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Simulation and RF test results on high power waterload for KSTAR LHCD system

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1. Introduction

A 5 GHz lower hybrid current drive (LHCD) system is planned to support an advanced tokamak operation on the KSTAR experiment [1]. As an initial stage, in order to study the LH coupling and flux-saving in the plasma current ramp-up, prior to long pulsed non-inductive operation in KSTAR, we have installed a pulsed 5 GHz, 500 kW LHCD system in 2012 [2]. The RF output of the klystron is transmitted to the LH launcher through 80 m long transmission line. To reduce the ohmic power loss over the transmission line, we used oversized rectangular waveguide of WR284 and its cross section is 72.14 mm x 38.1 mm. The WR187-229-284 waveguide taper is designed and fabricated to minimize mode conversions during the transition from WR187 to main transmission line of WR284 using HFSS simulations [3]. We have also designed a 5 GHz, high-power waterload with a WR187-229-284 transition for the KSTAR LHCD system using HFSS [4]. Its main role is to terminate microwave and measure the absorbed power into the waterload to calculate the overall ohmic power loss of TE10 mode through the 80-m long transmission line including WR284 E/H bends. In this paper we present simulation and RF test results of the prototype waterload.

2. High power waterload with a cone-shaped quartz

2.1 HFSS simulation results

The waterload features a large cone-shaped quartz tube installed vertically on the top of WR284. The thickness and diameter of quartz are 6 mm and 160 mm, respectively. Fig. 1 shows the waterload with a cone-shaped quartz. For the impedance matching of waterload, we make a cone-shaped quartz tube filled with water. In the simulations the dielectric constants of water and quartz are 78.3 and 3.78, respectively. Loss tangent of two materials are 0.16 and 1*10-4, respectively. The input VSWR is minimized by adjusting the tuning button located on the center of bottom WR284 and moving up the quartz waterload vertically. When we shifted upward of waterload 1 mm compare with the waveguide center of WR284, the reflection coefficient obtained from the simulation is less than -30 dB at the operating frequency of 5 GHz as shown in Fig. 2. The input VSWR obtained is less than 1: 1.1. Considering an input power of 500 kW, the integrated RF losses in the quartz are close to 60 W due to the very low RF losses of the quartz (tan delta~1.0e-4). Almost all the RF power is thus absorbed in the water (499.8 kW). The RF volume loss densities in the water are illustrated in Fig. 3. As shown in log scale plot in Fig.3, almost all the losses are concentrated into the water.

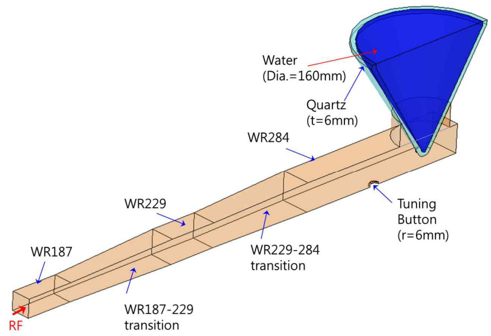

Fig. 1. Schematic diagram of a high power waterload with a cone-shaped quartz.

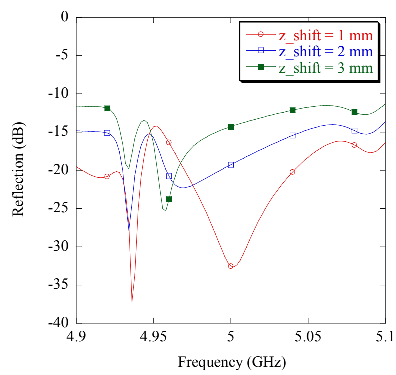

Fig. 2. Reflection coefficient of the waterload by shifting the quartz up at the optimized position of tuning button located on the bottom of WR284 as shown in Fig. 1.

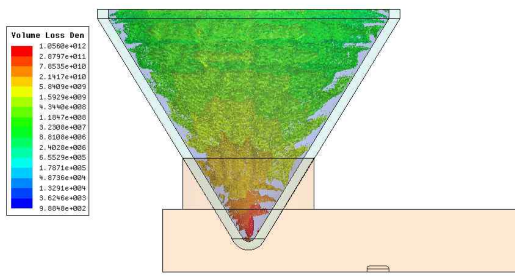

Fig. 3. Volume RF losses in the water for 500 kW input.

2.2 RF test results using a Vector Network Analyzer

In order to measure and compare the RF performance of the waterload with simulation results we have fabricated and tested the waterload with a cone-shaped quartz and a WR187-229-284 transition. For an accurate RF measurements in waveguide components using the Agilent's VNA we conducted TRL (Thru, Reflect, Line) full 2-port calibration [5]. Before the TRL calibration we first created new WR187 cal kit by modifying the standard WR90 calibration kit. Then we measured the reflection coefficient in the waterload. Fig. 4 shows the 3-d model and RF test set-up of high power waterload. As shown in Fig. 4 a cone-shaped quartz is located inside the stainless steel box which is connected to two water pipes for inlet and outlet. Two water pipes are welded to the top of stainless steel water box which is used for water tank and cover of the quartz. For vacuum and pressurized gas applications we put two Viton O-rings on top and bottom sides of quartz between quartz and stainless steel box. We have tested the reflection characteristics of the waterload by moving tuning button located on the bottom of WR284 and shifting the quartz position just by inserting metal rings as shown in Fig. 4.

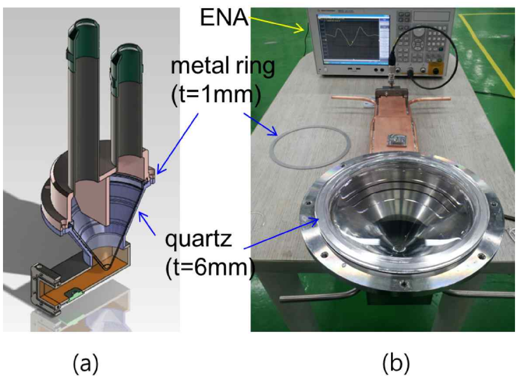

Fig. 4. (a) 3-d model and (b) RF test set-up of the waterload using Agilent's ENA.

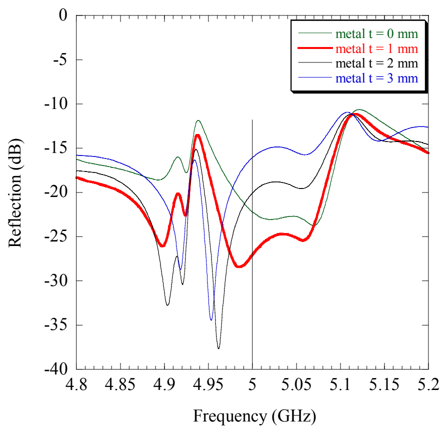

Fig. 5. Measured reflection coefficient of the waterload by inserting the metal ring below a cone-shaped quartz.

Fig. 5 shows the measured S11 of the waterload using the Agilent's ENA. At the fixed and optimized tuning button position we obtained very good performance of S11 at 5 GHz by changing the vertical position of quartz compare to the center of WR284. The reflection coefficients of the waterload obtained from simulation and measurement at 5 GHz are -32 dB and -27 dB, respectively. The RF test results are in good agreement with the simulation data.

We will conduct high power test for the waterload using 5 GHz, 500 kW prototype klystron and measure the total ohmic power loss of the 80-m long transmission line at the end of the WR284 oversized waveguide during 2013 KSTAR campaign.

3. Conclusions

We have designed, fabricated, and tested the prototype waterload with a cone-shaped quartz for initial KSTAR LHCD system in order to terminate microwave and measure the absorbed power into the waterload at the end of WR284 waveguide of KSTAR LHCD transmission lines. The VSWR of the waterload obtained from simulation and measurement are 1:1.05 and 1:1.1 at 5 GHz during low power test, respectively. It should be noted that the prototype waterload has good VSWR, high power handing, and easy fabrication at RF and microwave ranges. New type microwave dummy-load using a cone-shaped quartz filled with water was successfully operated at the operating frequency at low power. The waterload can be widely used in fusion and industrial systems of microwave heating and termination.

Acknowledgements

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