Development of a Low Reflection Dummy Load for Calorimetric Power Measurements in High-Power Millimeter Wave Systems

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We developed a prototype low reflection dummy load for calorimetric power measurements in high-power millimeter wave systems. The dummy load is featured by low reflection of millimeter waves by an internal cylinder designed for increasing the length of the ray trajectory in the dummy load. This structure prevents the millimeter wave reflection from the dummy load by absorbing the waves by the inner surface of the cylinder. Initial tests at high powers of up to 0.5 MW for 0.25 s were successfully able to measure output power with lower reflection back to the source than that of conventional short pulse dummy loads used in the past.

Keywords: dummy load, high-power millimeter wave, reflection

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Dummy loads are used during commissioning of electron cyclotron heating and current drive systems to absorb millimeter wave power and to measure the output power of gyrotrons and transmission lines (TLs). A brief history of various dummy loads developed in the past is presented in [1] and its references documents. Gyrotron power needs to be measured for more than 0.5 s considering the thermal expansion of the gyrotron cavity resonator. Dummy loads capable of a pulse length of > 0.5 s usually require metal walls (possibly with a coating for absorbing millimeter waves) instead of ceramics or water tubing used in very short pulse dummy loads (< 100 ms). However, compared with very short pulse dummy loads, metal dummy loads have a relatively high reflectivity of > 1% and usually required the use of pre-loads to reduce reflection. In this paper, the design and initial experimental results of an all-metal, low reflection dummy load, or LRD for short, are reported.

Figure 1 shows a cross section of the prototype LRD, which is composed of a main chamber, water jacket, input flange, bottom flange, reflecting mirror, inner cylinder, and input waveguide having an inner diameter of 60.3 mm. Vacuum pumping ports and water inlet/outlet pipes are also included. The main chamber is made of an aluminum alloy and the inner cylinder is made of SS304, the inner surfaces of which are coated with TiO_2 (0.2 mm thickness) to absorb millimeter waves. The “outer surface” of the inner cylinder, however, is not coated. A conical shaped copper mirror having an angle of 114° is mounted on the bottom flange. Although not essential for operations up to 1 s, the outer surface of the main chamber has cooling fins for in-

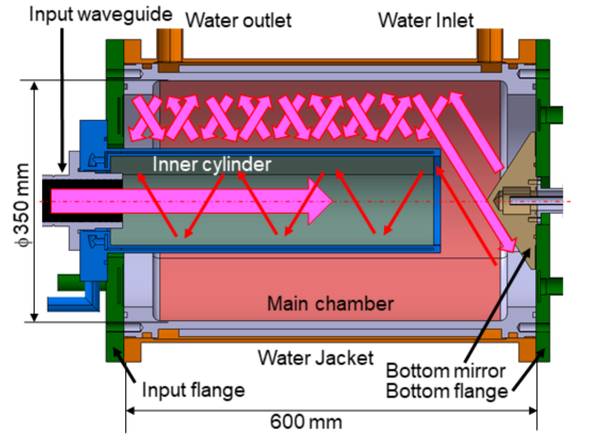

Fig. 1 Low reflection dummy load (LRD) prototype cross section.

creased cooling efficiency, which will be used for investigating cooling efficiency in high-power, long-pulse operations in a future upgrade.

The low reflection characteristics of the LRD are owing to the inner cylinder. One important role of the inner cylinder is to separate the inside of the dummy load into two regions (outer and inner regions of the inner cylinder) so as to increase the length of the ray trajectory in the dummy load until the ray returns to the input waveguide, which in turn results in low reflection back to the source gyrotron. Beams reflect off the bottom mirror and propagate in the main absorption area (between the outer surface of the inner cylinder and the inner surface of the main chamber) back toward the input side and then return to the bottom side (see Fig. 1). The beam has no opportunity to be coupled into the input waveguide during its propagation in the main absorption area. Millimeter wave power

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is absorbed by the TiO_2 coating on the inner surface of the main chamber. The conical mirror angle and height were designed to obtain about 10 absorptions/reflections on the TiO_2 surface per travel cycle. Using this design, at least, parallel rays in the geometrical optics launched from the waveguide do not directly return to the inner cylinder. The rays first reflect off the inner surface of the main chamber and then reflect off the outer surface of the inner cylinder. In addition, these rays do not go back to their initial reflection position on the bottom mirror after their first travel cycle. The actual number and positions of reflections depend on the operating frequency and input mode purity because of the large diffraction effect of the waves reflected at the bottom mirror, which is different from the geometrical optics rays. The inner surface of the inner cylinder has another important role in the LRD for low reflection back to the source. Some of the diffracted beams are allowed back into the inside of the inner cylinder. However, these beams are angled in such a way with respect to the center axis of the dummy load that a beam is expected to be absorbed or reflected several times off the TiO_2-coated inner surface of the inner cylinder until the beam reaches the input waveguide. This feature enabled to remove a kind of pre-loads, which were used in the past to avoid large reflection waves in higher order modes.

To confirm performance characteristics of the LRD, preliminary high-power experiments were carried out by using a multi-frequency (82 GHz, 110 GHz, and 138 GHz) gyrotron in the JT-60SA ECRF system [2]. An existing short pulse dummy load (SPD), shown in Fig. 11 of [1], was also tested under the same conditions for comparison, however, a tapered waveguide was used to connect the 31.75-mm SPD inlet to the 60.3-mm waveguide in JT-60SA. The dummy load to be tested was connected to the gyrotron via a matching optics unit and a TL having five miter bends and a total waveguide length of approximately 15 m. The gyrotron was operated at fixed operating parameters for each frequency. Figure 2 shows the calorimetrically measured energy absorbed by each dummy load (LRD and SPD), and the rise in temperature of the DC-break cooling water, which acts as an internal stray rf absorber and surrounds the large DC-break between the gyrotron collector and body structures. The DC-break water temperature rise is mainly caused by mode conversion of forward waves in the gyrotron. But, if some of the waves reflected from the dummy load (or TL), some portion of the reflected wave will be absorbed by the DC-break cooling water. As seen in Fig. 2, the absorbed energy in the LRD is higher than that of the SPD in all three frequencies. In addition, the DC-break water temperature rise of the LRD was lower than that of the SPD. These experimental results suggest that, as expected, the newly developed LRD has lower reflection characteristics than those of the SPD. A quantitative analysis of the absorbed wave power, reflected wave power, and modes will be performed in the near future.

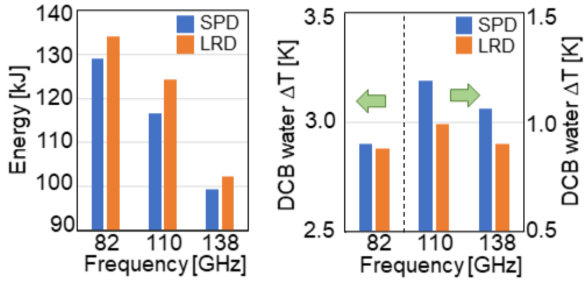

Fig. 2 Absorbed energy at dummy load (left) and the temperature rise of the gyrotron DC-break cooling water (right) using an existing short pulse dummy load (SPD) and the newly developed low reflection dummy load (LRD) for oscillations of 0.25 s at three frequencies of 82 GHz, 110 GHz, and 138 GHz.

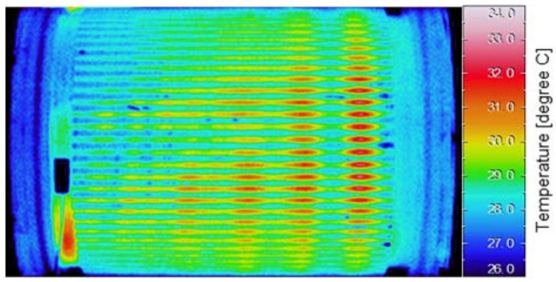

Fig. 3 Thermal image of the main chamber outer surface taken 1 s after a pulse (0.4 MW/0.15 s/110 GHz).

An experiment to confirm the power and pulse length capabilities of the present design of the LRD was carried out. Using the design, the main chamber is capable of 1 MW for 1 s if the horizontal temperature rise has a peaking factor of 2 with respect to the uniform temperature rise and is uniform in the azimuthal direction. In the high-power experiments, some higher order modes caused a non-uniform profile in the azimuthal direction of the main chamber. Figure 3 shows an example of the temperature rise of the outer surface of the main chamber measured by an infrared camera at an oscillation of approximately 0.4 MW for 0.15 s at 110 GHz. The water jacket was removed for this experiment, and the LRD was operated without cooling. As expected, the horizontal temperature distribution showed several hot spots corresponding to the positions of the beam reflections. On the other hand, the temperature rise distribution in the azimuthal direction was not uniform due to higher order modes in the input beam. By assuming a peaking factor of 4 in the azimuthal direction, the present design was expected to be capable of up to 0.5 MW for 0.5 s. High-power tests up to approximately 0.5 MW for 0.25 s and 0.17 MW for 2.9 s were carried out without incident, so far. Further increases of pulse length and power in high-power experiments, and further analyses for increasing power and pulse length capabilities by optimizing the materials, shape, and cooling efficiencies of the main chamber are on-going.

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