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RF antenna analysis with the ICANT code

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Abstract

The ICANT code computes self-consistently the surface current distribution on a 3D antenna model radiating in a plasma or vacuum and has been used to analyze the coupling properties of various antenna models. In this work it is used to assess near-fields generated by different versions of the TCABR (Tokamak Chauffage Alfvén wave heating experiment in Brazil) antenna as well as coupling properties of the TEXTOR tokamak in Forshungszentrum Jülich. Two different strap models planned for the TCABR antenna are shown to be practically equivalent in terms of maximum electric field. Textor coupling calculations are close to experimental values.

Keywords: Fusion; Plasma heating; Ion-cyclotron waves; Alfvén waves

1. Introduction

A new model for the Alfvén wave antennas was recently installed at the TCABR [1] tokamak at the Universidade de São Paulo (USP). This new set is intended to reduce the self-inductance and provide better control of spurious interaction with diagnostics. An assessment of the RF near fields was made for two proposed designs of these new straps, in order find the sources of the high electric near-by fields and to find the most dangerous points in the antenna area. The code used to provide those field pictures was ICANT [2].

In order to validate the ICANT code with respect to the coupling efficiency predictions, experimental measurements of the loading resistance of the TEXTOR tokamak ICRH antennas, for two different models of previously installed central conductors [3], were compared with the code predictions and a good agreement

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was found. The expression of the loading resistance is $R = \frac{2P}{\int I^2\,\mathrm{d}y}$, where P is the power deposited in the plasma by the pair of straps and I is the current along the poloidal (y) direction of each strap.

This paper is separated in three parts. A brief description of the ICANT code is given in the first, the result of the near-fields for the TCABR antenna in the second, and the comparison between numerical and experimental results of TEXTOR antenna coupling in the third.

1.1. ICANT code

The ICANT code calculates self-consistently the distribution of currents on a set of perfectly conducting surfaces so that a 3D ICRH antenna can be modeled. It does so by superposing the current basis functions on each rectangular element of the metallic surface and imposing the vanishing of the tangential electric field at the surface of the ideal conductors. The surface current on the conductors $\mathbf{j}(\mathbf{r})$ is represented by a superposition of elements $\mathbf{j}(\mathbf{r}) = \sum_{m=1}^{N} a_m \mathbf{T}_m(\mathbf{r})$, with $\mathbf{T}_m(\mathbf{r})$ the current element m at position $\mathbf{r}$ and a_m its complex coefficient.

Among the N current elements, N_p passive elements are to be determined self-consistently and a small number N_a ($N_\mathrm{a} + N_\mathrm{p} = N$) is imposed to fix the value of the current on the hot conductors, usually at the feeding point. The self-consistency condition is a weak version of the condition of vanishing of the tangential electric field at the surface of ideal conductors $\int_{V_\mathrm{A}} \mathbf{T}_m^*(\mathbf{r}) \cdot \mathbf{E}(\mathbf{r})\,\mathrm{d}V = 0 \quad (l = 1, \ldots, N_\mathrm{p})$ and this implies that the power integral computed by ICANT reduces to that part generated by the active elements:

$$P = -\frac{1}{2}\int_{V_\mathrm{A}} \overset{*}{\mathbf{j}} \cdot \mathbf{E}\,\mathrm{d}V = -\frac{1}{2}\sum_{m=1}^{N_\mathrm{a}} a_m \int_{V_\mathrm{A}} \mathbf{T}_m^*(\mathbf{r}) \cdot \mathbf{E}(\mathbf{r})\,\mathrm{d}V \qquad (1)$$

The electromagnetic problem solved in the vacuum region is matched with a surface impedance matrix calculated by a full-wave code (here, BRAFFA [4], which calculates only the Fast Wave contribution) as a boundary condition on the plasma-vacuum interface. Pure vacuum can also be used.

As output of the calculations one obtains the current profiles, the deposited power, the power spectrum, as well as the near field structure (all components of electric **E** and magnetic **B** fields).

In order to better describe the Alfvén wave heating experiments, it is foreseen to merge the ICANT code with the ALFVÉN [5] code for future evaluations of the coupling power during TCABR experiments.

1.2. TCABR new antenna near-fields

The new Alfvén wave antenna, recently installed in the TCABR tokamak, is shown in Fig. 1. The strap does not entirely surround the plasma column, what reduces the poloidal mode number definition but image currents in the wall (therefore RF interference with diagnostics) and inductance are also reduced in this new design and the antenna installation is simpler than the in the original model [6].

A detail at the right of Fig. 1 shows one of the strap elements, covering 90° of the poloidal section. A plane geometry sketch of this elementary strap is shown in two candidate models in Fig. 2. The sectional model (Fig. 2) was expected to have more uniform electric field and, as result, smaller electric field at the edges than the solid model, which has just been installed. Here we have made a comparison of the near-fields for those two different strap models do derive particular differences in field amplitudes between these two models.

The frequency used in those calculations is 4 MHz, as the TCABR antennas are operating in the 4–6 MHz frequencies band. Fig. 3 shows the current amplitude along the strap models as blue arrows, proportional to the current density and normalized to a current density at the feeding point of 1 kA. It also shows the profile of the total electric field just 0.5 cm over the strap. The current feeding is done at the "upper" radial contact and it flows along the poloidal structure towards the short-circuit. The field amplitude is therefore larger at the upper part, closer to the feeding point, and the picture is reversed if feeding is altered. The current flow is shown to preferentially occur at the edges of the straps, which is a general trend also reflected in the field profiles.

Fig. 4 shows the evolution of the radial component E_x of the electric field in the immediate vicinity of the strap ($x = -0.5$ cm) and closer to the plasma border (but still in vacuum $x = -2$ cm). They show only a very