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Experimental dependence of plasma breakdown on wave polarization in the TJ-II stellarator

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Introduction

The existing second harmonic ECRH breakdown models for stellarators [1, 2] share a common hypothesis: at the beginning of the discharge, where no plasma still exists, an average uniform electric field is created inside the vacuum vessel of the device, due to the multiple wall reflections of the ECRH injected power. The energy source term, issued from non-linear wave-particle interaction theory (essential to understand ECRH breakdown at second harmonic), is calculated with this randomized field, for which all the information about polarization is lost. However, the experiments performed in Heliotron J [3] show a clear dependence of plasma breakdown on polarization and the model developed in [2, 4], which only takes into account the energy provided by non-linear wave-particle interactions, demonstrates that those are indeed necessary but not sufficient to explain the complete gas ionization. Therefore, the hypothesis about the initial energy source is probably failing before full ionization around the torus is completed. Nevertheless, if the plasma is being produced simultaneously around the torus, it is still reasonable to think that the initial behaviour of the discharge (the firsts miliseconds after ECRH switch-on) should not depend on the polarization even though the final breakdown time does. The experiment presented here intends to determine whether or not this hypothesis can still be used for modelling the initial phase of the plasma breakdown.

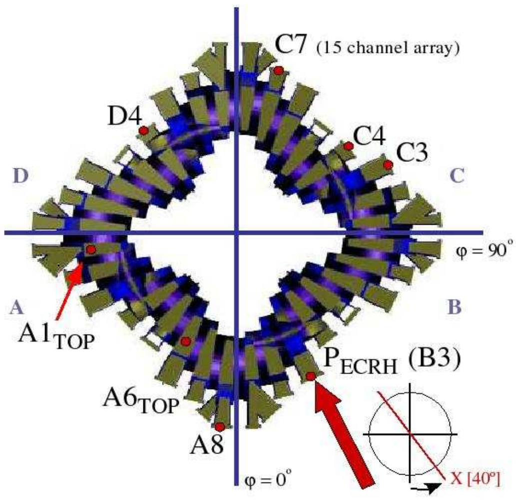

Figure 1: H_α *monitors (●) and CCD camera location. X-mode is coupled when the linear polarization angle in respect to the vertical direction is* $\beta \approx 40^\circ$.

Experimental set-up

TJ-II plasmas are routinely created with two 53.2 GHz gyrotrons delivering a total power of 500 kW. In order to clarify the interpretation of the results, our breakdown experiment has been carried out with one single gyrotron. All the shots were performed with constant power ($P_{ECRH} \approx 260$ kW) and similar initial neutral hydrogen pressure $p_0 \approx 0.01$ mTorr . The ECRH beam linear polarization was varied from X-mode to O-mode and plasma breakdown behaviour was investigated by means of seven H_α monitors distributed around the perimeter of the device (Fig. 1), one 15-channel array of H_α detectors located at sector C7 covering 6 centimeters of plasma (Figs. 1 and 2), and a fast CCD camera looking through the C8 port along the direction represented in Figure 1. Other usual plasma diagnostics as ECE, Thomson scattering and microwaves interferometry were also available. For each shot, the local breakdown time (τ_{bd}), defined as the time elapsed between the ECRH switch-on and the time position of each of the H_α emission peaks, is measured (see Fig. 3). Moreover, the initial growth rate of the discharge (γ, also local) can be determined by fitting the first part of the H_α signals to an exponential function $I = I_0 e^{(\gamma t)}$. In addition, τ_h, the time delay between the ionization peak and the heating peak (detected by those of the H_α monitors whose viewing chord points to the vacuum vessel wall) can also be determined (see also Fig. 3).

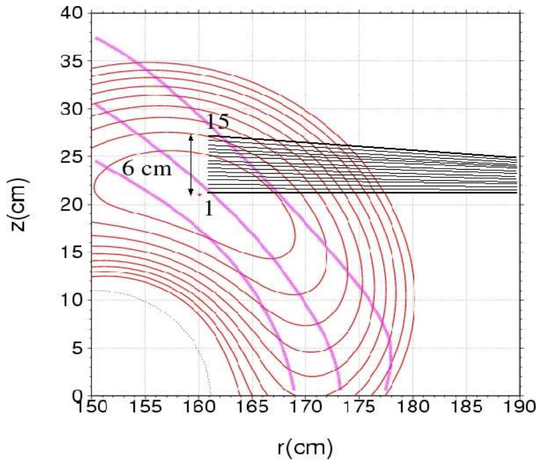

Figure 2: *Viewing chords of the H_α's array channels. Channel 1 is looking to the plasma center.*

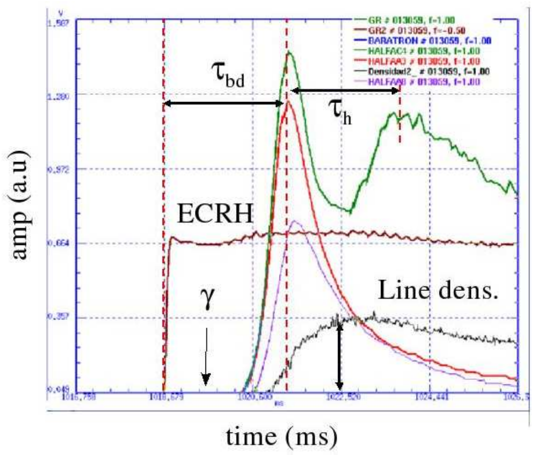

Figure 3: *Measured parameters: τ_{bd}, τ_h, and γ.*

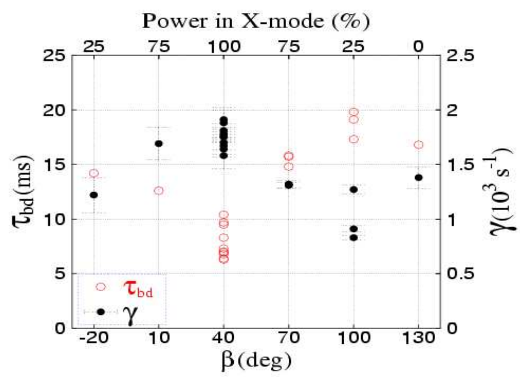

Figure 4: *Breakdown time and initial growth rate obtained from $H_\alpha^{A1_{TOP}}$.*

Experimental results

Six polarizer positions were used, corresponding to four levels of power coupled in the X-mode (see Figure 4). The viewing chord of the H_α detectors differs between machine sectors. In particular, $H_\alpha^{A1_{TOP}}$ is mainly receiving volume integrated radiation. Figure 4 shows the breakdown time measured at this sector and the initial growth rate as deduced from the $H_\alpha^{A1_{TOP}}$

signal, for each position of the polarizer (the equivalent power level in the X-mode is also shown). Both parameters depend clearly on the polarization. The smaller breakdown time (higher growth rate) is obtained for 100 % of the power in X-mode. The determination of γ (by fitting $\ln(H_\alpha^{A1_{TOP}})$ with $f(t) \equiv ln(I) = \gamma t + \ln(I_0)$) is illustrated in Figure 5 for two different levels of power coupled to the X-mode. The emission detected by the H_α's array when all the power is coupled to the O-mode is represented in Figure 6. A shift of the breakdown time (breakdown propagation) is observed. In particular, the time delay of channel i in respect to channel 1 ($\Delta\tau_{bd}(i)$), is shown in Figure 7 for maximum and minimum X-mode coupled power. For 100% X-mode, the saturation of the H_α signals hinders the determination of the peak position. This is reflected in the large error bars of the central channels. In spite of this, it can be seen that no delay occurs between these channels (C1, C2, C3 and C4; covering around 1.5 cm of plasma). This is consistent with the beam size at the resonance crossing point. The rest of channels show an increasing delay as we move towards the edge. The maximum delay occurs for the last channel in the O-mode case ($\Delta\tau_{bd}(15) \approx 1.5$ ms). Finally, Figure 8 shows τ_{bd} for each sector and three levels of power in the X-mode. Gyrotron power is launched through the B3 port and breakdown is detected in the toroidal direction almost simultaneously, within the time resolution, in all the measuring ports. Figure 9 represents the heating peak position dependence on polarization. As expected, heating is delayed for O-mode injection and thus the linear polarizer behaves as expected. The lack of symmetry observed in Figs. 4 and 9 is probably due the not so constant pressure conditions.

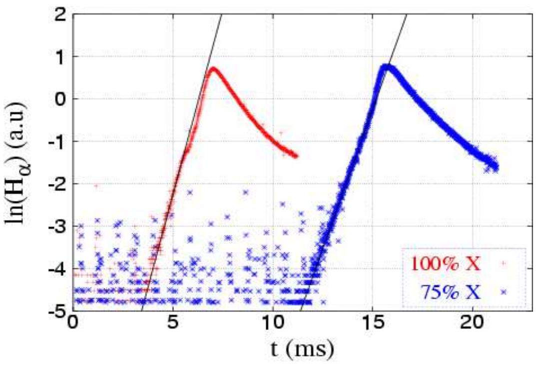

Figure 5: *Linear fit of the $H_\alpha^{A1_{TOP}}$ signal logarithm ($\gamma = 1.75 \times 10^3\ s^{-1}$ for 100% X-mode and $\gamma = 1.31 \times 10^3\ s^{-1}$ for 75% X-mode). Fit is started when the signal to noise ratio is significant.*

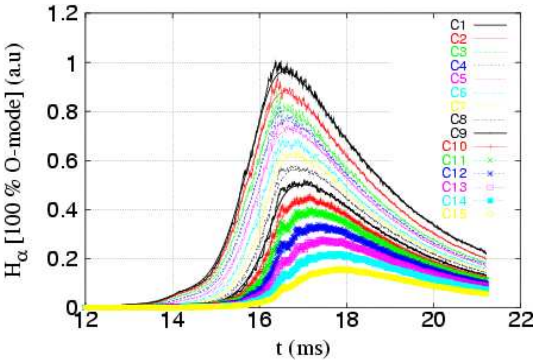

Figure 6: *H_α signals obtained with the 15-channel array for* 100% *O-mode.*

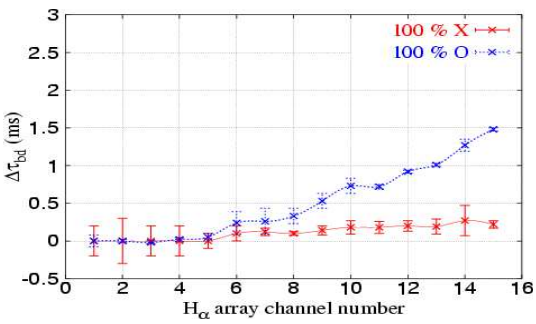

Figure 7: *Time delay in respect to the central channel.*

Discussion

The main result of the experiment is that the wave polarization has a strong influence on the breakdown performance; not so strong, however, as in Heliotron J, where no breakdown was reached for O-mode injection [3]. The different behaviour is probably due to the different magnetic configurations of both devices. Nevertheless, the discharge growth rate obtained from signal fitting is not exactly the initial one since, due to the H_α detectors sensitivity, no measure of the emitted photons is available at the very beginning (see Fig. 5) and a possible effect of the polarization during this phase can not be seen. Anyway, even if the hypothesis of an energy source produced by an average electric field could still be sustained during the first miliseconds, there is a clear evidence demonstrating that the energy source described in the models has to be modified to consider non-linear wave particle interaction with polarization effects and linear heating processes at the beam-resonance crossing point, at least if a complete simulation of the breakdown process is desired. Valuable information about breakdown propagation in the direction perpendicular to the field, which can be useful to include a spatial dimension in the models, has also been obtained from the H_α's array and the CCD camera observations (which are not presented here due to the lack of space). Careful analysis to convert integrated line radiation into local radiated photons is needed to pursue the studies in this direction. In relation to the parallel propagation of breakdown, and from the result presented in Figure 8, any toroidal delay that could help us to determine if breakdown is being produced simultaneously along the torus or if it is produced first in the gyrotron sector and then propagates along the torus, is masked by the fact that the detectors are viewing the plasma along different chords.

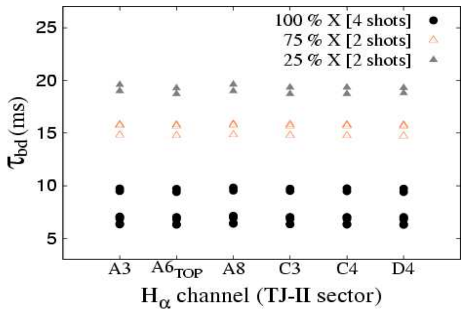

Figure 8: *Breakdown time around the torus.*

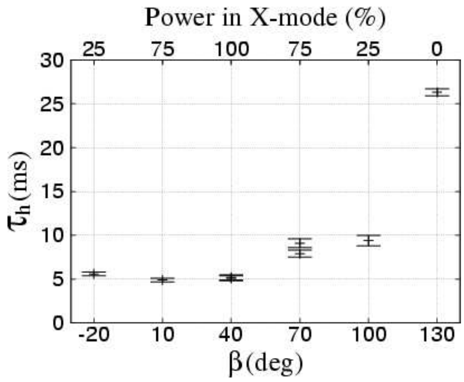

Figure 9: *Time position of the H_α^{C4} heating peak.*

References

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