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First experiments with the new load resilient ICRH antenna on TEXTOR

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Introduction

A new antenna pair has been recently installed on TEXTOR due to rearrangement of the diagnostic positions resulting from the installation of the Dynamic Ergodic Divertor [1]. The antenna configuration allows a large flexibility of operation as well as testing the “conjugate-T” or (CT) mode of operation that is foreseen for the new JET-EP [2] and ITER [3] antennae. This mode is characterized by its insensitivity to the variations of the antenna loading resistance and hence would help to solve the problem of generator tripping in presence of ELM’s. First tests have shown the resilience of this antenna on variation of the antenna load in different heating scenarios.

Experimental set-up

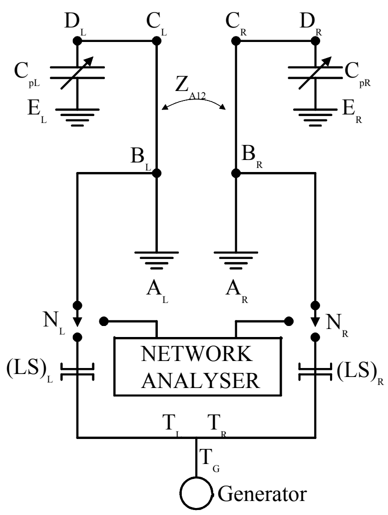

Figure 1: Equivalent circuit of the antenna

The equivalent circuit of Figure 1 shows the antenna constituted by a pair of identical radiating strip conductors (A-C), inserted in antenna boxes, which are grounded at top side and connected at the bottom to a vacuum tuneable capacitor C_p (grounded in E) by means of a section of coaxial line (C-D). A tap at position (B) feeds each radiating strip conductor. The two feeding lines are connected to the same generator by a T junction. The lengths B_R-T and B_L-T between each tap and the “T” are adjusted by means of the line stretchers $(LS)_R$ and $(LS)_L$.

Six voltage probes and 2 directional couplers are installed in the line between the generator and the conjugate T, 4 voltage probes and 2 directional couplers are installed in each line between the conjugated T and the antenna strap.

Matching procedure

The first experiments were carried out in normal plasma conditions: Bt=2.25 T, Ip=350kA, Deuterium beam power 850kW, P_{ICRH}=300 kW, f_{ICRH}= 32.5 MHz. The hydrogen minority concentration in the Deuterium plasma was rather high (> 10%).

The practical procedure to find the matching conditions is described in detail in [4]: (i)we first adjust the capacitors to have the strap resonating at the working frequency (ii)we obtain matching on vacuum to (i.e. on the R_{ant}=0.3 Ω/m) by adjusting the line stretchers. (iii)then with plasma we minimize the reflection (|Γ|) in the line between the T and the generator, step by step for different detuning of the capacitors ΔC_p (with opposite sign in each line). Figure 2a shows that a good matching (Γ<0.1) is obtained for a detuning of ±10 pF to ±15 pF corresponding to 1% of reflected power. Figure2b shows a comparison of |Γ| with $|\Gamma_L|$ and $|\Gamma_R|$, the reflection in the separated lines B_L-T_L and B_R-T_R for ΔC_p=±12.5pF .We obtain |Γ|<0.1 with $|\Gamma_L|$ and $|\Gamma_R|$>0.2.

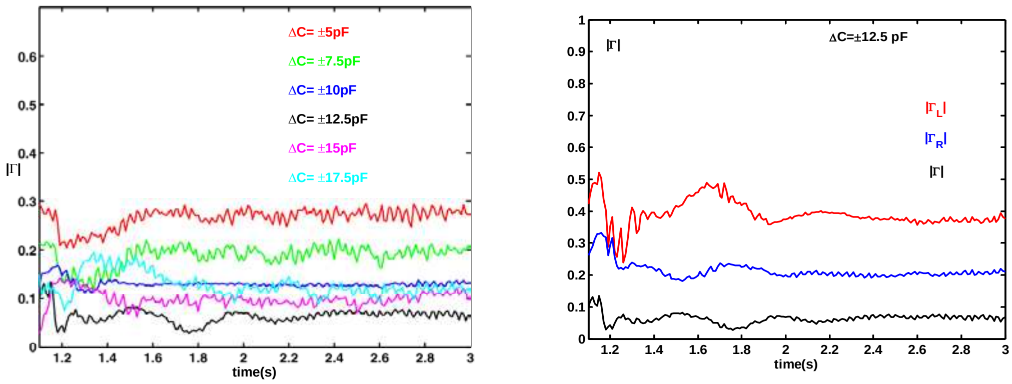

Figure 2: Reflection coefficient |Γ|, $|\Gamma_L|$ and $|\Gamma_R|$, in the respective sections generator-T_G, T_L-B_L and T_R-B_R for the given values of the detuning ΔC_P

Determination of the antenna distributed loading resistance

Due to the load resilience of the coupling system it is not possible anymore to determine the loading resistance from measurements of the power reflected at the RF generator as it was normally done in the old experimental scheme[5]. The antenna distributed loading resistance is now determined using directional couplers and probes in the two lines between each strap and the conjugate T. We therefore have 2 measurements one for each strap. In this first analysis we will neglect the impact of mutual coupling between the 2 straps in the determination of the antenna loading resistance

The determination of the antenna resistance and self inductance is possible if we combine measurements of reflection and standing wave pattern using directional couplers and probes except when we are to close to the exact matching in the individual lines. We also remark that the error bars on the measured values are becoming higher when the resistance is increasing.

Measurements of resilience versus antenna distributed load resistance

Figure 3 displays the antenna distributed load measured in a discharge in which the plasma is slowly displaced away from the antenna with $\Delta C_p = \pm 10$ pF. We notice a decrease of the mean antenna distributed resistance when the plasma is moved 2 cm away from the plasma. The impact of this displacement is stronger on one of the antennae. This effect is also seen on the reflection coefficients $|\Gamma_L|$ and $|\Gamma_R|$ (Figure 3). The coefficient $|\Gamma|$ remains lower than 0.2 which correspond to a VSWR< 1.5 at the generator side.

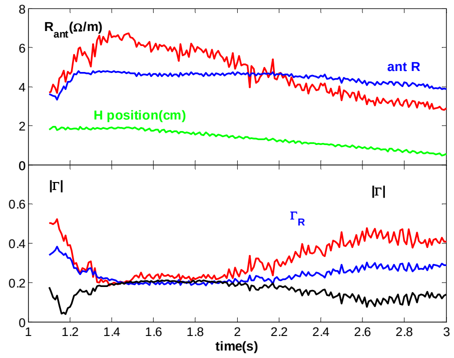

Figure 3:Evolution of the antenna resistance and of the reflection coefficient during a slow displacement of the plasma away from the antenna

The resilience of the ICRH system on the loading resistance is particularly well observed in discharges with a very fast displacement of the plasma. In Figure 4 we present the evolution of the antenna impedance as a function of time. At the time 1.3 s the plasma is suddenly displaced ~ 6 cm to the high field side as can be seen in the edge density measurements performed by a He beam[6]. The antenna resistance is decreased by a factor 2 but this has no impact on the power reflected at the generator.

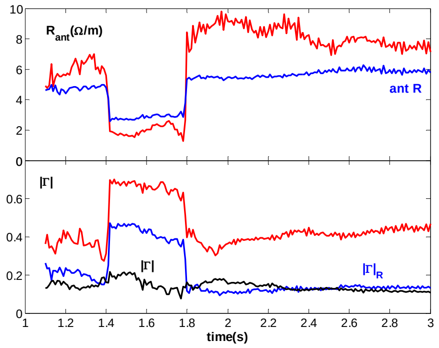

Figure 4: Evolution of antenna loading resistance and of the reflection as function of time. At t=1.4s the plasma is suddenly displaced away from the antenna.

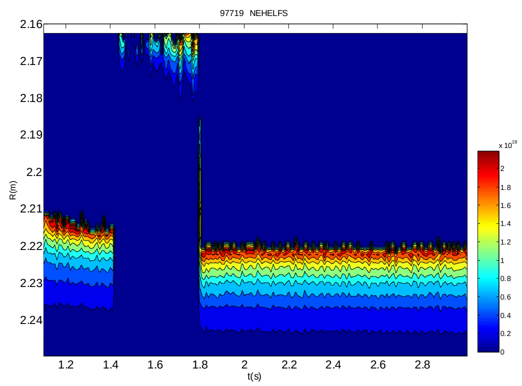

Figure 5: He beam measurement of the density at the plasma edge. The limiter of the antenna is located at R=2.23m.

Measurements of the load resilience during limiter H-mode discharges

A very good scenario to test the antenna load resilience is the newly obtained limiter H-mode of TEXTOR featuring ELMs [7]. The operational conditions are B_t=1.2 T, q(a) = 4; $n_e = 2*10^{19}$ m^{-3} accompanied by a shift of the plasma towards the high field side i.e. away from the ICRH antenna. The ICRH absorption mechanism is 3rd Harmonic of Deuterium. In Figure 6 we present the evolution of the recycling flux showing a sudden increase of the recycling flux, the correlated increase of antenna resistance and the evolution of the reflection coefficients as a function of time. Figure 7 displays the reflection coefficient versus the antenna resistance.It shows the typical behaviour of |Γ| as a function of the antenna resistance R_{ant} for conjugate T matching[1,4]. The conjugate T matching allows to keep |Γ| lower than 0.2 for a large range of R_{ant}. At the time t=2.995s the antenna resistance is very low and the power reflected to the generator reaches the maximum accepted value of the reflected power (see red squares).

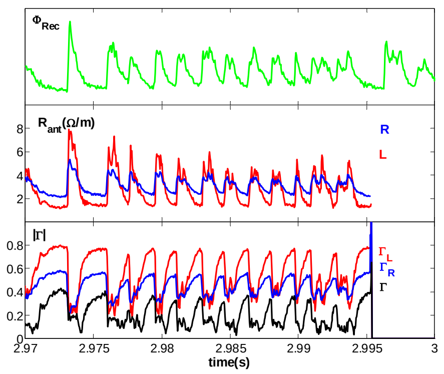

Figure 6 Recycling flux, antenna loading resistance and reflection coefficient as function of time

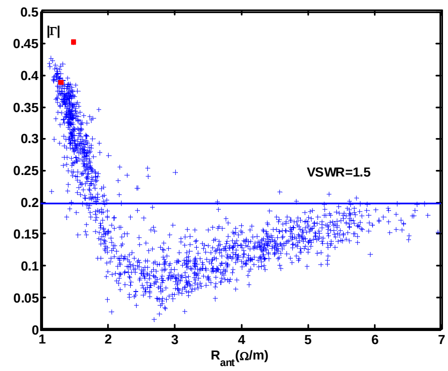

Figure 7 Reflection coefficient at the generator as function of antenna loading resistance

Conclusions

The first tests of the new ICRH antenna have shown the good load resilient performance of the conjugate T configuration. The extension of the resilience region towards lower R_{ant} value will be studied in further experiments.

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