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# RF high voltage test and thermal analysis on the ICRF vacuum feed-through

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## 1. Introduction

The KSTAR Ion Cyclotron Range of Frequency (ICRF) system has been developed for high-power, long-pulse plasma heating at frequencies from 25 to 60 MHz [1]. KSTAR achieved the first high-performance confinement fusion plasmas in the 2010 experimental campaign [2], which is an important milestone for the reactor-relevant research of steady-state, high performance fusion plasma in the superconducting tokamak. In the ICRF system, a vacuum feed-through (VFT) was fabricated and utilized for vacuum sealing between the pressurized transmission line and a vacuum chamber [3]. The feed-through has to withstand high RF voltage or large RF current, while keeping the antenna in high vacuum. In order to study RF voltage and thermal characteristics in the VFT, we have fabricated and tested a new feed-through in the vacuum chamber with a high voltage/current RF test stand.

## 2. RF high voltage test and temperature analysis

### *2.1 RF high voltage test*

The RF high voltage test of the VFT was performed at the frequency of 30.8 MHz using a test stand as shown in Fig. 1. The transmitter is capable of delivering 2 MW in the range of 25 ~ 60 MHz and 300 s long-pulse operation [1]. The 9 inch coaxial section from a short stub to the VFT is pressurized with $N_2$ gas at 2 $kgf/cm^2$ to increase the stand-off voltage. The 6 inch coaxial feed-through is placed at the end of the test stand. Its end is electrically opened but connected to a vacuum chamber. The voltage at the feed-through reaches the maximum. We have measured a transmitter power, the line voltage, and the temperature of the outer conductor surface of VFT using IR camera during the RF pulse operation. When 100 kW RF pulse with 1 sec duration was injected to the test stand, the measured RF voltage of the VFT is about to be 30 kV. The RF power dissipation due to the dielectric loss in two alumina cylinders of VFT is calculated to be 162 W and 163 W, respectively, using HFSS.

The fixed temperature used at the outer most steel surface of the VFT is anticipated to be the measured value with IR camera in the experiment. As shown in Fig. 2, temperature variation on the steel surface is negligible so that their surface temperature distribution was treated constant.

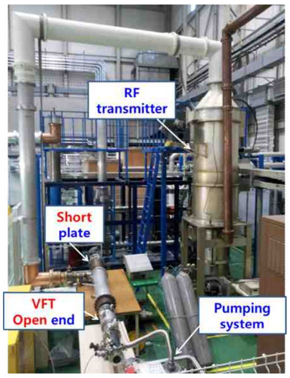



Fig. 1. RF high voltage test stand of a vacuum feed-through.

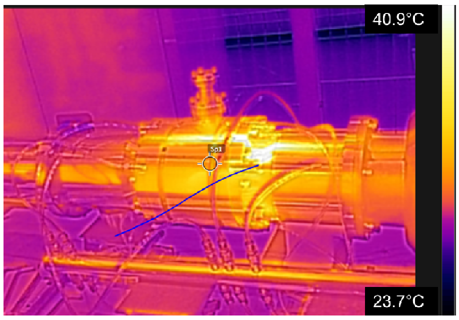



Fig. 2. Temperature measurements for the outer steel surface of the vacuum feed through using IR camera

### *2.2 Temperature analysis using ANSYS*

The inner alumina cylinder in the VFT plays a role of RF heat source with the heat generation of 100 ~ 200 W. The air was treated as a conductive media with a constant thermal conductivity. The radiation effects were investigated, although they were anticipated to be negligible in the temperature ranges (~100 $^oC$) of interest in this simulation [4]. Quite a few numbers of boundary conditions were used to represent real situations, while reducing any unnecessary computational costs. Table 1 shows a list of the boundary conditions used in ANSYS thermal analysis. Several different sizes or numbers of tetrahedron elements were used for numerical discretization schemes. A typical meshing scheme used in the simulation is illustrated in Fig. 3. The mesh size and total applied heat flux in Figs. 4 and 5 are 3.5 mm and 200 W, respectively.

Table 1. Key models and boundary conditions used in ANSYS Thermal Analysis

| Location | Models and Boundary Conditions | Value |
|---|---|---|
| Outer Steel Surface | Constant temperature | 40 $^{o}$C |
| Inner Alumina (Al2O3) | Volumetric Heat Generation | 200 W |
| Air Volume | Conductive Heat Transfer Mode | k=0.0242W/m$^{o}$C |

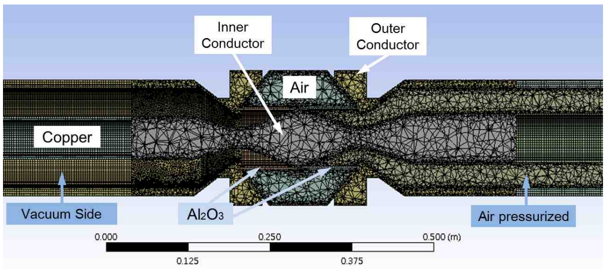
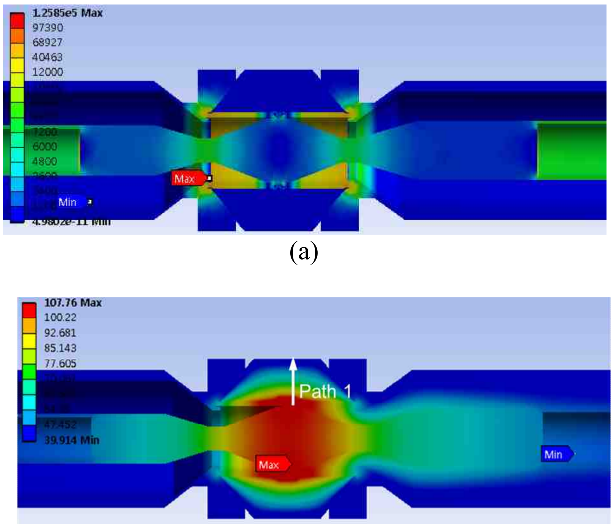



Fig. 3. Typical tetrahedron meshing scheme of the vacuum feed-through

Typical contour plots for temperature and heat flux distributions in the body of the vacuum feed-through are shown in Fig. 4. Note that most of the heat is conducted through the metal structure, while the air next to the alumina cylinders is insulating. The steel at the corner of the end of the alumina cylinder releases substantial heat flux through the physical contacts. In the temperature contours, the air side exhibits blurry radial temperature distributions in the steel and structure, whereas the vacuum side shows no heat-affected zone in the gap between the metal structure and the steel.




(a)

(b)

Fig. 4. Contour plots for (a) heat flux (W/m$^2$) and (b) temperature ($^{o}$C) of vacuum feed through. [Left: vacuum side, right: air filled]

Fig. 5 shows the radial temperature distribution along the path 1 shown in Fig. 4 as a function of mesh size. We have confirmed converging results within 1% accuracy, when the element sizes is reduced as shown in the temperature distribution along the path at the VFT marked in Fig. 4.

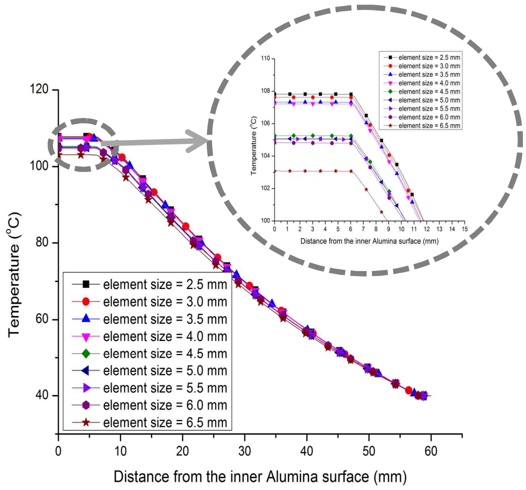



Fig. 5. Radial temperature distribution vs. element size

## 3. Conclusions

We have fabricated and tested a vacuum feed-through to investigate the RF high voltage and thermal characteristics of the KSTAR ICRF system for high power and long pulse operation. In comparison with the temperature measurement of VFT at the RF high voltage test, we found ANSYS thermal analysis helps us to resolve the temperature distributions in complex geometry such as the vacuum feed-through.

## Acknowledgements

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