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Design of an ICRF system for plasma–wall interactions and RF plasma production studies on TOMAS

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HIGHLIGHTS

- An ICRF antenna for the TOMAS facility has been designed with the electromagnetic software CST MWS.
- A matching network allowing to couple 6 kW between 15 and 45 MHz has also been designed.
- The antenna geometry has been optimized for a given plasma to guarantee broad band matching.
- The sensitivity of each solution was studied.
- The system can cope with loading variations (±50%) around the reference value.

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ABSTRACT

Ion cyclotron wall conditioning (ICWC) is being developed for ITER and W7-X as a baseline conditioning technique in which the ion cyclotron heating and current drive system will be employed to produce and sustain the currentless conditioning plasma. The TOMAS project (TOroidal MAgnetized System, operated at the FZ-Juelich, Germany) proposes to explore several key aspects of ICWC.

For this purpose we have designed an ICRF system made of a single strap antenna within a metallic box, connected to a feeding port and a pre-matching system. We discuss the design work of the antenna system with the help of the commercial electromagnetic software CST Microwave Studio®. The simulation results for a given geometry provide input impedance matrices for the two-port system. These matrices are afterwards inserted into various circuit models to assess the accessibility of the required frequency range.

The sensitivity of the matching system to uncertainties on plasma loading and capacitance values is notably addressed. With a choice of three variable capacitors we show that the system can cope with such uncertainties. We also demonstrate that the system can cope as well with the high reflected power levels during the short breakdown phase of the RF discharge, but at the cost of a significantly reduced coupled power.

1. Introduction: ICWC on the TOMAS device

Wall conditioning in magnetic controlled fusion devices is a common tool to influence fuel and impurity recycling, to improve plasma performance and discharge reproducibility [1]. It will be required in ITER to control the surface state of plasma-facing components (PFC), easing plasma start-up, influencing the fuel or impurity recycling as well as mitigating the build-up of tritium inventory [2]. Ion cyclotron wall conditioning (ICWC) is based on low temperature ion cyclotron resonance (ICR) plasmas in reactive or noble gases, generated in tokamaks in the presence of the toroidal magnetic field [1]. It has the advantage over glow discharge conditioning (GDC) that it is applicable in the presence of magnetic fields. This is a key feature that allows wall conditioning

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during operational campaigns on superconducting fusion devices with permanent magnetic field. Therefore, the ICWC mode of operation is included in the functional requirements of the ITER ion cyclotron resonance heating and current drive (ICRH & CD) system, and will be employed on ITER during the operational cycles, i.e. when only the toroidal magnetic field produced by superconducting magnetic coils is present [3]. ICWC is also considered in stellarators: the ICRF system foreseen for W7-X will also allow for monopole operation for ICWC applications [4].

The readily available plasma facility TOMAS (TOroidal MAgnetized System, operated at the FZ-Juelich, Germany) [5] with its metallic PFC provides a carbon-free environment for ICWC plasma surface interaction studies, and can provide valuable data for verifying plasma production simulations. Its major and minor radiuses are 0.78 and 0.26 m respectively, the wall area is 10 m^2. This dedicated device will allow to study key aspects of ICWC: material migration during large plasma exposure times, cleaning and change of morphology of metallic surfaces, characterization of density and temperature profiles, as well as fluxes to the wall, and benchmark above numerical codes. At the low magnetic field considered for TOMAS the operation mode is the so-called HCH (high cyclotron harmonics) regime with a typical frequency close to the 10th harmonics of the proton H^+. In this scheme the electrons absorb more than 90% of the incoming power via electron-neutral collisions for both the Fast Wave and the Ion Bernstein Wave [7]. This scheme was already tested on TEXTOR, JET and ASDEX Upgrade [6,7]. It was notably observed that energetic ions can be generated in HCH regime, which still needs to be understood. Dedicated plasma production experiments like TOMAS are required to support the code development and to deepen the theoretical background needed to make predictions for future machines such as ITER. It will complement similar experiments on larger devices (JET, ASDEX Upgrade, . . .).

2. Design of an ICRF system for TOMAS

The ICRF antenna for TOMAS is supposed to deliver 6 kW of power at a frequency comprised between 10 and 50 MHz, taking into account the constraints imposed by the geometry and dimensions of the device that limit the space available for antenna installation. Therefore a single-strap antenna located in an individual box with lateral limiters has been considered. The low loading conditions expected in the wall conditioning/plasma production modes of operation require the development of an efficient matching system: a pre-matching capacitor with capacitance C_A is connected to the strap through the top port, while a classical L-section two-capacitor (with series and parallel capacitances C_S and C_P resp.) circuit is connected to the strap via an approximately central tap feed. Fig. 1 shows the conceptual circuit model, the strap circuit and a view of the 3D model of the front face of the antenna developed with the three-dimensional electromagnetic software CST Microwave Studio (MWS)® [8]. CST MWS simulations will allow to determine the input impedance matrix **Z** as well as the detailed RF field maps for given input power and capacitors parameters. **Z** can also be used as input to circuit simulation scripts. It is important to note that CST MWS allows to use materials described by arbitrary 3 by 3 dielectric tensor. We could then simulate loading by a magnetized plasma described by the Stix's cold plasma dielectric tensor [9].

The antenna geometry must be optimized for a given plasma loading to guarantee that it can be matched in the broadest frequency range possible. We must ensure that the system will work for varying plasma loading conditions. For this purpose we have studied the effect of the variation of the strap width ($strap_w$) and the box depth (box_d): see Fig. 1(c)). It is known that these parameters can have substantial effects on the coupling to the plasma [10] and hence influence the matching parameters.

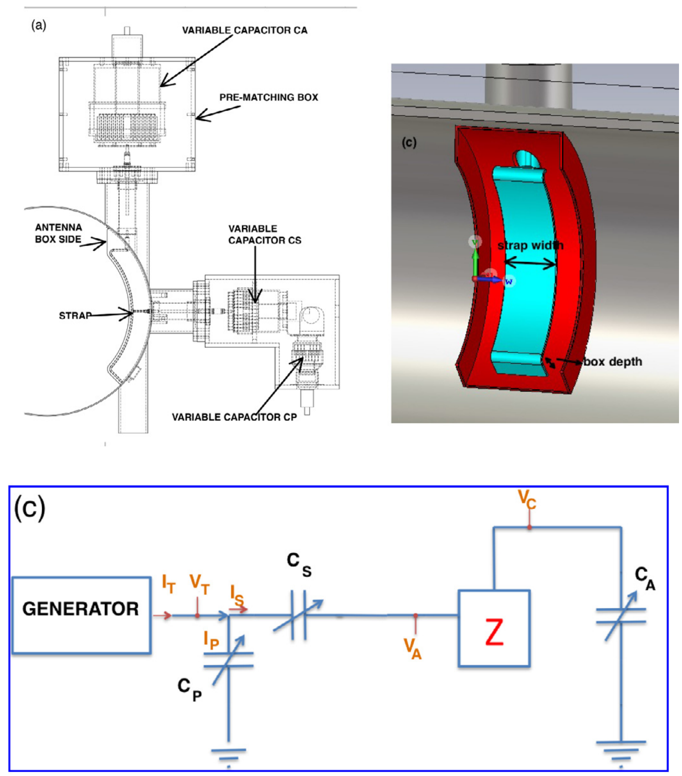

Fig. 1. (a) Layout of the ICRF system; (b) front face of the antenna strap box (the strap width and strap box parameters are defined); (c) circuit model.

Table 1
Characteristics of the three capacitors considered for TOMAS ICRH matching system. V_{peak} and V_{max} are the maximum voltages each capacitor can sustain in short-pulsed operation and continuous operation respectively.

	Selected capacitor	C-range/pF	V_{peak}/kV	V_{max}/kV	I_{rms}/A
C_A	Comet CV2C 1000	35–1000	30	18	220
C_S	CVDD-1000-10S	25–1000	10	6.0	140
C_P	Jennings CVCH-1000-5	7–1000		5.0	70

We consider an homogeneous Hydrogen plasma with density $n_e = 10^{11}$ cm^{-3} and toroidal magnetic field $B_T = 0.15$ T. This plasma occupies the whole inner volume of TOMAS, except the inside of the antenna box which is vacuum. We varied the strap width between 60 and 110 mm, and the depth of the box between 25 and 45 mm. The reference frequency is 25 MHz. For each combination of parameters the impedance matrices are evaluated with MWS and the matching solution is obtained taking into account the technical constraints on the capacitor voltage and current. These limitations are provided by the manufacturers and can be read in Table 1. Examples of results are shown in Fig. 2. From these results we can conclude on the one hand that no matching is possible for too small box depth ($box_d \le 25$ mm) as the upper limit on the pre-matching capacitance C_A is reached. On the other hand larger straps reduce the voltages and currents in the capacitors. Nevertheless the connection between the top feeding line and the strap becomes mechanically challenging to achieve for too large widths. Therefore the strap width is limited to 90mm, while the box depth has been chosen at 40mm.

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