RF Test of the KSTAR ICRF Antenna with a Water-Cooling

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1. Introduction

The KSTAR ICRF (Ion Cyclotron Range of Frequency) antenna is being developed for the high-power and long-pulse operation. For a 300 s operation at a high power of 6 MW, the antenna needs to be actively cooled to remove the dissipated RF loss power and incoming plasma heat loads. The antenna has many cooling channels inside the current strap, Faraday shield, cavity wall, and vacuum transmission line (VTL) to the heat loads. In the previous test campaign, the vacuum feedthrough (VF) and the transmission line of the unmatched section could not be cooled because the cooling channels were not ready for them. So the maximum available voltage was limited below 31.2 kVp for a 300-s operation. In the present campaign, the cooling channels for the VF and the transmission line were carefully designed and installed inside their inner conductors, which were connected in series. The high power and long pulse capabilities of the antenna were experimentally estimated with a water-cooling.

2. Descriptions of Water-Cooling Scheme

The antenna which can be plugged in through a main horizontal port, is composed of four center-grounded current straps located in cavities separated toroidally by septa, and screened by a single-layer Faraday shield. A 3-D view of the antenna is shown in Figure 1.

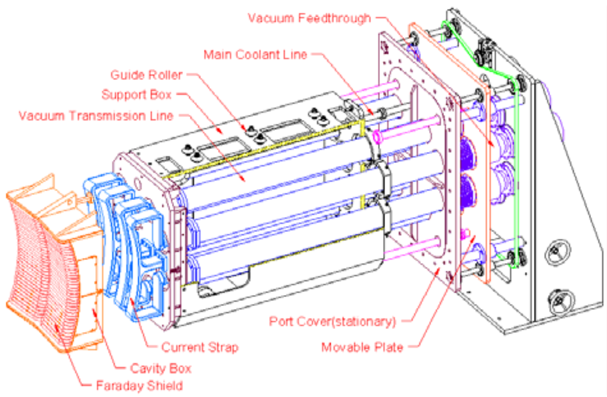

Figure 1. Detail 3-D drawing of the ICRF antenna.

The portion of the current strap that couples power to the plasma is 752 mm long, 98 mm wide and 20 mm thick. The strap has cooling channels along both edges, and channels are connected with those of the center conductor of the VTL as shown in Figure 2. The cooling water for 4 current straps is distributed in parallel inside the back plate of the cavity. The Faraday shield consists of a single layer of water-cooled tubes covering a pair of toroidally adjacent straps. The material of the tubes is Inconel 625, and the tube diameter is 15.9 mm with a wall thichness of 1.25 mm. The tube is copper-plated to reduce electrical losses, and it will be coated with B_4C on the front surface. Each of the two shield sections consists of 33 tubes. The 3 tubes in each section are cooled in parallel and the two sections are cooled in series as shown in Figure 3. The cavity box is constructed of SS316L plate and is basically a welded fabrication with a bolted on back plate to facilitate assembly. The cavity wall provides the cooling water path to the Faraday shield tube, and there are cooling paths along the front edges of the septum plates and upper/lower walls of the cavity. The surface of the cavity is plated with copper to reduce the RF losses. The VTLs consist of 8 coaxial lines, which are made of the seamless SS304 tube plated with copper. The VTL has water cooling channel inside the center conductor featuring a coaxial tube. The cooling channels of the VTLs are connected with those of the current straps as shown in Figure 2.

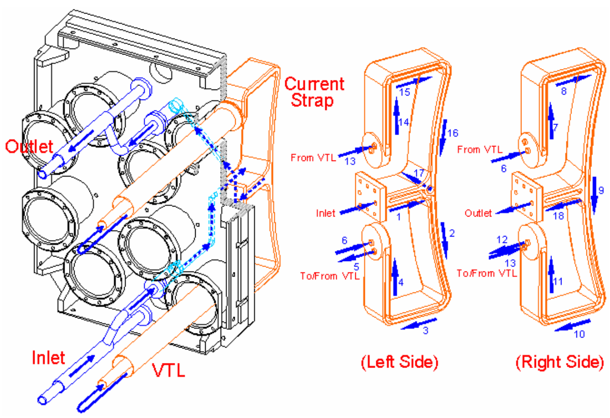

Figure 2. Cooling channels inside the current strap and the vacuum transmission lines.

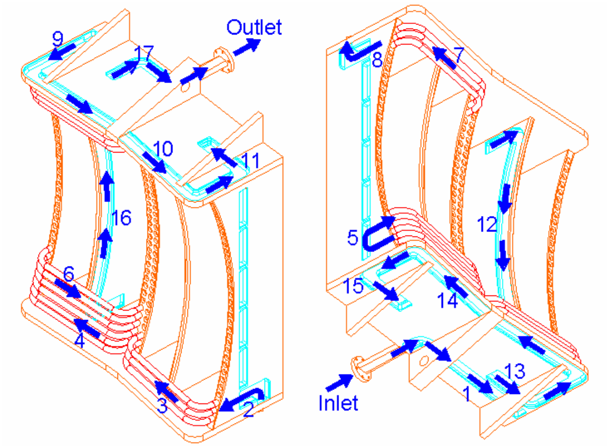

Figure 3. Cooling path diagram for the Faraday shield and the cavity walls.

3. RF Test of the Antenna with a Water-Cooling

The RF power tests of the antenna were performed at a frequency of 30 MHz. In the previous test campaign, the RF tests were performed with a water-cooling on the antenna, the VF and the transmission line. Schematic diagram of the test circuit is shown in Figure 4. In this circuit, the half of a current strap was connected to the RF source, and other three straps are shorted at the input ports. The unmatched line section from stub tuner to vacuum feedthrough is pressurized with N_2 gas to increase standoff voltage.

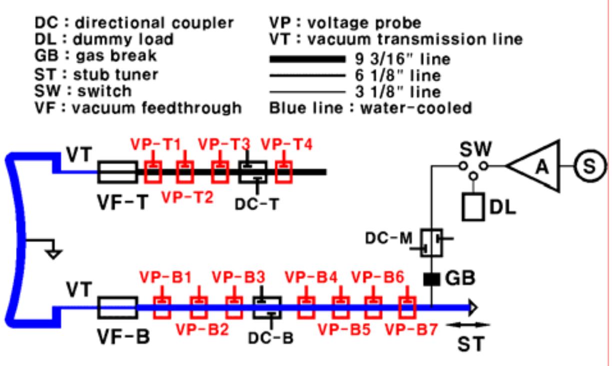

Figure 4. Schematic of the RF test circuit.

During the RF pulse, temperatures at several positions of the cavity wall were measured by embedded thermo-couples. The line voltage, forward and reflected powers, and RFTC pressure were also measured. For the conditioning of the antenna and the VTL, about twenty RF pulses were applied at low power range just before applying the main RF pulse. During the conditioning process, the maximum vacuum pressure was maintained lower than 2×10^{-5} mbar. After the conditioning, the main test pulses were applied to the antenna. The applied powers were gradually increased shot by shot. As a test result of the maximum standoff voltage for a 300-s duration, the time evolutions of the forward and reflected powers, the maximum peak voltage, the maximum temperature of the antenna, and the vacuum pressure of the test camber are shown in Figure 5. During the pulse duration, the reflected power was continuously increased as shown in Fig. 5(a). It might be caused by a temperature increase in the short stub tuner. The temperature of the stub tuner was abnormally increased up to 125 °C. It was due to the poor contact of the short plate with the outer conductor which was a non-cooled component. The maximum line voltage was 33.2 kVp, which is slightly higher than that of the previous campaign of 31.2 kVp. The maximum temperature of the cavity wall was saturated at 47 °C. The vacuum pressure was saturated at below 7.2×10^{-6} mbar.

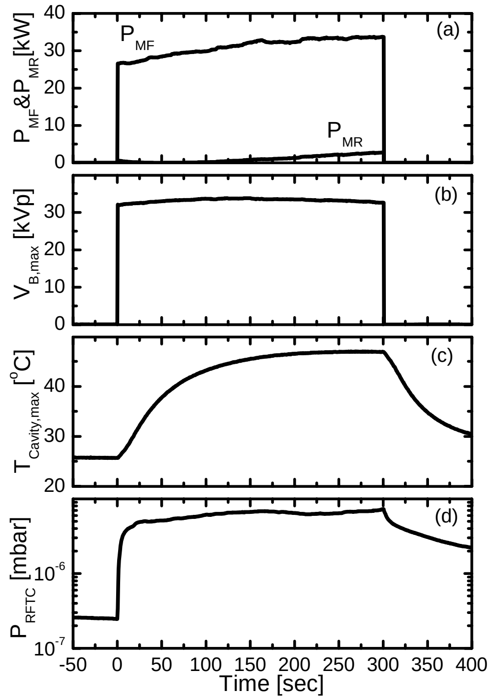

Figure 5. Time evolutions of the RF powers (a), line voltage (b), temperatures of the antenna cavity (c), and vacuum pressure of the RFTC (d) measured in long-pulse tests.

4. Conclusion

The test results are promising that a long pulse operation at higher RF voltage will be attainable through an active cooling of not only the inner conductor of the VF and the transmission line but also the outer conductor of them.