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# Conditions and underlying physics to achieve higher performance in PPCD operation in a reversed-field pinch device, TPE-RX

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## 1. INTRODUCTION

The reversed-field pinch (RFP) is a magnetic confinement system for thermonuclear plasma whose configuration is sustained via the dynamo mechanism through fluctuations of velocity and magnetic fields. The pulsed poloidal current drive technique (PPCD) [1] is used to improve the plasma confinement properties by the reduction of the magnetic fluctuations [2]. The PPCD induces one or more poloidal current pulses in the toroidal circuit, producing the poloidal electric field which, in standard RFP plasma, is generated by the dynamo mechanism.

In this paper we will show how to obtain high performance during the PPCD regime in the RFP device TPE-RX [3]. We will analyse three operating conditions necessary to obtain higher PPCD performance: triggering time of PPCD pulses, filling pressure of the deuterium gas ($p_{D2}$) and wall condition [4]. Then the soft X-ray (SXR) behaviour during PPCD will be described. Finally, in agreement with reference [5], we will show that the key parameter is the component of the electric field parallel to the magnetic, $E_{\parallel}$.

## 2. EXPERIMENTAL CONDITIONS

We have run seven cases of five-pulsed PPCD. Each case contains 50 discharges. The tested operating conditions are the triggering time of the PPCD pulses, $p_{D2}$ and the wall conditions. First, we changed the triggering time with $p_{D2}$=67mPa after sufficient wall conditioning, CASE 1, 2 and 3. Second, we changed $p_{D2}$ using the same triggering time of CASE 1 and after sufficient wall conditioning, CASE 4 and CASE 5 (80 and 93 mPa). Third, the same triggering time and $p_{D2}$ of CASE 1 have been used, but the discharges have been obtained after the opening of the vacuum vessel, in order

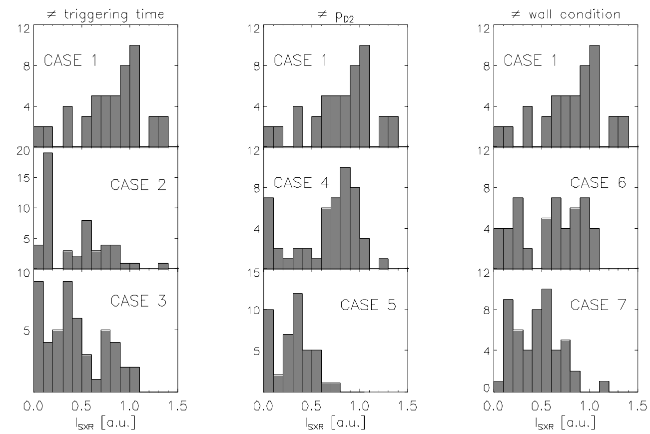


Fig.1: Histogram of maximum $I_{SXR}$

to observe the effect of the wall conditioning: CASE 6 (after 72 cleaning discharges) and CASE 7 (after 10 cleaning discharges). The histogram of the maximum SXR intensity, $I_{SXR}$, is shown in Fig.1.

## 3. CONDITIONS TO ACHIEVE HIGH PPCD PERFORMANCE

In order to compare the performance of PPCD, $I_{SXR}$ has been used. In order to understand how to achieve high performance in PPCD, individual statistics of Type-G discharges (see next paragraph) have been compared. The overall effect of PPCD has been taken into consideration time-averaging between 18ms and 4ms after the last PPCD pulse. This time average will be denoted by < >. In the cases of different triggering times (CASEs 1, 2 and 3), delayed PPCD pulses have a negative effect on the performance, as shown in Fig. 2(a), where the shot-averaged value of $I_{SXR}$ peak against $\Delta\tau_{PPCD}$ (the time delay between the last and the first PPCD pulse) is shown. Regarding the effect of $p_{D2}$ (CASEs 1, 4 and 5), better performance is obtained with lower $p_{D2}$, Fig. 2(b). In the cases with different wall conditions (CASEs 1, 6 and 7) $I_{SXR}$ increases as wall conditioning proceeds, Fig. 2(c), where the wall conditions have been represented by the intensity line of oxygen V impurity, $I_{OV}$. Among all CASEs, CASE 1 is found to give the highest on-average $I_{SXR}$. Upon changing the trigger time (CASEs 1, 2 and 3), the performance degrades as the pulses are delayed. For the same triggering time (CASEs 1, 4 and 5) the best performance is obtained at the lowest $p_{D2}$. Regarding the effect of the wall conditioning (CASEs 1, 6 and 7), sufficient wall conditioning, (CASE 1), provides the best performance.

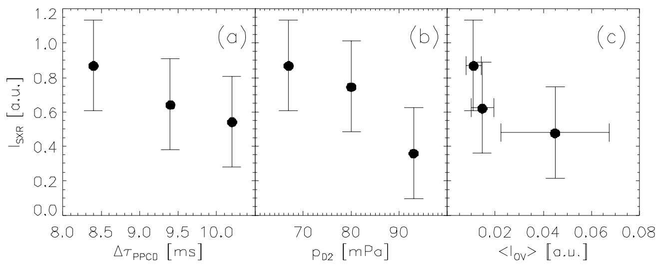


Fig.2: Correlation between $I_{SXR}$ with $\Delta\tau_{PPCD}$, $p_{D2}$, and $<I_{OV}>$ .

## 4. SOFT X-RAY BEHAVIOR DURING PPCD

In PPCD discharges, $I_{SXR}$ generally reaches a value an order of magnitude higher than that in standard discharges. But this is not always the case; even if the experimental conditions are the same, in the 20% of the shots, the maximum $I_{SXR}$ is comparable to that of the standard discharges. In the low $I_{SXR}$ discharges, the decrease of $I_{SXR}$ begins more than 5ms before compared to the high $I_{SXR}$ shots. Hereafter the PPCD discharges with $I_{SXR}$ peak before 28.5ms will be called Type-B while the others Type-G. This behavior is clear in Figs. 3(a) and (e), where the shot-averaged time evolution of $I_{SXR}$ is shown. In order to understand the cause of Type-B discharges, the shot-averaged temporal evolution of representative signals, for CASEs 2 and 5, are shown in Fig.3. The effect of the PPCD pulses is evident in Figs. 3(b) and 3(f), where $E_\parallel$ is shown: every pulse produces the increase of $E_\parallel$. In CASE 2, we found that the Type-B discharges are originated by an instability in m=0, n=1 magnetic mode, Fig. 3(d).

Similar results have been obtained for CASEs 1 and 3. In the case with high $p_{D2}$ (CASE 5) while $I_{SXR}$ of Type-B discharges decreases, the amplitude of magnetic mode is constant, whereas the difference is in the concentration of impurities [Fig. 3(h)]. Similar results have been obtained for CASEs 4, 6 and 7.

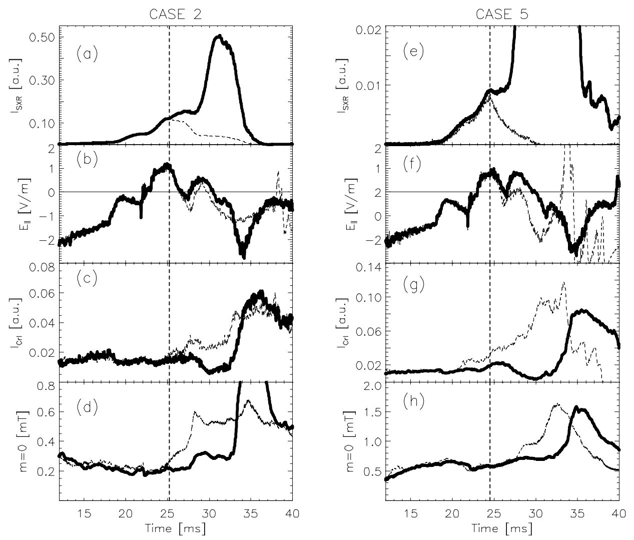

Fig.3: Shot-averaged time evolution of main signals for Type-G (thick line) and Type-B (thin dashed line) discharges in CASE 2 and 5.

## 5. THE ROLE OF $E_\parallel$

The PPCD performances are connected with the value of $E_\parallel$ as stated in [5]. A positive value of $E_\parallel$ is required to obtain good PPCD. In Fig. 4 we show the trend of $I_{SXR}$ peak as a function of $\langle E_\parallel \rangle$ for all the discharges in our database, CASEs 6 and 7 are excluded since the different wall conditions produce a quantitatively different behavior. In all cases negative values of $\langle E_\parallel \rangle$ corresponds to discharges with $I_{SXR}$ approaching to zero, that is, when PPCD cannot increase $\langle E_\parallel \rangle$ to positive values, the beneficial effects of this technique are completely lost. Instead, when PPCD increases $\langle E_\parallel \rangle$, higher values of $I_{SXR}$ are reached; higher performance is obtained with a higher value of $\langle E_\parallel \rangle$. In order to understand this relationship, in Fig. 5(a) we show the dependence of the root mean square of the m=0 magnetic modes, $\langle m_0 \rangle$, versus $\langle E_\parallel \rangle$ for all the 350 discharges in our database. The negative trend is evident. The increase of $E_\parallel$ produces the reduction of m=0 fluctuations and hence the improvement of the PPCD performance. Type-B discharges are characterized by negative $\langle E_\parallel \rangle$ and by high $\langle m_0 \rangle$. In order to investigate the role of m=0 fluctuations, and hence of $E_\parallel$, in Fig. 5(b) we show the correlation between $\langle m_0 \rangle$ and $I_{SXR}$. While at high values of $\langle m_0 \rangle$ there is mainly Type-B PPCD, high $I_{SXR}$ can

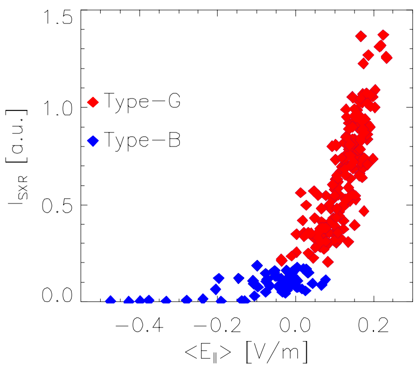

Fig.4: Correlation between $I_{SXR}$ and $\langle E_\parallel \rangle$. Blue symbols correspond to the Type-B shots and red symbols to Type-G.

be reached only with a low $<m_0>$. But since, at low $<m_0>$, $I_{SXR}$ can have a wide range of variation, the magnetic fluctuations are not the unique control parameter. In Fig. 5(c) we show that $I_{SXR}$ is correlated also with $<I_{OV}>$. The negative trend is partially hidden from the superimposition of all the experimental cases, but, for example, the discharges with less wall conditioning (CASE 7) are highlighted with X symbols; even if this case is quantitatively different from all the others, the negative trend between $I_{SXR}$ and $<I_{OV}>$ is evident.

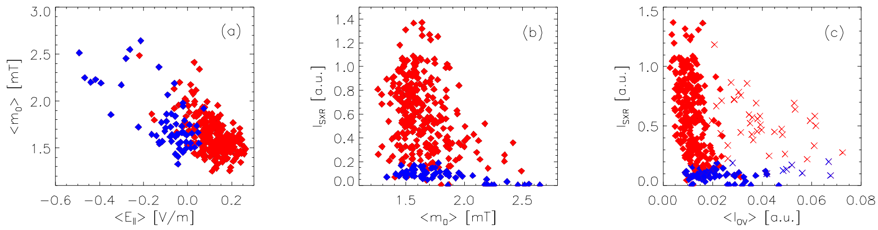


Fig.5: Correlation between $<m_0>$ and $<E_\parallel>$ (a), $I_{SXR}$ and $<m_0>$ (b), $I_{SXR}$ and $<I_{OV}>$ (c). Blue symbols correspond to the Type-B shots and red symbols to Type-G.

**6. CONCLUSION**

In this paper, we have shown methods of optimising discharges and hence of achieving the improvement of plasma confinement properties. First, we investigated the origin of Type-B discharges and we found that they may be caused by a growth of m=0, n=1 magnetic mode (which is related to the triggering time) and/or by impurities concentration. The impurity influx may change the plasma current profile and might produce instabilities, which degrade the discharge. Second, we have shown that close PPCD pulses, low $p_{D2}$ and good wall conditions are necessary conditions to obtain high performance. One of the key parameter is $E_\parallel$; the increase of $E_\parallel$ reduces the m=0 magnetic fluctuations and hence improves the performance. When PPCD increases $E_\parallel$, the sustainement of the RFP configuration needs a lower contribution from the dynamo mechanism and hence the magnetic fluctuations are suppressed.

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