# Water-cooling Effect in the ICRF Antenna for KSTAR

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## 1. Introduction

An ICRF (Ion Cyclotron Range of Frequency) antenna is being developed for the high-power and long-pulse operation at KSTAR (Korea Superconducting Tokamak Advanced Research) tokamak. 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 to the heat loads. The high power and long pulse capability of the antenna was experimentally estimated without and with a water-cooling.

## 2. Antenna Details

The antenna-array 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.

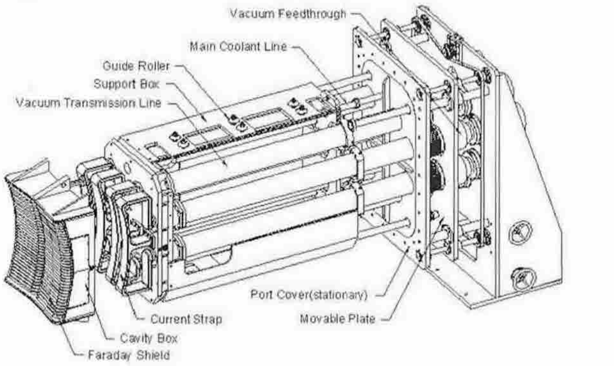


Figure 1. Detail 3-D drawing of the ICRF antenna.

The portion of the current strap that couples power to the plasma is 752 mm long, and is located 10 mm from the back surface of the Faraday shield. Each current strap is 98 mm-wide and 20 mm-thick. The strap material is copper-plated SUS304. The strap has cooling channels along both edges, and channels are connected with those of the center conductor of the vacuum transmission line. The Faraday shield is constituted 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$\phi$ 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 two sections are cooled in series and the 33 tubes are cooled in parallel with each other. The cavity box is constructed of SUS316L 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 other cooling paths along the edges of the septum plates andupper/lower walls of the cavity. The surface of the cavity is plated with copper to reduce the RF losses. The vacuum transmission lines consist of 8 coaxial lines, which are made of the seamless SUS304 tube plated with copper to reduce RF losses. The line has water cooling channel inside the center conductor.

The components that must be cooled are four current straps, centre conductors of eight vacuum transmission lines, Faraday shield tubes and antenna cavity box, especially near the front of the box. For this purpose, the antenna has very complicated water channels as shown in figure 2.

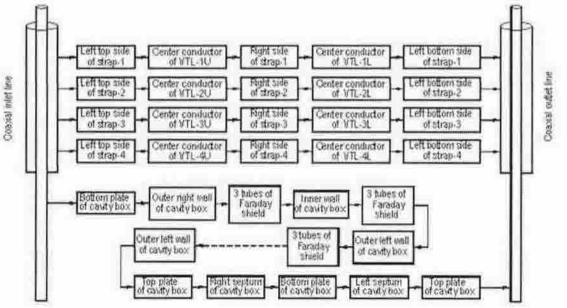


Figure 2. Cooling path diagram for the ICRF antenna.

## 3. RF Test of the Antenna

The RF power tests of the antenna were performed at a frequency of 30 MHz. In order to estimate the water-cooling effect, two RF tests were carried out; without water cooling and with water cooling at nearly same RF voltage for 300 sec duration. Schematic diagram of the test circuit is shown in figure 3. In this circuit, the half of a current strap is connected to the matching circuit via a vacuum feedthrough, 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.

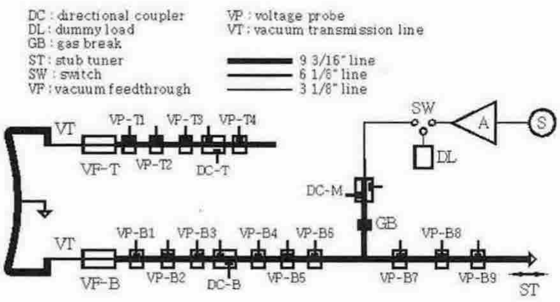


Figure 3. Schematic of the RF test circuit.

During the RF pulse, temperatures at several positions of the cavity wall were measured by embedded thermo-couples and the temperature profile of the antenna was measured by an IR camera. The line voltage, forward and reflected powers, and RFTC pressure were also measured. For the conditioning of the antenna and the vacuum transmission line, 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 $2\times10^{-5}$ mbar. After the conditioning, RF power tests without water cooling and with water cooling were performed to compare RF characteristics of the antenna between two cases. The resultant 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 4. In comparison with the non-cooled antenna, the water-cooled antenna showed several good performances as follows;

- The bandwidth of the frequency tuning required to minimize the reflected power was much lower than the case of non-cooling. The tuning width was 12 kHz for the non-cooling case and 2 kHz for water-cooling case. VSWR values were 1.78 and 1.55 respectively.
- The maximum temperature, 106 °C was much lower than the case of non-cooling, 382°C.
- The vacuum pressure was saturated and continuously decreased. In the case of non-cooling, the pressure increased after mid time of the RF pulse.

## 4. Conclusion

The water-cooled antenna showed significantly improved performances in long pulse operation. The test results are promising that a long pulse operation at higher RF voltage will be attainable through an active cooling of the vacuum feedthrough and the transmission line.

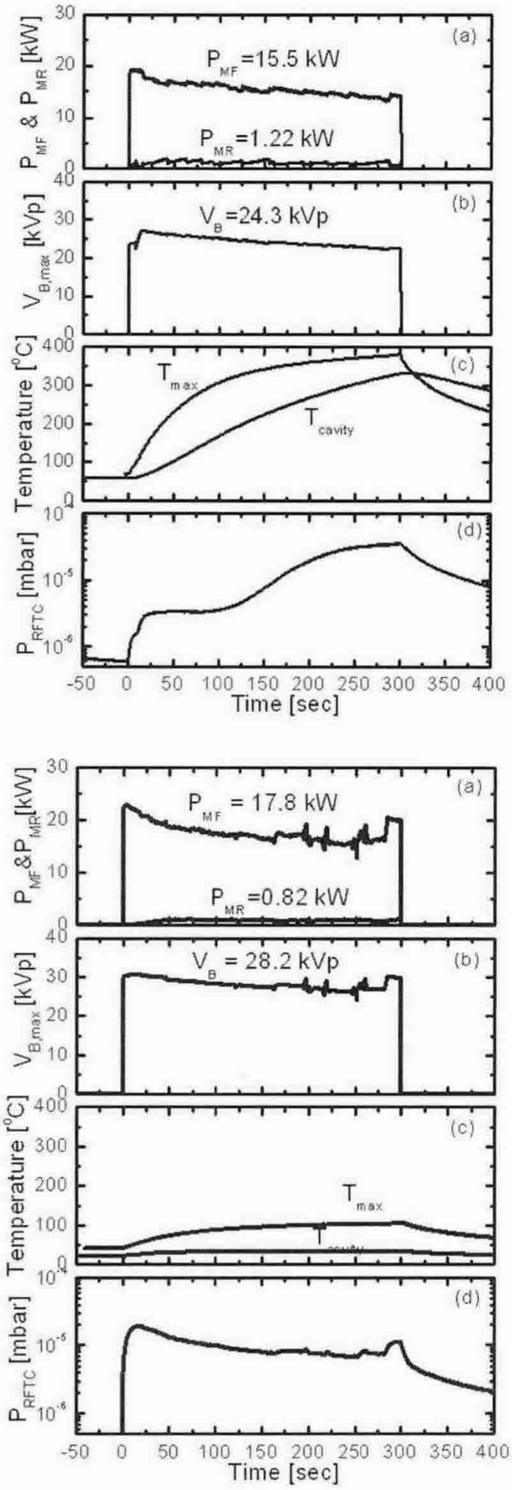


Figure 4. Time evolutions of the RF powers (a), line voltage (b), temperatures of the antenna (c), and vacuum pressure of the RFTC (d) measured in long-pulse tests without water-cooling (upper), and with water-cooling (lower).