26^{th} EPS Conf. on Contr. Fusion and Plasma Physics, Maastricht, 14 - 18 June 1999 ECA Vol.23J (1999) 1137 - 1140

Oscillating Poloidal Current Drive Experiments in RFX

S. Martini[1], T. Bolzonella[1], A. Canton[1,2], A. Intravaia[1,2], L. Marrelli[1], P. Martin[1,2], R. Pasqualotto[1], R. Piovan[1]

[1]*Consorzio RFX, Corso Stati Uniti 4, 35127 Padova, Italy*
[2]*Istituto Nazionale di Fisica della Materia – Unità di Ricerca di Padova*

INTRODUCTION

It is well known that sustaining the Reversed Field Pinch (RFP) magnetic field configuration entails a dynamo mechanism to generate internal poloidal currents of amplitude comparable to the toroidal one [1]. The current driven tearing instabilities internally resonant to the field reversal radius, which underlie the RFP dynamo, lead to magnetic field stochastisation and transport degradation in the plasma core, which accounts for a large part of the measured global energy flux [2]. As these instabilities are driven by the current density gradient, active poloidal current profile control by RF waves [3] or DC injection [4] is presently looked at as a promising way of improving the RFP confinement. A test of the concept on a time transient base was done first on the MST and then on the RFX reversed field pinch experiments by a technique named Pulsed Poloidal Current Drive (PPCD) [5]. The PPCD drives currents in the plasma inductively by applying a pulsed poloidal voltage and allows achieving strong reduction of magnetic fluctuations and large energy confinement improvements [6,7]. In this paper we present the first results of a new technique tested on the RFX experiment [8] named Oscillating Poloidal Current Drive (OPCD). The OPCD consists in the application of a continuous sequence of poloidal voltage pulses to the plasma, with the aim of extending the proof-of-principle of the PPCD from a pulsed to continual one.

EXPERIMENTAL SETUP

The current modulation in the toroidal field coils for OPCD operation in RFX is obtained using high power Gate Turn-off Thyristor (GTO) as switching devices. The circuit arrangement is shown in fig. 1. During the reversed magnetic field phase of the pulse, the constant voltage generator TFAT sustains the reversed current in the coils; the GTO closing and opening causes the variation of the equivalent resistance in series with the toroidal field winding, which results into a modulation of the current in the winding itself. The period of the applied oscillation can be varied with a lower limit of 2 ms. With the aid of a proper capacitor connected in parallel to the circuit (see figure) to improve the performances, the resulting poloidal voltage modulation can be of the order of a few volts, which is comparable to that produced during PPCD experiments [7]. In the following the sign assumption for the poloidal voltage is such that a negative voltage corresponds to inductive currents in the plasma which increase the toroidal flux in the core.

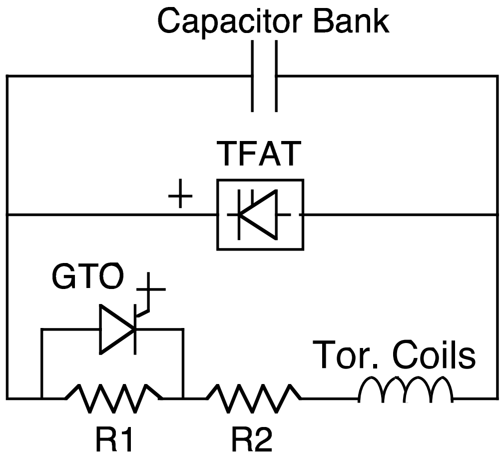

Fig.1. Scheme of the toroidal field circuit for OPCD experiments in RFX.

RESULTS

A first series of OPCD experiments at plasma currents I of 0.8÷1 MA have been performed. It has been found that for the OPCD to achieve a positive effect the oscillation period must be in

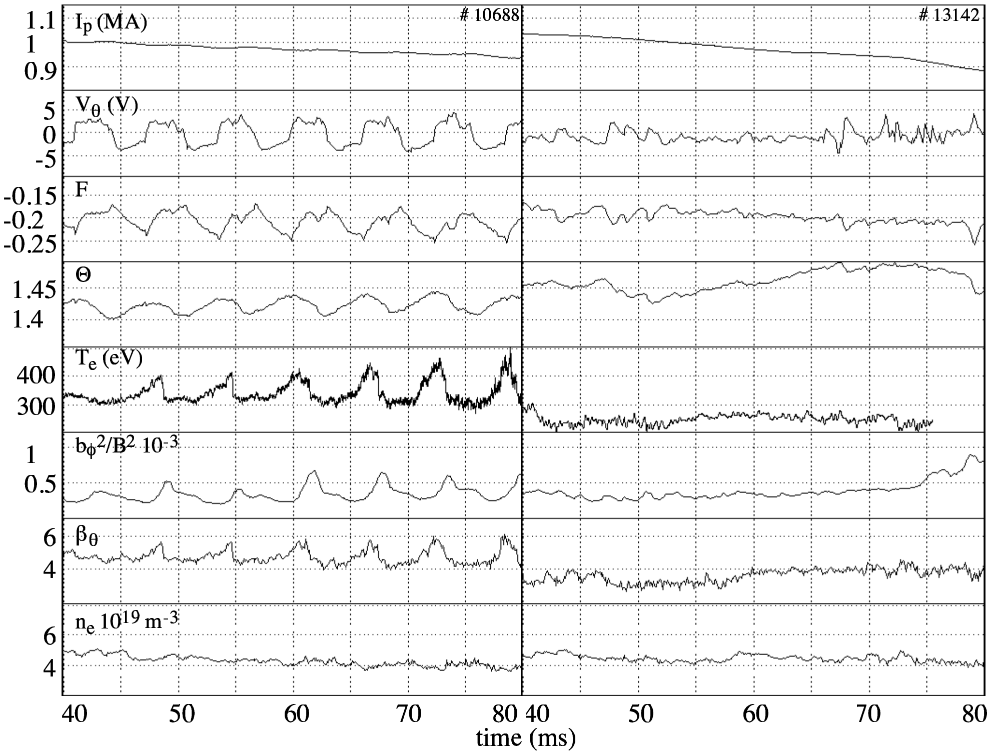

Fig.2. Comparison of several plasma parameters during a pulse with OPCD (left) and a standard one (right).

the range 6÷8 ms, while the optimum plasma parameters are the same as those favourable to PPCD [9], namely plasma density n and field reversal parameter F in an intermediate range ($I/N \equiv I/\pi a^2\langle n\rangle \approx 3\div4\cdot10^{-14}$ Am, $F \equiv B_\varphi(a)/\langle B_\varphi\rangle \approx -0.1 \div -0.25$). In optimised conditions, effects similar to those of PPCD are observed during each of the OPCD phases where the driven poloidal current sums up to the dynamo current. As shown in the example of figure 2 (left), a reduction of the magnetic fluctuation energy b_φ^2/B^2 is observed, which is accompanied by an increase of the central temperature (up to 75% according to measurements by the SXR double filter technique) and of the poloidal beta. The energy confinement time increases by ≈ 50%.

During the phases where the direction of the driven current is reversed (opposite to that provided by the dynamo), magnetic fluctuations increase and the central temperature decreases. By comparing the temperature measured during OPCD with those measured in standard pulses on a statistical basis (see fig.3), it can be seen that the central temperature during the antidynamo phase of the OPCD is similar to that of standard pulses.

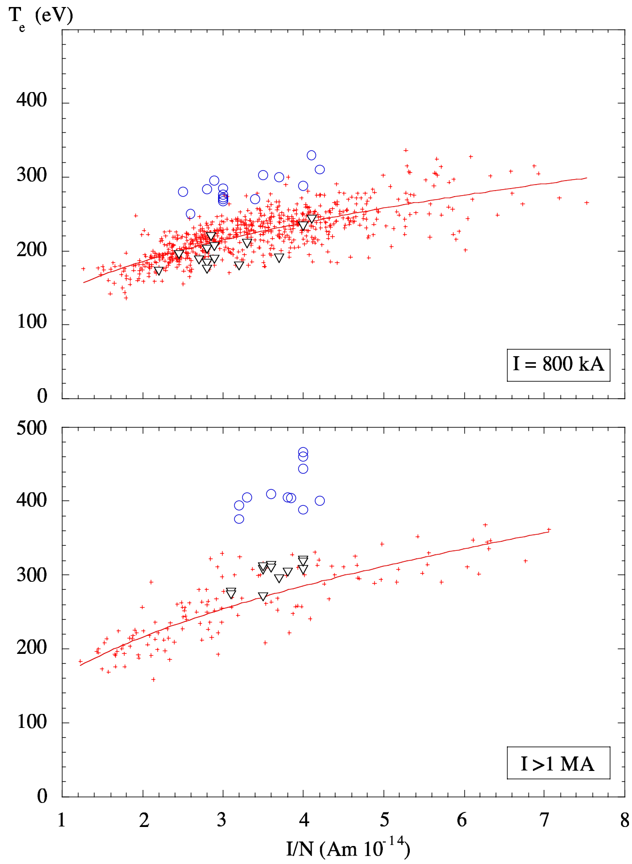

Fig.3. Maximum (circles) and minimum (triangles) values of T_e during oscillations induced by OPCD compared to a standard pulse database (crosses) vs. I/N.

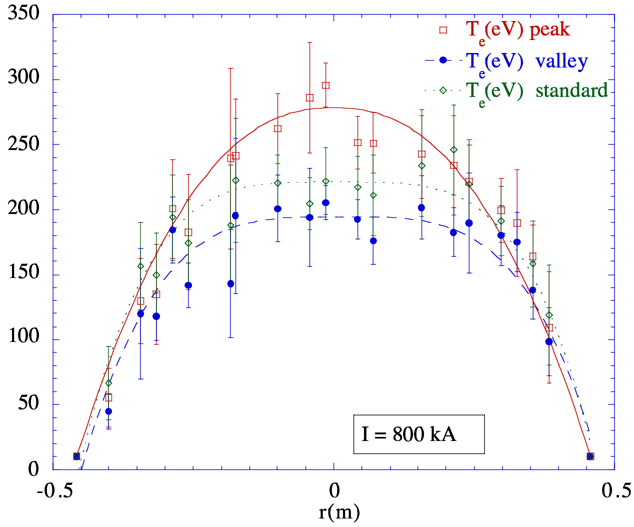

Fig.4. T_e profiles measured by Thomson scattering at the valley and at the peak of an OPCD oscillation. The average profile for a standard pulse is also shown.

Analysing single pulse Thomson scattering data taken at different phases of the OPCD for several shots, it has been possible to reconstruct an average profile measured both at the peak and at the valley of the OPCD oscillation for the 800 kA database. These profiles are shown in fig.4, along with an average profile for standard pulses of comparable current and density. The data confirm the temperature profile is significantly more peaked during the positive current drive phases of the OPCD, whereas it is flatter and quite similar to that of standard pulses during the negative current drive ones.

It may be interesting to note that the magnetic profiles during successful OPCD pulses where no relaxation events are observed [10], evolve in such a way as to describe counterclock wise loops in the F-Θ plane (see fig.5 upper frame). This behaviour is opposite to that observed during dynamo relaxation events, which are characterised by clock wise loops in the F-Θ plane (see fig.5 lower frame).

DISCUSSION AND SUMMARY

The behaviour of the magnetic profiles shown in fig.5 proves that the OPCD technique is a way to drive the RFP plasma through a cycle opposite to that seen during dynamo relaxation events. The loop can be described as a sequence of three phases: inductive drive of poloidal current accompanied by suppression of flux generation by internal dynamo modes (downward left to right on F–Θ trajectory), decay of driven current with dynamo modes still suppressed (nearly vertical upward on F–Θ), inductive drive of inverse poloidal current accompanied by increased flux generation by internal dynamo modes (right to left on F–Θ trajectory).

The fact that the T_e increase induced by the OPCD affects only the core region ($r/a \leq 0.8$) suggests that the significant global energy confinement obtained with OPCD is due to a strong decrease of the heat conductivity in the plasma core. This is indeed confirmed by the transport analysis shown in fig.6. The reduction of heat conductivity is consistent with the reduction of parallel losses along stochastic field lines, which results from the substitution of the toroidal flux generation via dynamo activity with that provided by the inductive current driven by the applied negative poloidal voltage.

Conversely, the similar central T_e and confinement values observed during the

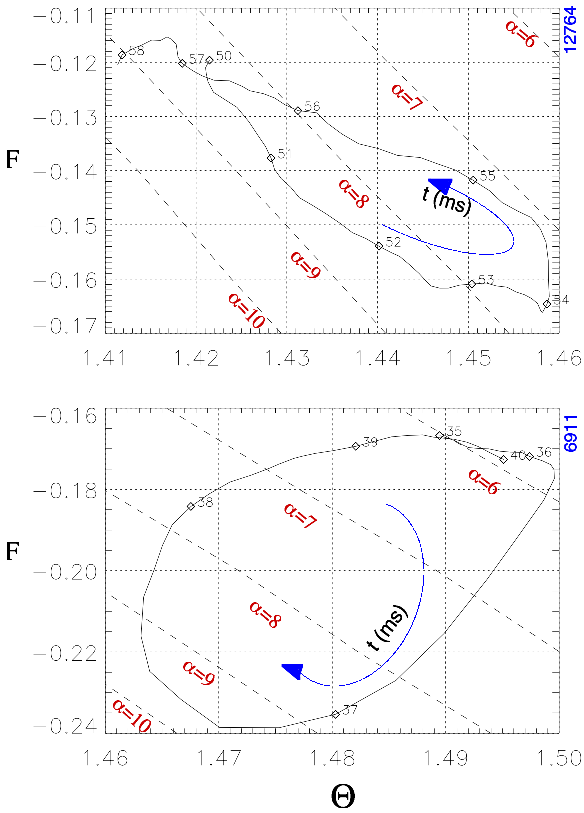

Fig.5. Trajectory in the F-Θ plane during an OPCD oscillation (upper frame) and a dynamo relaxation event (lower frame).

OPCD valleys and the standard pulses are consistent with the fact that the increased magnetic activity caused in the plasma core during the anti-dynamo phases of the OPCD has little impact on the global confinement. This can be explained considering that the global confinement, in both of the latter cases, is largely determined by the transport barrier present in the outer part of the plasma, i.e. around or even outside the magnetic field reversal surface.

The periodic reduction of the amplitude of the MHD dynamo modes induced by OPCD results also in a reduction of the non-axisymmetric perturbation of the last closed flux surface [11]. This proves useful in mitigating the intensified localised plasma-wall interaction normally observed along the footprint of the LCFS magnetic perturbation [12]. The latter effect plays probably an important role, together with the increased confinement in the plasma core, in helping RFX to reach record values of T_e at current ≥1 MA (fig.3) without causing carbon blooms and fast discharge termination [13]. Moreover it can be noted that the low T_e OPCD values for the 1MA pulses are slightly better than those of standard pulses, which could also be an effect of the more benign plasma wall interaction achieved with OPCD.

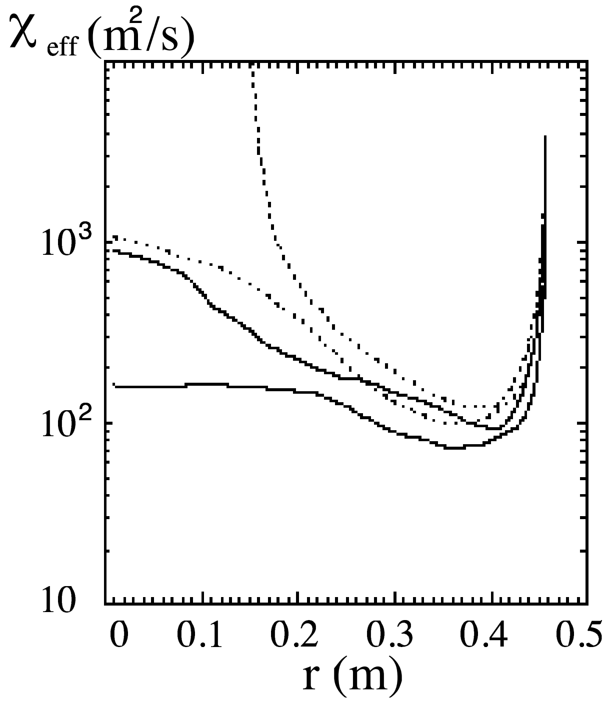

Fig.6. The radial profile of thermal conductivity during OPCD temperature peaks (solid line) and valleys (dashed line). The dashed region around each profile corresponds to 25%-75% confidence interval, as estimated with a Montecarlo code.

In summary, the OPCD experiments in RFX can be seen an extension on a non-transient base of the positive effects already obtained with PPCD. Indeed, in terms of time average over a complete oscillation period, the OPCD induces an improved plasma performance relative to the standard pulse, which can be repeated indefinitely through the current flat top phase of a stationary RFP pulse. These results offer further support to the possibility of achieving a non-transient confinement enhancement by applying continuos poloidal current drive in RFPs.

References

[1] S. Ortolani and D.D. Schnack *Magnetohydrodynamics of Plasma Relaxation*, World Scientific, Singapore (1993)
[2] F. D'Angelo, R. Paccagnella, *Stochastic diffusivity and heat transport in presence of a radial dependence of the perturbed magnetic field in the Reversed Field Pinch*, to be published on Plasma Phys. and Control. Fusion
[3] E. Uchimoto, M. Cekic, R.W. Harvey, et al., Phys. Plasmas **1**, 3517 (1994)
[4] D. Craig, A.F. Almagri, J.K. Anderson, et al., Phys. Rev. Lett. **79**, 1865 (1997)
[5] J.S. Sarff, S.A. Hokin, H. Ji, et al., Phys. Rev. Lett. **72**, 3670 (1994)
[6] R.Bartiromo, et al., Phys. Rev. Lett. **82**, 1462 (1999).
[7] M.R. Stoneking, et al., Phys. Plasmas **4**, 1632 (1997)
[8] R.Bartiromo, et al., Phys. Plasmas **6**, 1830 (1999)
[9] T. Bolzonella, et al. 24th EPS Berchtesgaden, 1997, I, 321
[10] Martini et al. Plasma Phys. and Control. Fusion **41** A315 (1999)
[11] P. Zanca and S. Martini, *Reconstruction of the plasma surface in a RFP in presence of non-axisymmetric perturbations,* submitted to Plasma Phys. and Control. Fusion
[12] M. Valisa et al, Journal of Nucl. Materials **241-243**, 988 (1997)
[13] M.Valisa et al., *Plasma-wall interactions in RFX*, 17th IAEA Conf. on Plasma Physics and Controlled Nuclear Fusion Res. (Yokohama,1998) paper IAEA-F1-CN-69/EXP3/14