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INVESTIGATION OF THE BREAKDOWN AND RF SHEATH POTENTIAL FOR EAST ICRF ANTENNA*

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Abstract

A new ion cyclotron range of frequency (ICRF) antenna was designed with four current straps in Experimental Advanced Superconducting Tokamak (EAST). It is to provide heating, current drive and some physics experiments in EAST. The breakdown and RF sheath potential for the antenna are investigated by a three dimension electromagnetic code in the paper. The plasma is simulated by a slab with high relative permittivity approximating the plasma loading of the antenna. Calculations show that the maximum of electric field is around the end of the coaxial feeds and the strip line and the electric field is strongly dependent on antenna phasing. Especially the maximum of electric field is decreased to 27.5 KV/cm with the (0,π,π,0) phasing between toroidal straps while the value is 32.8 KV/cm with (0,0,π,π) phasing. A challenge in ICRF is the impurity contamination which is related to sheath potential. The topology of the radio frequency (RF) sheath is optimized to reduce the potential for EAST ICRF antenna. The RF potential is mitigated obviously with the broader side limiter by a factor of 2.

INTRODUCTION

Ion cyclotron range of frequency (ICRF) system is an important heating and current drive scenarios in fusion plasma. In EAST, a four straps ICRF antenna was designed in a frequency range of 30 MHz to 110 MHz with long pulse [1]. The designed power of ICRF antenna is 6 MW. In current tokamak the capacity of ICRF systems is mainly limited by the maximum voltage and impurity [2].

The study of breakdown and impurity problem is needed to improve the performance of antenna. The field was researched to minimize breakdown in the new Alcator C-Mod antenna system [3]. The source of impurity is attributed to the sputtering by ion accelerated in RF sheath. Impurity issue was studied in the other ICRF antenna [4,5].

In this paper, the three dimensional electromagnetic performance of EAST ICRF antenna is mainly analysed for study on breakdown and impurity issue. The tool is a commercial code CST MICROWAVE STUDIO (MWS) which yields the frequency response by performing a transient electromagnetic simulation. The distributions of electric fields are simulated. The maximum of voltage is calculation for various phasing in the structure of antenna. Besides, the topology of RF sheath is optimized for decreasing impurity.

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THE STRUCTURE OF THE ICRF ANTENNA

A view of the four straps ICRF antenna model and one current strap are shown respectively in Fig. 1. The model includes the strap, the faraday screen, the box, the limiter and so on. The strap is 100 mm wide and 12 mm thick. There is no plasma under magnetic confinement which is instead with a dielectric slab with large permittivity in CST. Here, we choose sea water with permittivity about 81. Because good agreement for simulated and measured scatter parameters was got by sea water [6]. Plasma is located at the typical position 60 mm in front of straps.

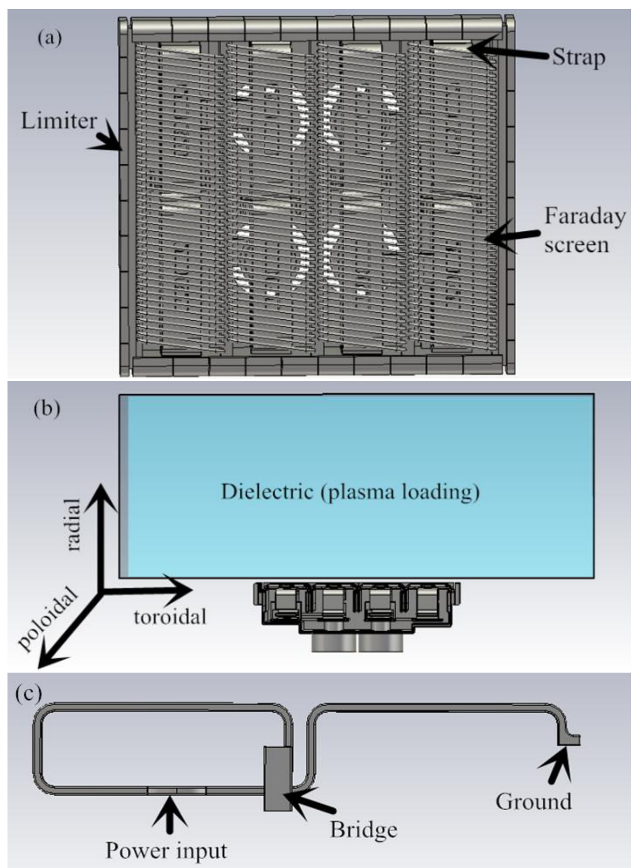

Figure 1: (a) The 4 straps ICRF antenna on EAST. (b) The scheme of the antenna and dielectric. (c) One current strap.

THE DISTRIBUTIONS OF ELECTRIC FIELD

The E-field is investigated in antenna to find the region where the E-field is high. In Fig. 2 shows the horizontal

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profile of amplitude of E-field for 55 MHz with various toroidal phasing. Each strap is fed 1.5 MW power. In the picture, the high strength of E-fields is around the end of the coaxial feeds and the strip line. The maximum of E-field are 32.8 KV/cm and 27.5 KV/cm for (0,0,π,π) (Fig. 2(a)) and (0,π,π,0) (Fig. 2(b)) phasing, respectively. Besides, for (0,π,0,π) (Fig. 2(c)) phasing the maximum of E-field is 28.6 KV/cm. It should be noted that the distribution of E-field is computed for 55 MHz, calculations show that the E-field is related to the frequency. The results indicate that the electric field is strongly dependent on antenna toroidal phasing and the maximum of E-field can be effectively mitigated with the (0,π,π,0) phasing.

The limited breakdown voltage is determined by about 15 KV/cm for E||B and the voltage is allowed to reach about 35 KV/cm for the RF E-field across the B-field [3]. The direction of B-field has 8 degrees angle with horizontal direction in ESAT. Here, the maximum of E-field is blow the 35 KV/cm, however, the E-field component along the B-field is required to discuss in detail. The future research is underway.

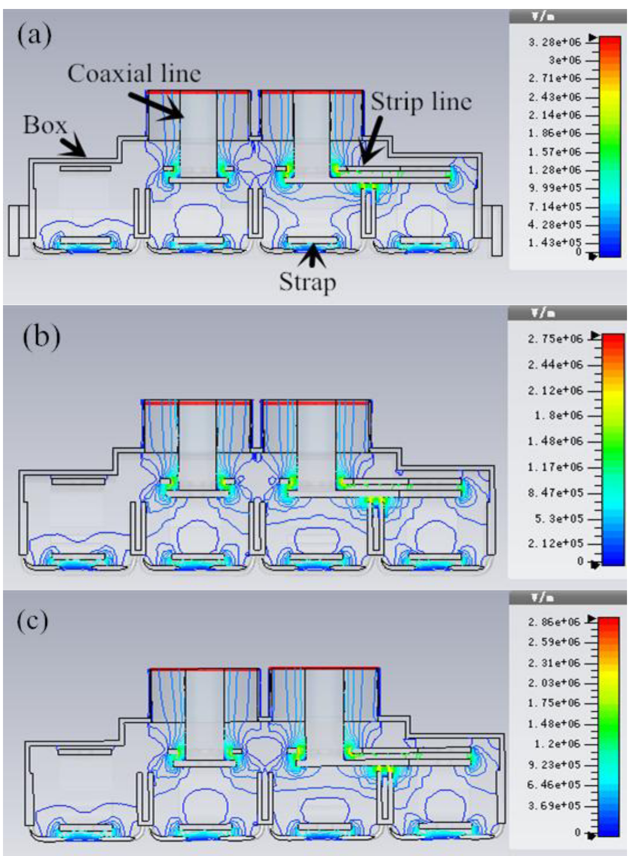

Figure 2: The horizontal profile of amplitude of E-field for (a) (0,0,π,π) (b) (0,π,π,0) and (c) (0,π,0,π) phasing.

THE RF SHEATH

Impurity contamination with ICRF antenna operation has been universally observed. In EAST, the increasing impurity during ICRF working was also observed in experiment [7]. An interpretation of this question is that the application of ICRF power leads to an appearance of parallel RF electric fields [4]. ICRF antenna operation drives an oscillating RF potential V along the field lines which cross the near fields, given by $V=\int_L E_{//} d_l$, where the $E_{//}$ is the parallel electric field and the integration is along the open B-field line just as show in Fig. 4(a). A high potential induces an acceleration of deuterium and light impurity ions in the sheaths near plasma facing components (PFCs). This causes the impurity sputtering of the PFCs [5].

Figure 3 depicts the distributions of amplitude of E-field at a plane 35 mm in front of the straps for (0,π,0,π) (Fig. 3(a)) and (0,π,π,0) (Fig. 3(b)) phasing. It is shown that the high field areas are both visible close to the antenna limiter. Thus, the topology of RF sheath is modified to study how to decrease the impurity.

It is seen that two models with a broader side limiter 50mm and a slotting top and bottom limiter in Fig. 4. There are five proposals by simulation for calculating the RF potential. Case 1: there is no any modification; case 2: the side limiter is widened by 50 mm; case 3: the top and bottom limiter is slotted; case 4: the side limiter is slotted; case 5: the top and bottom limiter is widened by 50 mm. In Fig. 5, the RF voltages are calculated along B-field lines for 50 MHz with five cases. Two of the B-field lines are shown in Fig. 4(a). The results show that the RF potential can be mitigated with case 2 and case 3. Especially the maximum of potential has fallen by half with case 2. By contrast, case 4 and case 5 can intensify the potential.

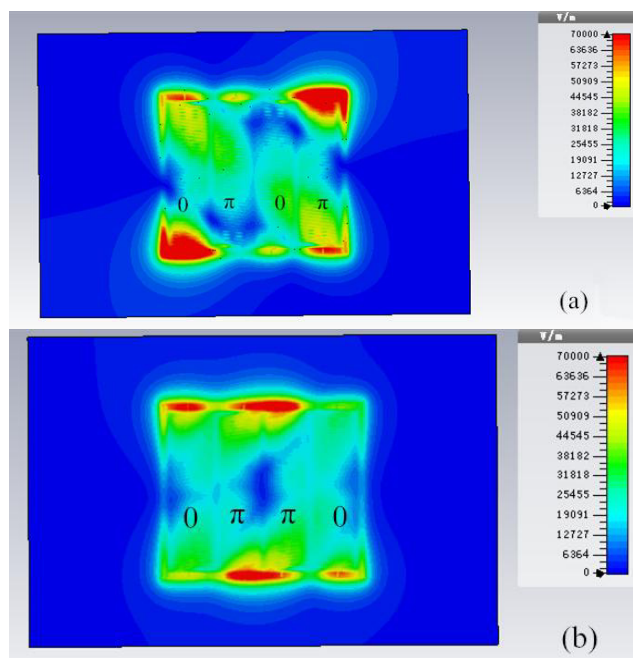

Figure 3: The distributions of amplitude of E-field at a plane 35 mm in front of the straps for (a) (0,π,0,π) phasing (b) (0,π,π,0) phasing.

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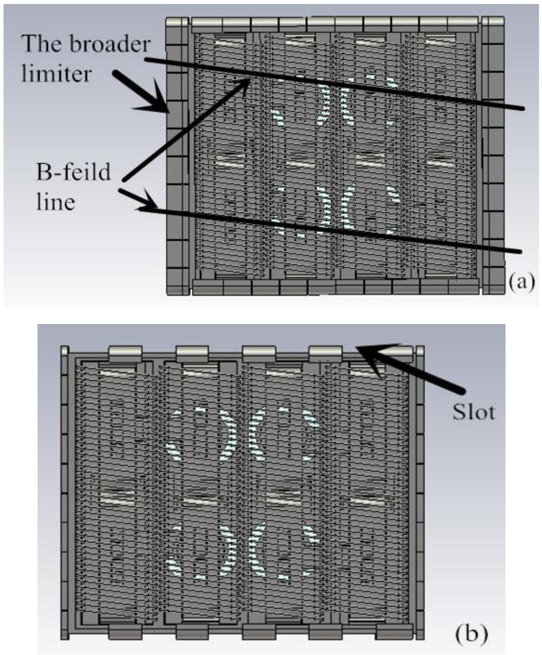

Figure 4: The antenna model with the broader side limiter (a) and the slotting top and bottom limiter (b).

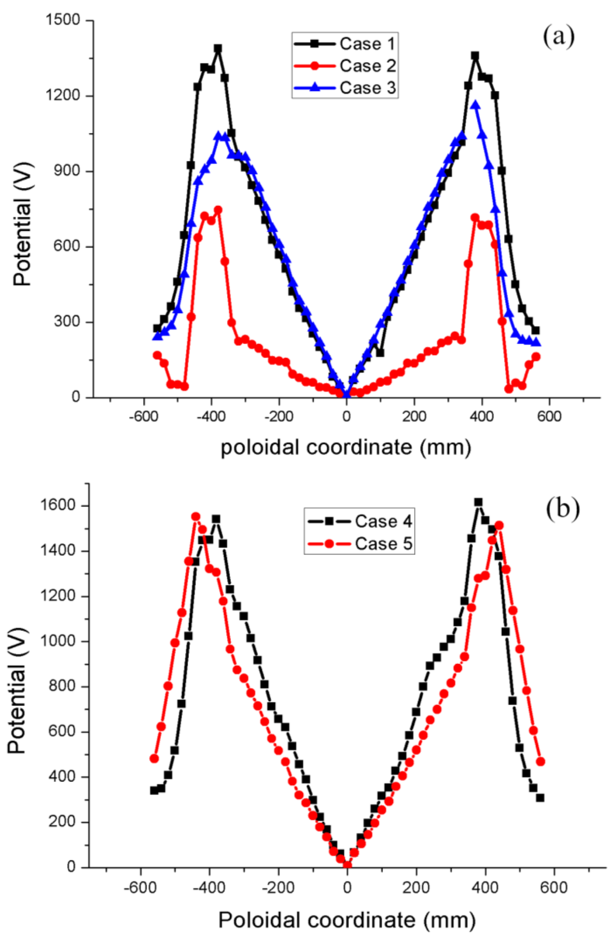

Figure 5: The distributions of RF potential along poloidal coordinate with five cases for (0,π,0,π) phasing. (a) Case 1: no any modification, case 2: the broader side limiter, cases 3: the slotting top and bottom limiter. (b) Case 4: the slotting side limiter, case 5: the broader top and bottom limiter.

CONCLUSION

The present design of the EAST ICRF antenna is analysed for E-field and impurity issue. The high E-field occurs around the end of the coaxial feeds and the strip line. The E-field is strongly relative to antenna phasing. As a result, the (0,π,π,0) phasing provides lower E-field which is 27.5 KV/cm with 55 MHz than the ones for other phasing. The worst situation is for (0,0,π,π) phasing and the maximum of E-field is 32.8 KV/cm. When the modifications include the limiter to make it toroidal broader or poloidal slot, the RF sheath potential can be effectively reduced which can lead to impurity in tokamak. On the contrary, the toroidal slotting or poloidal broader limiter made the RF potential rise.

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