw operation when mirror angles are optimized for lowest loss operation.

The tests on the LDLMBs showed that mirror losses, especially on the downstream LDLMB (0.21%), were close to the theoretical predictions (0.16% at room temperature). However, losses in the adjacent waveguides were higher than expected for pure HE_{11} transmission because of higher ohmic and mode conversion losses of the HE_{21} and TE_{01} modes.

The tests conducted at the JAEA test stand are valuable in validating designs and determining where design improvements are needed. In addition, the US ITER Project

Office (USIPO) plans to test a complete prototype ITER transmission line in order to validate the designs for use on ITER, and GA has provided some components to the USIPO for initial tests.

III. NEW COMPONENTS UNDER DEVELOPMENT

Several other components are under development at GA to meet the needs of the ITER ECH transmission lines, namely: (a) sliding joint waveguide to use as an alternative to waveguide bellows, (b) 170 GHz mode analyzer/beam splitter for measurement of HE_{11} mode content during high power long pulse operation, and (c) alignment monitor for aligning the mm-wave beam into the 170 GHz 63.5 mm waveguide with minimal tilt and offset error to minimize the generation of higher order modes at the waveguide entrance.

A prototype of the sliding joint waveguide was fabricated and is shown in Fig. 4. It is capable of 30 mm compression and is made of hard copper with high thermal conductivity so it can be used in the presence of significant high-order mode content.

Fig. 4. Prototype of 63.5 mm diameter sliding joint waveguide, shown without protective shield normally surrounding the bellows section.

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