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Analysis of wall particle content with premagnetization plasmas

C. Grisolia *, Ph. Ghendrih, G. Martin, D. Van Houtte

Association Euratom-CEA, DRFC, CE Cadarache, F-13108 St. Paul-les-Durance Cédex, France

Abstract

In this paper, after a brief description of the premagnetization plasma experimental setup, a study of this phase is presented in which premagnetization plasmas are shown to be indicative of global wall saturation status. Then a new criterion of wall saturation is described. Global parameters of the premagnetization plasma are summarized in the so called *premagnetization diagram*. This diagram is shown to allow for a real time evaluation of the wall saturation status. Therefore, it gives a unique possibility of feedback control the prefill injection and/or the electric field to improve main plasma breakdown and current ramp-up.

Keywords: Tore Supra; Tokamak; Wall pumping; Wall conditioning; Wall particle retention

1. Introduction

Control of neutral recirculation during steady state operation is one of the challenges of ITER. Problems related to the wall particle content are tritium inventory, stability of the divertor detached plasma and density and isotopic control. Regarding the issue of density control and wall saturation process, a specific procedure is routinely used on Tore Supra during the premagnetization phase [1].

We have shown previously that premagnetization plasmas are indicative of global wall saturation status. On the one hand, the internal inductance (li_q) (measured when $q_{edge} = 6.5$ during current ramp-up) was shown to increase with the characteristic evolution time of the density decay τ_0 when plasma is moved from outer limiter (~ 1 m^2) to the inner wall (~ 10 m^2). τ_0 is known to be the signature of the wall saturation status [2,3]. On the other hand, sustainment time of plasma current induced at the start of premagnetization (τ_{I_p}) was shown to increase with li_q. Moreover, the rise of τ_{I_p} is concomitant to the increase of the disruption frequency. Therefore, premagnetization plasma breakdown (PPB) provides a measure of the global wall saturation status in a non perturbative fashion and prior to the main plasma breakdown (MPB).

In this paper, after a brief description of the premagnetization plasma experimental setup, a study of this phase is presented. Then a new criterion of wall saturation is described. Global parameters of the premagnetization plasma are summarized in the so called premagnetization diagram. This diagram is shown to allow for a real time evaluation of the wall saturation status. Therefore, it gives a unique possibility of feedback control the prefill injection and/or the electric field to improve MPB and current ramp-up.

2. Plasma premagnetization experimental setup

About 1.8 s before the MPB, a small D_2 injection allows the breakdown of a plasma at the start of the premagnetization phase. The vessel pressure at the PPB is not a crucial parameter of the premagnetization results described hereafter. However, to get comparable observations, the deuterium pressure P_{D_2} is kept constant in the present experimental setup. Moreover, as premagnetization plasmas must not modify the wall saturation status, P_{D_2} should be maintained small ($P_{D_2} \sim 2 \times 10^{-3}$ Pa) compared to the pressure used for MPB ($1–2 \times 10^{-2}$ Pa).

In Fig. 1, the operating conditions during this phase are presented for a standard case obtained with saturated wall (see below, part three). The loop voltage is large and constant $V_{loop} \sim 12$ V (see Fig. 1a). The central solenoid of

* Corresponding author.

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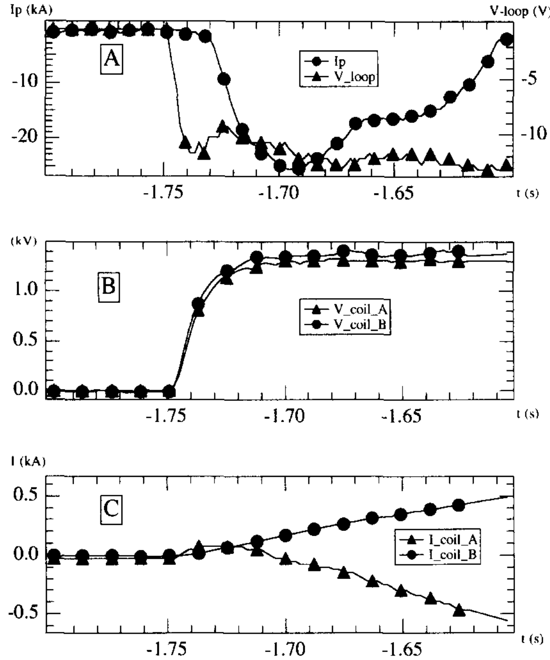

Fig. 1. Premagnetization parameters (wall saturated): (A) plasma current (I_p) and loop-voltage (V_{loop}); (B) central solenoid voltages; (C) central solenoid currents.

Tore Supra is composed of 3 coils: a central one and two coils placed in the upper and lower central region. The rise time of the coils voltages is approximately 20 ms. The current of the other poloidal coils is maintained to zero during the premagnetization phase. Due to iron core transformer magnetization, the coils current increase slowly (Fig. 1c) and generate a vacuum magnetic field (B_v) characterized by a vertical component decreasing outwards.

The premagnetization plasmas are characterized by a small negative plasma current, 15 kA $< |I_p| <$ 30 kA, a central linear density, 2×10^{17} m^{-2} $<$ nl $<$ 3×10^{18} m^{-2}, and a plasma current lifetime in the range 20 ms $< \tau_{I_p} <$ 150 ms. During all the plasma duration there is no control of the plasma position so that the magnetic equilibrium is very sensitive to the magnitude and peaking of the plasma current. The latter is determined by the plasma temperature since the loop voltage is controlled. This loop voltage allows for a significant ohmic heating $\sim$ 200 kW.

3. Premagnetization plasma study

Let us consider the time traces of I_p and nl of two premagnetization plasmas typical of different wall states (see Fig. 2). The triangle symbols represent the premagnetization plasma obtained with a desaturated wall while the square symbols correspond to a wall status close to saturation. In the later case, a bifurcation to a MARFE occurred

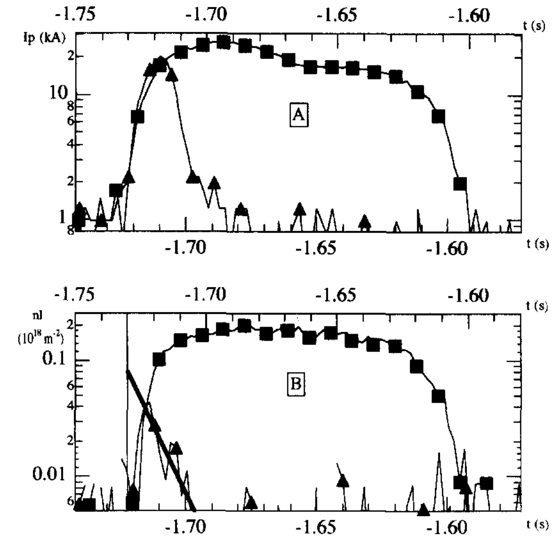

Fig. 2. Absolute plasma current (A) and line average density (B) for saturated (square) and non saturated (triangle) wall.

during the main plasma current ramp-up which leads eventually to a disruption.

As it was discussed in Ref. [1], τ_{I_p} is correlated to the wall particle content. For desaturated conditions, there is a wall pumping effect of the particles leading to a rapid collapse of the plasma ($\tau_{I_p} \sim 34$ ms). Conversely, the

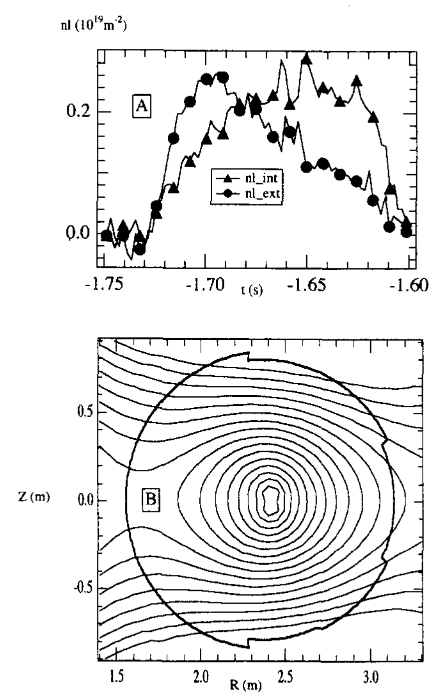

Fig. 3. (A) Central (nl_{int}, $R = 1.97$ m) and outer (nl_{ext}, $R = 2.63$ m) linear density; (B) magnetic isoflux reconstruction showing X-point formation 40 ms after PPB (saturated wall).

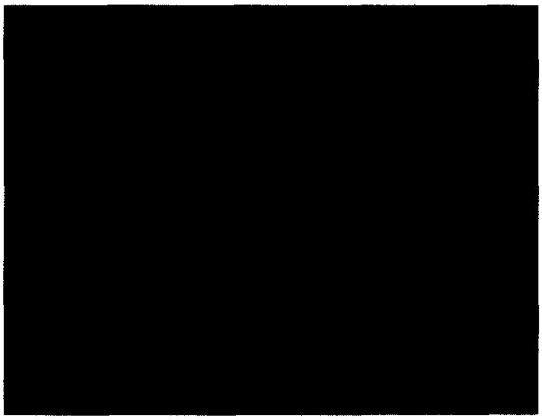

Fig. 4. Tangential view of the vessel (CCD camera picture) with high recycling zones on top and bottom of the inner wall.

saturated wall leads to a stabilized plasma during premagnetization, $\tau_{I_p} \sim 150$ ms, the plasma current decreasing before the particle content.

The global equilibrium of these premagnetization plasmas is insured by the rise of the vertical field. There is a competition between the inward force $B_v \times j_p$ (where j_p is the premagnetization current density) and the outward force generated by the vertical poloidal field created by the plasma itself.

In the saturated wall configuration there is a compensation of the plasma poloidal field and of the external vertical field leading to an in vessel X-point (located in the midplane on the high field side) $\tau_{B_v} \sim 60$ ms after plasma breakdown. This modifies the recycling pattern as indicated by the increase of the line average density measured on the high field side (see Fig. 3a) and leads to a slowing down in the contraction of the current channel. The in vessel X-point is confirmed by a CCD camera picture giving a tangential view of the vessel (see Fig. 4). After almost 60 ms, a bright zone appears on the bottom and top of the vessel, close to the inner wall. This corresponds to a high recycling zone due to the X-point. The latter is also observed with magnetic isoflux reconstruction (see Fig. 3b). In this saturated case, the effective particle life time τ_p^* (deduced from nl decrease in Fig. 2b) is long and $\tau_p^* \gg \tau_{B_v}$, so that such a «magnetic equilibrium» is reached allowing for a marked increase in the plasma duration.

In the non-saturated wall configuration, due to high wall pumping efficiency, τ_p^* is very short ($\tau_p^* \sim 7$ ms see Fig. 2), and $\tau_p^* \ll \tau_{B_v}$ leading to a very peaked (high temperature) current profile and a disruptive termination of the premagnetization plasma.

This analysis of plasma stability driven by the vertical field is confirmed by one set of experiments using a special procedure where premagnetization breakdown is obtained with $B_v \sim 0$. In this case, $\tau_{I_p} \sim 520$ ms which is three times more than the longest premagnetization plasma obtained with the standard procedure.

4. Premagnetization diagram

In order to allow for a feedback control on the prefill injection and/or on proper plasma breakdown voltage, clear evidence of wall saturation given by premagnetization plasma current is required. On Tore Supra a new type of diagram is used, called the premagnetization diagram. It gives a pre-shot evaluation of the wall saturation status and consequently enables to follow the wall saturation evolution on a shot to shot basis. This diagram is presented in Fig. 5a. The absolute value of the mean premagnetization current ($\langle I_p \rangle$) is plotted against the absolute value of the integral ($\int I_p\, dt$). $\langle I_p \rangle$ is equal to $\int I_p\, dt$ divided by τ_{I_p}. In the diagram, typical shots are presented representing almost all experimental situations and wall saturation status.

Point A is obtained for a deep desaturated wall (same shot as Section 3). Since premagnetization breakdown occurs at a given P_{D_2} pressure, I_p obtained for deep desaturated wall always gives a representing point around A.

Then as the wall saturation increases, the characteristic point moves from A to G through D (E stands for the saturated shot of Section 3). Conversely, desaturation experiments lead to the reverse trajectory.

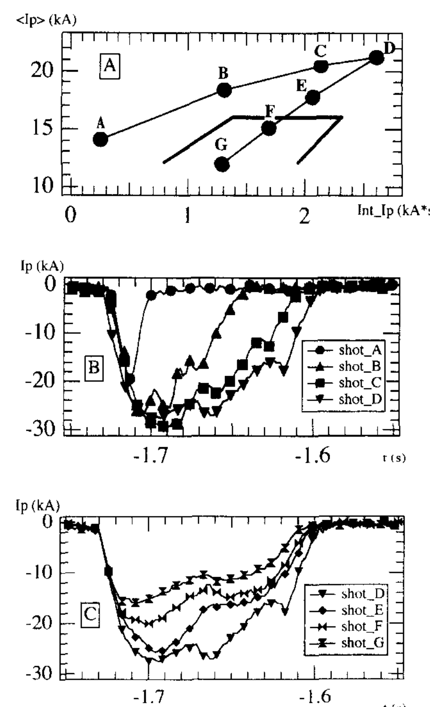

Fig. 5. (A) Premagnetization diagram: absolute mean value of premagnetization current ($\langle I_p \rangle$) versus its absolute integral (Int – I_p) for a series of shots from desaturated (point A) to saturated (point G) wall. (B) and (C): Time trace of premagnetization plasma currents for the shots of the diagram.

The two parts of the trajectory (A to D and D to G) stem from two different behaviors. Between A and D, as the wall saturation status evolves, τ_{I_p} and $\int I_p\,dt$ increase together (see Fig. 5b). Due to the increase in the wall particle content, premagnetization plasmas appear to be more and more stable.

At point D, τ_{I_p} reaches its maximum value and remains almost constant thereafter (see Fig. 5c). Then from D to G, the wall content becomes too high, the plasma is suffocated by the recycling flux coming from the wall. $\int I_p\,dt$ decreases monotonically from D to G. Since the residual vessel pressure increases with wall saturation status, the premagnetization breakdown can be obtained without any D_2 injection for saturated walls. In this case, the characteristic point is close to G.

At Tore Supra, PPB have now been recorded for more than 500 shots. All premagnetization plasmas give points which follow the trajectories described above. It has to be stressed that all the points situated between D and G below the horizontal line (see Fig. 5a), characterize wall saturation status such that, under these conditions, MPB is impossible.

The premagnetization diagram criterion is routinely used at Tore Supra. It is particularly useful during radiating layer experiments where high density is required. Due to particle balance between the wall and the plasma, intermediate wall saturation levels are needed to get density increase with relatively low D_2 gas influx. Using wall saturation and desaturation procedures (for the latter with active pumping of the outboard pump limiter), wall status remains constant between C and D allowing for large recycling fluxes without any MARFE.

This real time analysis of wall saturation status is obtained 1.5 s before MPB. Thus feedback control becomes possible. For instance, if the characteristic point lies between D to G, above the horizontal line, high recycling fluxes are obtained during MPB which is becoming harder due to high plasma resistivity. Decrease of the D_2 prefill pressure and/or increase of the breakdown voltage could improve the MPB. The feedback of these two quantities with the premagnetization plasma results is now under investigation at Tore Supra.

At last, if the characteristic point lies between D and G and below the horizontal line, a desaturation experiment must be performed. Thus, the operating scenario can be switched automatically towards conditioning procedure such as rf conditioning using ICRF heating or Taylor discharges.

5. Conclusions

In this paper, the premagnetization plasma phase is described. The properties of the premagnetization plasma are shown to be strongly correlated to the wall saturation status. For desaturated wall conditions, due to the pumping wall capabilities the plasma rapidly collapses whereas for saturated conditions, the plasma current lifetime is four to five times greater. The increase in the plasma stability comes from a compensation of the destabilizing vacuum vertical field by the plasma poloidal field. For the saturated case, this leads to an X-point creation which modifies the recycling pattern. Premagnetization and main plasma break-down behaviors are comparable and the study of premagnetization plasma gives a new insight on the main plasma break-down phenomenon which is under analysis at Tore Supra.

The premagnetization diagram is also presented. It gives a real time evaluation of the wall saturation status just before the shot. This new criterion is used at Tore Supra to monitor the wall status in dedicated experiments such as radiating layers. Feedback control on the plasma prefill pressure and/or on plasma break-down voltage is now under investigation at Tore Supra to insure successful main plasma break-down and thus to optimize plasma operation.

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