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Thermal and Stress Analysis of The Faraday Shield in KSTAR ICH System

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Abstract

The Korea Superconducting Tokamak Research (KSTAR) tokamak will have 6 MW of radio-frequency (rf) heating in the ion cyclotron range of frequencies (ICRF). The response of the antenna to the heat loads is analyzed and the resulting stresses in the Faraday shield during the normal operation is calculated. Various heat loading conditions including in the analyzes are the heat loads from the plasma, the ripple-trapped beam particles and the rf loss.

I. Introduction

Engineering design of the ICRF heating system of the KSTAR began in 1997[1]. Recently, The prototype, uncooled antenna is designed for short-pulse operation to investigate such areas as coupling efficiency to the plasma, impurity production mechanisms, and rf current and voltage limitations on the antenna and transmission line components.

The ICH/FWCD launcher consists of a large antenna mounted through a standard rf port of KSTAR vacuum vessel. The antenna consists of four current straps, each of which is grounded at the center and has a coaxial feed line connected to each end of the current strap. The antenna is constrained to be 830 mm high and 730 mm wide in order to fit through the port. The antenna structure is radially movable under vacuum so that the antenna position relative to the plasma can be adjusted to optimize the power transferred to the plasma. The antenna, including the Faraday shield tubes, is water-cooled to permit long-pulse operation. Figure 1 and 2 show a side view and the cooling path of the ICH antenna in KSTAR, respectively.

The Faraday shield protects the antenna system from direct exposure to the plasma environment and also polarize the electromagnetic wave correctly for efficient heating of the plasma. It must withstand heating by the RF system itself, by the direct radiation from the

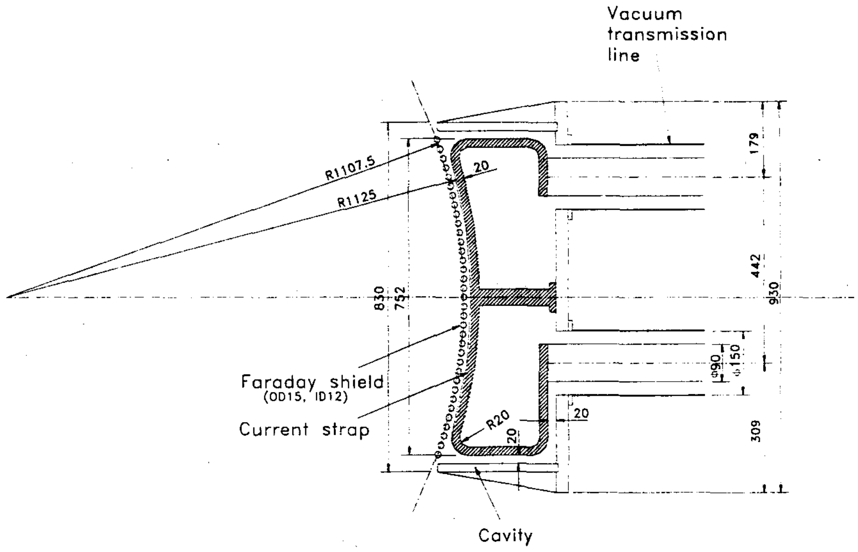

Figure 1. Side view of the ICH antenna.

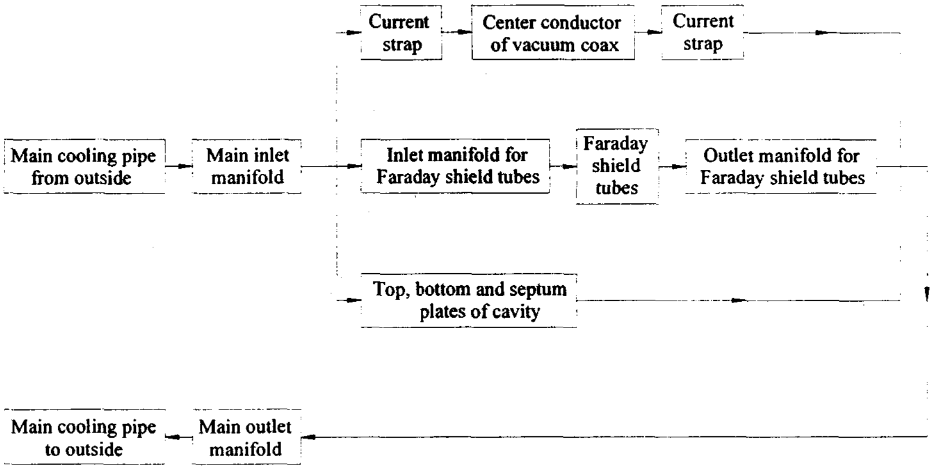

Figure 2. Cooling path diagram

plasma, and from the sudden heat load imposed by plasma disruption. For this purpose, Faraday shield is designed as a water-cooled and single-layered tube with approximately 30% transparency. The material of the tube is copper-plated Inconel 625 which has sufficient yield stress, and the tube size is 15mmOD x 12mmID. The tube is copper-plated to reduce electrical losses, and then coated with plasma-sprayed layer of B_4C on the front surface with thickness of about 0.1mm. Each of two shield sections consists 35 tubes which are horizontally arranged and the gap between adjacent tubes is 6.4mm. Figure 3 shows a cooling path of the Faraday shield.

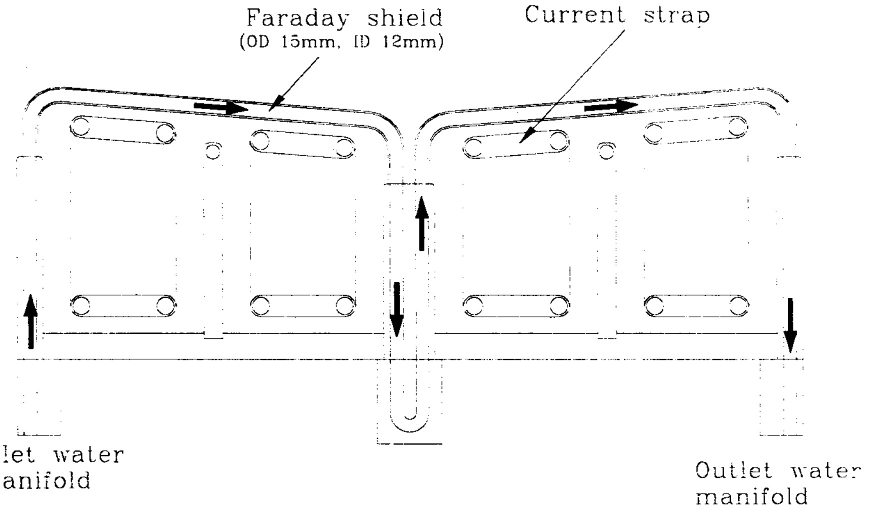

Figure 3. Cooling path of the Faraday shield

One of the major questions regarding the ion cyclotron system concerns the reliability and survivability of the ion cyclotron antenna subjected to the long-pulse operating conditions in KSTAR. The main complication presented by this operation is requirement for active cooling of the Faraday shield. In this paper, we analyzes the response of the antenna to the various heat and calculates the resulting stresses in the Faraday shield during the normal operation.

II. Thermal and stress analysis

The primary issue during normal operation with the full heating power is the response to the heat loads from the plasma. The thermal specifications are summarized in Table 1. P_{beam} is the amount of neutral beam power injected into the plasma, and P_{total} is the total heating power. Q_{ripple}, which is proportional to P_{beam}, is the heat flux from the ripple-trapped beam particles; $Q_{radiated}$, proportional to P_{total}, is the heat flux radiated onto the antenna from the plasma.

Table 1. Thermal spcifications of the RF system.

Parameter	Value	Parameter	Value
P_{beam} (MW)	24	Ripple heat on tube(W)	489
P_{total} (MW)	40	Radiated heat on tube(W)	1330
Q_{ripple} (MW/m^2)	0.3	RF heat on tube(W)	217
$Q_{radiated}$(MW/m^2)	0.25	Total heat on tube(W)	2036

The deposition patterns of the heat loads on the tubes are shown in Figure 3. The ripple-trapped particles drift vertically to deposit their power on the tubes, but only about the front 1/3 of the tube can be exposed to this heat flux as it is shielded by the tube below it. The rf heat flux is relatively small compared to the other heat loads. It has both axial and azimuthal variation on the Faraday shield tubing.

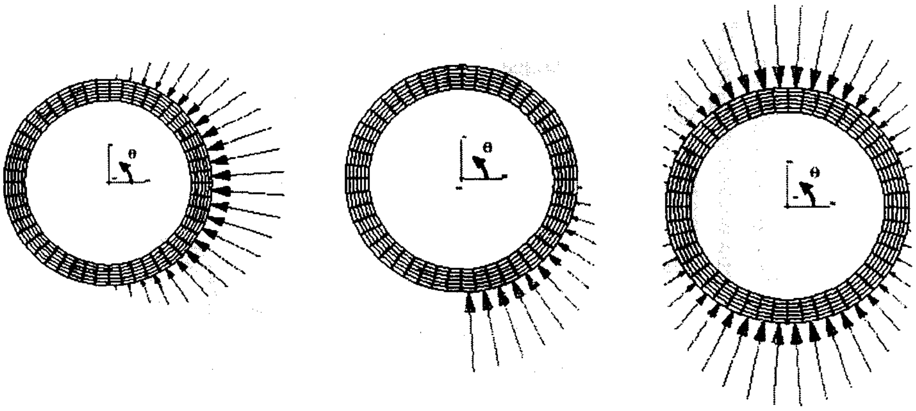

Figure 3. Deposition patterns for radiated heat load (left), ripple-trapped particle heat load (center), and rf heat load (right)

In the thermal analysis, we assume that the water inlet temperature is 40 °C, and that at that temperature the tube is in a completely unstressed state. The flow velocity of inlet water is 2m/sec.The code used is ANSYS. Figure 4 shows the temperature of the tube, Figure 5 shows the stresses resulting from the thermal loads, and Figure 6 shows the resulting deflections of a Faraday shield tube

From the thermal analysis, the maximum temperature is 152° C and the maximum stress is 223 MPa. For Inconel 625 this represents about 60% of the yield stress (400Mpa) for annealed material at 600° C. The allowable for a thermal stress can be as high as 750MPa if no other stresses are present. The maximum coolant pressure stress is ~6 MPa for 10 ATM pressure, and is of no major stress consequence. Based on these results, the stresses in the Faraday shield tubes appear modest. The Faraday shield should easily withstand the thermal stress calculated in this paper.

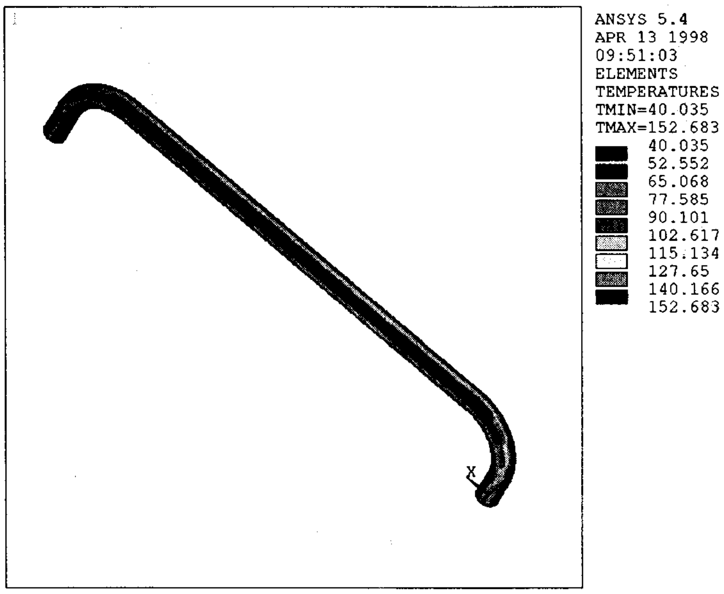

Figure 4. Steady-state temperature of a tube subjected to the thermal loads.

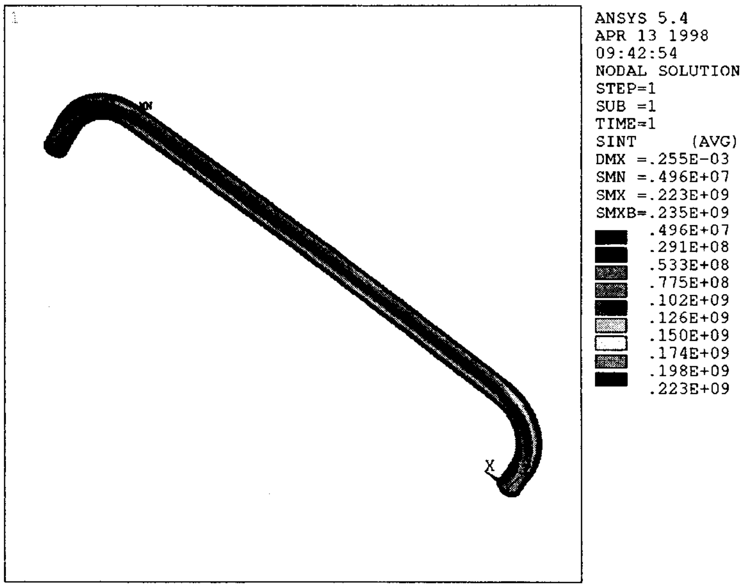

Figure 5. Tresca stress for the thermal loads.

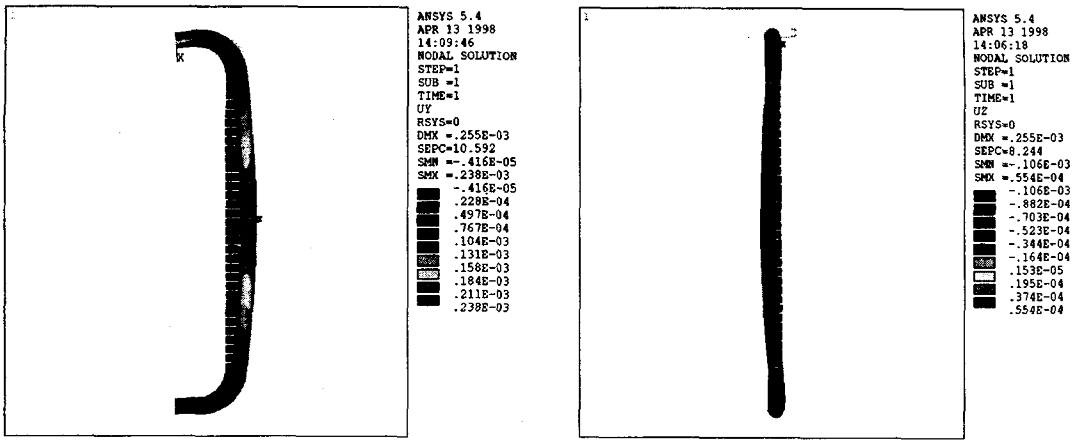

Figure 6. Radial (left) and vertical (right) deflections for the thermal load.

Acknowledgement

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Reference

[1] B.G. Hong et al., "Physics and Engineering Aspects of the ICRF Heating and Current Drive System on KSTAR" 17th IEEE/NPSS, Symposium on Fusion Engineering, October 6-9, 1997, San Diego, USA.