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ANALYSIS OF ANTENNA COUPLING DURING ION CYCLOTRON HEATING EXPERIMENTS AT TEXTOR

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Introduction

Additional voltage probes were installed in the lines of the conjugate-T antenna of the TEXTOR ICRH system in order to reconstruct the voltage standing wave pattern along the lines. The calibration procedure used for the probes and directional couplers is described. The performances of the two antennae during fast changes of the loading resistance are compared and causes of tripping are analyzed. Currents measured at the strap short circuits are compared to the values deduced from the measurements in the transmission line.

System description

The ICRH system of the TEXTOR tokamak consists of two power sources of 2 MW each delivering their power to 2 unshielded antennas located opposite toroidally and operating between 25 and 38 MHz. Each antenna is composed of two toroidally adjacent current straps. One antenna is tuned using a conjugate-T (CT) matching system [1] whereas the second one is matched classically using a stub, a line stretcher and an auto tuning system (AutoT) [2]. In the case of the CT antenna there are four parameters to adjust (see Figure 1): the capacitor values (C1 and C2) as well as the line stretcher lengths (LS1 and LS2). In the case of the classical matching there are only two parameters to adjust: the lengths of the line stretcher and of the stub.

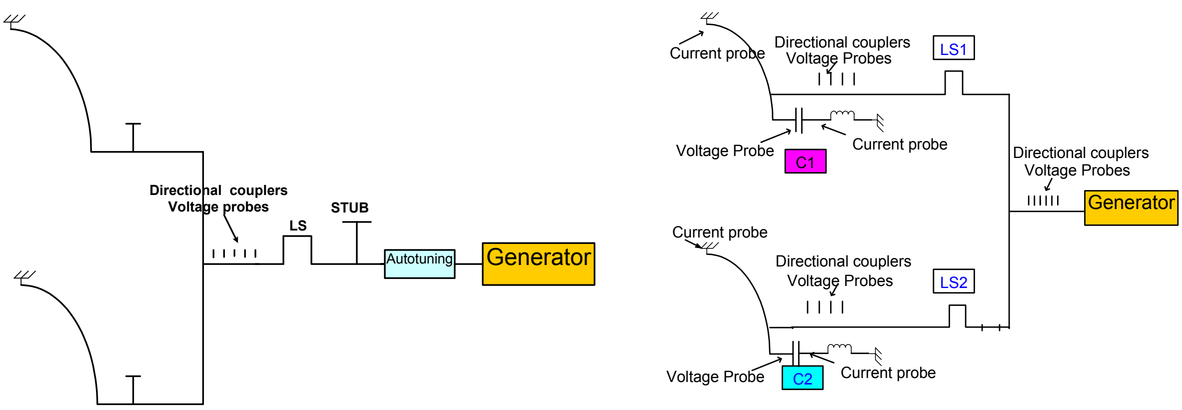

Figure 1 (a) Classically matched antenna (b) Conjugate-T antenna circuit and measurements.

The measurements of the antenna resistances are based on the determination of the standing wave pattern in the transmission lines between the ICRH generator and the RF antennae with voltage probes and directional couplers. Additionally for the CT antenna there are current probes at the strap short circuits and at the capacitors as well as voltage probes at the capacitors (see Figure 1).

Calibration procedure of the voltage probes and directional couplers

A careful precise calibration of the directional couplers and of the voltage probes in the lines of the conjugate-T is performed as follows.

The linear response of the voltage probes to increasing V_+ is first checked. For $V_+ \approx V_-$ (i.e. high reflection coefficient $\Gamma \approx 1$) with antenna in vacuum, the capacitor values are scanned in order to displace the position of the voltage maximum. This allows each of the voltage probes to measure up to the voltage maximum $V_{probe,max} = V_+ + V_-$ allowing to cross-calibrate voltage probes. Once the voltage probes calibrated one can use the available calibration data to recalibrate the directional coupler measuring V_- using the fact that the minimum voltage measured by the probes is $V_{probe,min} = V_+ - V_- = V_+ (1- \Gamma)$. V_+ can be absolutely calibrated vs power by making use of a dummy load.

Scenarios under investigation

Several heating scenarios are currently in use at TEXTOR, mainly the H minority heating in D majority, the second harmonic heating of H (at low B_t) and the minority heating of ^{3}He (at high B_t). The H minority heating scenario is the most widely used, e.g. during the limiter H-mode studies featuring ELMs (see next section), but has the drawback of being very sensitive to the minority concentration: a strong wall conditioning is needed to ensure a low enough minority concentration.

Analysis of resilience to fast changes of the loading resistance

ELMy discharges are obtained in the limiter H-mode regime on TEXTOR [3,4]. An example of variation of the antenna strap loading resistances during ELMs is displayed on Figure 2. The antenna loading resistances are increasing in phase with the spikes of the ELMs (as seen from the recycling flux). They are comparable for both antennas. For the CT antenna the reflection coefficients (Γ) are rather high (~0.65) in the two branches of the CT but combine to a low value in the common branch (<0.2) ensuring the load resilience of the CT. In this particular case Γ is decreasing during the ELMs. For the AutoT antenna the reflection coefficient is remaining lower than in the CT antenna during this ELMy phase.

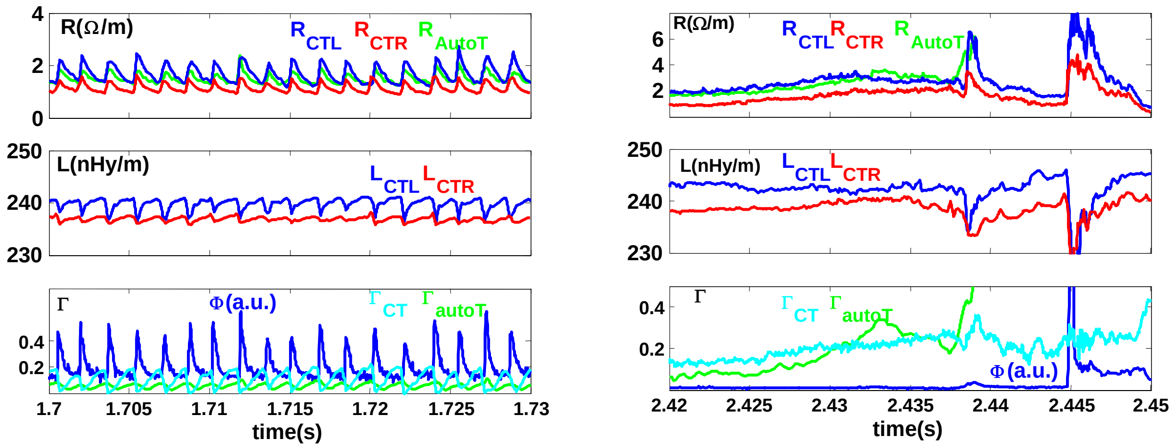

Figure 2 *a) Antenna strap loading resistances and inductances (of the classically matched antenna: R_{autoT}, of the left and right straps of the CT antenna: R_{CTL} and R_{CTR}, L_{CTL} and L_{CTR}), reflection coefficients (in the common branch of the classically matched antenna: Γ_{AutoT}, in the common branch of the CT: Γ_{CT}) and recycling flux Φ during ELMs.*
b) Idem but different time window.

There are limits to the tracking of the matching of the auto tuning system as seen in Figure 2b. At t=2.437s there is a trip on the AutoT antenna due to fast and strong increase of recycling flux accompanied by an increase of loading resistance that does not affect the CT system. At time t=2.445s the very strong recycling flux still not increases the reflection in the CT transmission line. At t=2.448s the decrease of coupling leads to a trip in the CT system. The time needed to move the capacitors limits the auto-tuning system: the generators are tripping in case fast changing antenna load. In the case shown in Figure 2b the CT system trips when the loading resistance is becoming too low. This is in accordance with results of the transmission line theory. In Figure 3 the reflection coefficients in the different transmission line segments are shown.

The system is load resilient for $|\Gamma|<0.2$, i.e. for R_A between 1.5Ω/m and 20Ω/m in this case. One can choose the lowest R_A for which he wants to be resilient but the lowest this value the narrowest the resilience domain will be.

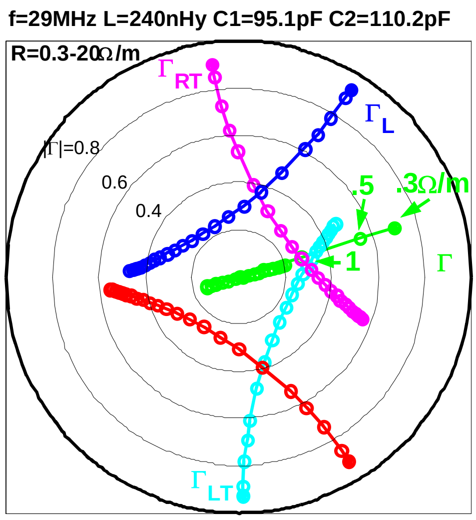

Figure 3 Reflection coefficients at the feeding points of the two straps of the CT antenna (Γ_L and Γ_R), at the T-junction in the two branches of the CT (Γ_{LT} and Γ_{RT}) and after the T-junction (Γ) in the Smith's chart for R_A varying between 0.3Ω/m and 20Ω/m (circles) Load resilience inside the $|\Gamma|=0.2$ circle. Circles at $|\Gamma|=0.4$, 0.6 and 0.8 are also shown.

Discussion of the results

The precision of the evaluation of loading resistance is determined by the uncertainties in the measurement of the reflection coefficient. The difference in the 3 resistances of Figure 2 corresponds to a difference of maximum 0.07 in the $|\Gamma|$ coefficient, which is the limit of the precision, due to noise on the signal and coupling between the antennas. An example of the evolution of the loading resistance for the CT antenna when the plasma is displaced 4 cm towards the inside of the machine (i.e. away from the antenna) is shown in Figure 4. The antenna loading resistance decreases by a factor ~3.

The amplitude and the phase of the current measured at the short circuit of the straps of the antennae are compared to the values calculated using the power and the reflection coefficients in the transmission lines. The agreement between measurements and modelling is good if we use for the length of the transmission lines the values electrically calibrated from tuning conditions on vacuum knowing the S matrix measured with a network analyzer. These values are within the error bars of the physical length of the lines. The difference of absolute value of loading resistance could again be due to a relatively small error in the determination of Γ.

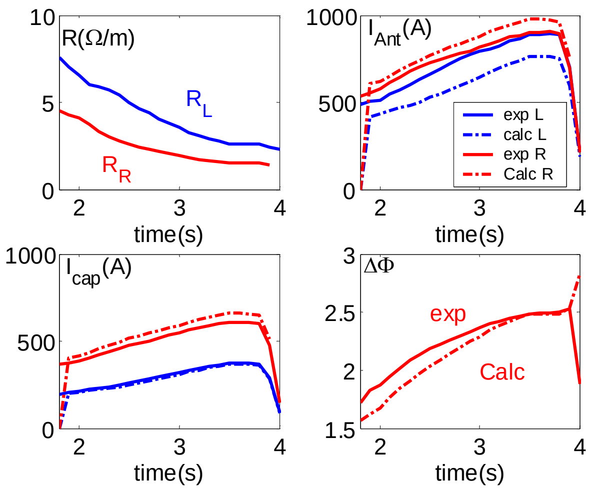

Figure 4 Evolution of the antenna loading resistances for a discharge where the plasma is slowly shifted 4 cm away from the antenna. Currents measured at the antenna and at the capacitor and phase difference between the currents in the left (L) and right (R) straps. The measured values of the currents (plain lines) are in good agreement with the values deduced from the transmission line model associated with the measurements in the transmission lines (dashed lines).

Prospects

With the enhanced measurement and tools developed future studies will focus on the influence of the phasing of the conjugate-T (which is depending on the load conditions) on the heating efficiency and conjugate-T performances. Possible improvement of the coupling using gas puffing close to the antenna will also be investigated.

References

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