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A New Faraday Screen For Tore Supra ICRH Antenna

K.Vulliez[a], L.Colas[a], A.Argouarch[a], A.Mendes[a], C. Hamlyn-Harris[b], A. Ekedahl[a], J.C. Patterlini[a]

[a] *CEA, IRFM, F-13108 Saint Paul-lez-Durance, France.*

[b] *UKAEA, Culham Science Centre, Abingdon, Oxfordshire, OX14 3DB, United Kingdom*

Abstract. In the framework of the Ion Cyclotron (IC) developments held in Cadarache, the design of a new Faraday Screen (FS) was initiated to replace the aging ones mounted on the 3 Tore Supra (TS) antennas. The new conceptual design proposed is steered by conclusive results of electrical simulation stressing the need to suppress the parallel RF currents flowing on the FS frame to reduce the RF sheaths. Two major modifications are implemented on a TS FS to reduce the $j_{//}$ circulation: apertures on the top and bottom closure walls of the antenna radiating box, and cantilevered FS bars (that is, bars not connected to the vertical central septum). This single connection point also eases the FS rod thermal expansion, resulting in less mechanical stresses. In addition, the cantilevered bar design avoids eddy current loops which reduces electromagnetically induced stresses during disruptions. If successful with plasma operation, this RF structure provides a promising new option to simplify the ITER IC Faraday screen design.

Keywords: ICRH, Faraday screen, ITER
PACS: 52.40, Qt ; 52.40, Fd.

INTRODUCTION

The manufacturing of a new Faraday Screen (FS) for the Ion Cyclotron (IC) antennas of Tore Supra (TS) was considered due to the degradation of the carbon boride coating and the aging of structural welds exposed to high flux and repetitive thermal cycles. Results of ICANT [1] electrical simulations initiated preliminary studies on an alternative electrical design for the TS antenna FS. The promising results of these simulations prompted the engineers at Tore Supra to consider the challenging mechanical aspects of the design for this innovative FS structure.

Motivation and Design Criteria

The formation of hot spots on the FS frame leads to strong operational limitations on IC antenna, especially when Lower Hybrid (LH) is combined with IC power. The reduction of these localized fluxes is the primary motivation for the IC antenna enhancements. The secondary objectives of the project are to: build a FS compatible with higher thermal flux as expected during the CIMES scenarios relying on high level of IC power during long plasma pulses; propose an optimized antenna front face reducing the RF potential, hence limiting the RF sheaths and hot spots; improve our understanding of the phenomenon associated to the RF potential with dedicated plasma experiments; qualify on plasma an alternative FS design applicable to the ITER IC launcher. The design and operating conditions of TS and its RDL [2] antenna make them good candidates for these type of studies, due to: the high power densities achievable with actively cooled antennas; suitable diagnostics (IR, Langmuir probes) to survey the antenna for qualitative comparisons (between different FS configurations and simulations); and long pulse scenarios.

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The primary design criteria are: an actively cooled stainless steel 316L (low cobalt) structure; minimize the number of water sealing welds on the structure (for example by using deep drilling techniques for the water channels) with all the welds on vacuum/water interface kept accessible for test and repair; the internal RF structure remains unmodified (including strap distance to plasma); poloidal curvature and toroidal recess (FS distance to plasma) unmodified; identical copper plating and boron carbide coating; improved design of the lateral collectors of the FS frame to enhance its power handling capability up to $1MW/m^2$; FS transparency of approximately 50%; FS openings designed to limit the risk of particle penetration into the antenna box; all Faraday screen components subject to a 6 MPa test pressure and 3 MPa operating pressure (strap and inner conductor operate on a separate water circuit).

Technical Description and Electrical Consideration

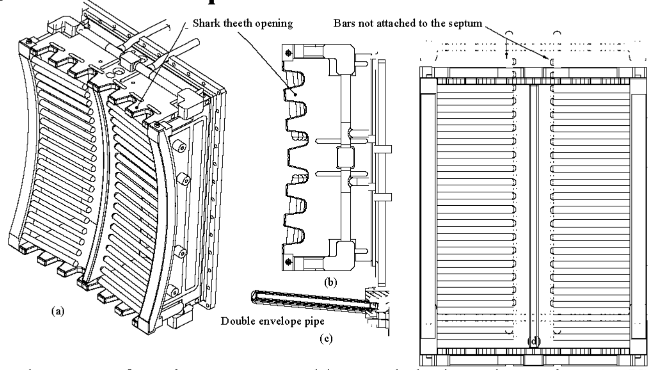

FIGURE 1. Faraday screen featuring unconnected bars and shark tooth openings (a) ISO view (b) Top view (c) cut view of a double envelope pipe (d) Front view

From a mechanical interfacing point of view, the new screen has to integrate with the existing interfaces of the TS antennas. The inner RF perimeter of the FS frame is almost identical (other than the front face and shark tooth), and the outer structure packaging is consistent with the same clearances and integrates to the same rear flange and mechanical attachments. The modifications on the FS RF structure are limited to the antenna parts facing the plasma, with three major modifications (Fig. 1): FS bars disconnected from the vertical septum; FS bars are aligned perpendicular to the side wall removing the 7° titling angle; openings made on the top/bottom plates of the FS frame following a "shark tooth" profile.

Most of the mechanical design effort was conducted on the lateral collectors which have been designed as a water manifold for the distribution of the parallel fed concentric pipe bar design. The design of this part of the antenna was mechanically challenging, due to its poloidal curvature and packaging restrictions around the interface with the FS bar water feeds and returns. In addition this component has the highest heat flux to withstand on the antenna (up to $1MW/m^2$ primarily from fast ions). The thickness of the plasma facing surface of this component was optimized to 2.5mm to reduce the thermal gradient (hence thermally induced stress) and maintain a structurally sound component to withstand the internal pressure. The maximum allowable steady state operating temperature is 465°C and the maximum peak stress during the commissioning phase at 6MPa is 120MPa. The thermal stresses during operation require a further detailed study over and above an elastic analysis and a study is underway to check for thermal ratcheting using nonlinear material properties and geometries. Repetitive cycles are considered to be the limiting factor for this component and a fatigue life of 20,000 cycles has been estimated with reference to the RCCM-MR.

The top and bottom corners are cut in order to improve the recess of the FS structure below the lateral collector, a modification which replicates one successfully implemented on the existing FS. The FS structure (without transmission lines and straps) has to remove a total of 150kW and has an available flow rate of 1.46kg.s^{-1}. The majority of this load is on the lateral collectors and bars (approximately 100 kW). Toroidal and polodial symmetry is used in the design of the hydraulic circuit which simplifies flow sharing issues. There are 2 inlet pipes (to reduce head loss) and 7 branches from the main manifold. The hydraulic resistance of each branch was calculated from the required flow rates and geometry. The design of each inlet branch was iterated (to reduce or increase the diameter) to balance the circuit and achieve the required flow in each branch off the manifold.

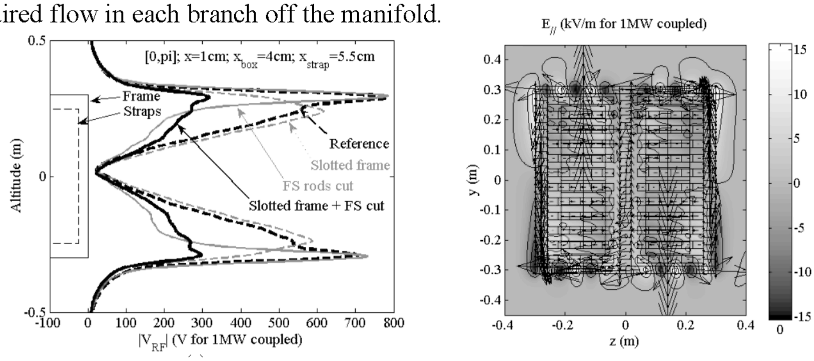

FIGURE 2. (a) V_{RF} along on the poloidal direction (vertical) for 1MW coupled (b) $E_{//}$ field.

From the electrical point of view, the 3 major structural modifications cut the $j_{//}$ RF paths reducing the slow wave excitation. In the simplest model of RF potential rectification by RF sheaths [3], the sheath effects are proportional to the RF potential quantified by the integral along open field lines $V_{RF} = \int E_{//} \cdot dl$ where the parallel RF field $E_{//}$ is linked with the slow wave. Along the field lines in front of the FS, this V_{RF} is excited by $\int j_{//} \cdot dl$ on the antenna structure. Near field simulations on TS geometry predict that the major contribution to the RF potential is the circulation of $j_{//}$ on the horizontal parts of the frame and on the FS bars. ICANT simulations on Figure 2 illustrate the local effects of the different modifications and their combination on the RF potential along the RF field lines in front of the FS. The addition of the two structural modifications significantly reduces the RF potential. The potential is still reduced, with lower magnitude however, when the antenna is surrounded by a thick metallic frame added to simulate the antenna inside a recess (port). These analyses were completed by TOPICA [1] and HFSS® simulations on more detailed geometries. The calculations show that the FS modifications have little effect on the coupling properties of the fast wave, and almost no impact on the settings of the antenna matching system.

These promising theoretical predictions are now to be validated experimentally. Plasma experiments will also answer the main design uncertainty, which is the voltage stand off capability. Intense parallel RF fields are expected at places where current paths are interrupted (fig.2b). To limit the risk inherent to this type of array, a minimal distance of 15mm between conductive surfaces was imposed as design criteria (V_{max}=75kV on the hypothesis of degraded vacuum rigidity of 5kV.mm^{-1}). Despite this margin, electrical phenomena linked to the proximity of the plasma and the interaction with the RF field could lead to voltage breakdown. Only RF experiments with plasma can provide a concrete answer to this question.

ITER Perspectives

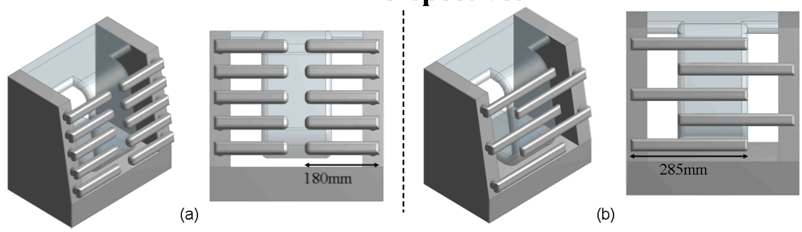

FIGURE 3. Alternatives design proposal for the ITER IC FS with bars attached on one side (1/6th of module represented) (a) comb-like array (b) staggered rows array.

The FS bar of the ITER IC antenna is a Plasma Facing Component (PFC) and has the unique feature (for PFCs) of being rigidly attached at both ends. This design is contrary to the other PFC, as it does not allow for differential toroidal thermal expansion, which leads to very high thermo-mechanical stresses at its supports. An array of bars attached on a single side will alleviate this stress. In addition it can also decrease the disruption induce electromechanical forces [4] by removing the current path loop, however, this theory still requires verification with electromagnetic modeling. Figure 3 presents some first pass representations (1/24th of the antenna) of two design options with bars attached on one side. The staggered rows arrangement is more interesting from the RF and thermal point of view covering the full length of the strap, but will impose higher electromechanical constraints regarding the halo currents.

CONCLUSION

The technical realization and the qualification of this innovative RF structure in plasma conditions is the next step of this project. The project schedule aims to have the structure mounted on Tore Supra by mid 2010. The promising results expected in terms of RF sheath reduction together with the mechanical advantages offered by this configuration will open new options for a simplified design of the ITER IC antenna Faraday Screen.

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