27th EPS Conference on Contr. Fusion and Plasma Phys. Budapest, 12-16 June 2000 ECA Vol. **24B** (2000) 444 -447

First FIR multichord Faraday rotation measurements in RFX

A. Murari,[1,2] M. O'Gorman,[3] A. Boboc,[1] L. Giudicotti,[1,2]
P. Innocente,[1] S. Prunty,[4] E. Zilli[1,2]

[1] Consorzio RFX, Corso Stati Uniti 4, 35127 Padova (Italy)
[2]INFM Padova, Dept. of Electrical Engineering,
Via Gradenigo 6/A 35131 Padova (Italy)
[3]Dept. of Physics, University College Cork, Ireland
[4]Dept. of Electrical and Electronic Engineering,
University College Cork, Ireland

Introduction

In the Reversed Field Pinch (RFP), the configuration results from the interplay between a magnetic field regeneration mechanism called dynamo, which is responsible for the reversal of the toroidal component of the magnetic field, and current resistive diffusion [1]. As a consequence of the resulting high level of current redistribution, the internal magnetic topology is largely determined by the plasma, the details of which are not fully known. Previously the RFP internal fields have been deduced by external magnetic measurements with the help of a steady state equilibrium model [1] (the so called μ&p model). The essential features of the poloidal field component have been experimentally confirmed by inserting pick-up coils into low current plasmas. Nonetheless, a systematic non-invasive investigation at higher currents is considered fundamental not only for the understanding of the configuration but also for its control.

This paper presents some preliminary investigations of RFP Faraday rotation angle profiles obtained by means of Far Infrared Polarimetry (FIR). This diagnostic provides a measurement of the Faraday rotation angle of a linearly polarised laser beam; this rotation angle ψ is related to the plasma parameters by the relation:

$$\Psi = K\lambda^2 \int n_e B_{\theta||} dl \tag{1}$$

where K=2.63 × 10^{-13} rad/T, λ is the wavelength of the FIR beam, n_e is the electron density, $B_{\theta||}$ is the component of the poloidal magnetic field parallel to the direction of the laser beam and the integral is calculated along the propagation path. From equation (1) it is apparent that, if the plasma density profile is known, the measurement can provide information on the component of the magnetic field parallel to the laser beam.

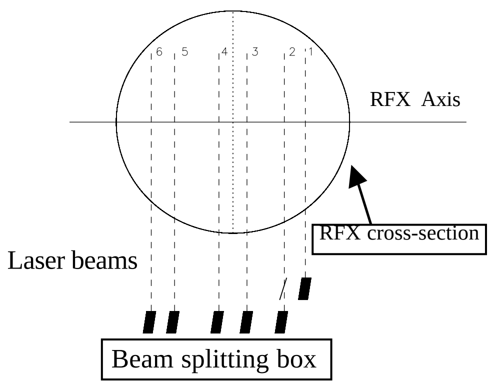

***Fig.1** Present Viewing chords of RFX polarimeter.*

In the next section, the measured Faraday rotation profile is shown for various steady state plasma conditions, allowing a comparison with the results of the μ&p model in several experimental regimes. In the following section the modification of the profile during transient phases, such as Pulse Poloidal Current Drive (PPCD) [2] or the setting-up and ramp-down of the plasma current, are presented. Some preliminary indications referring to advanced confinement conditions, which are also achieved transiently, are presented. Finally we conclude with a mention of the potential of the diagnostic to provide useful information on more detailed subjects, like the magnetic deformation due to the locked mode or the Quasi Single Helicity states (QSH).[3]

The Faraday rotation profile in steady-state conditions

In RFX [4], a large reversed field pinch (RFP) experiment with circular cross section (major radius R_0=2 m, minor radius a=0.46 m, target plasma current I_p=2 MA), a six chord polarimeter [5] has been installed and operated [6] during the main experimental campaigns of 1999. Five of the vertical chords (chord number 1 has not been completed; see Fig.1) have been proved to work satisfactorily and preliminary indications about the magnetic configuration and the perspectives of the diagnostic technique can be drawn.

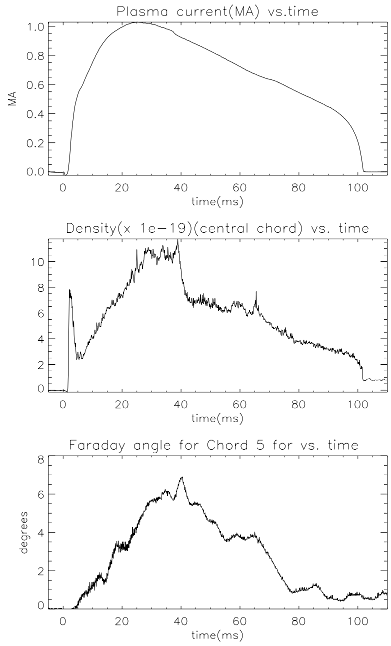

Fig.2 *Time evolution of plasma current, interferometric electron density and chord 5 Faraday angle.*

In Fig.2 the time evolution of the signal from one of the chords is presented, together with plots of the plasma current and central density, showing the satisfactory signal-to-noise ratio achieved and the general trend of the measurements. In Fig.3, the experimentally measured Faraday rotation values are compared with the simulated profile obtained from the μ&p model [1] for the steady state phase of a typical 800 kA discharge. In the simulations the inverted density profile has been included using the measurements of a 16 chord interferometer [7] located 30 degrees toroidally apart from the polarimeter. Furthermore, a first order toroidal correction to the cylindrical μ&p model, accounting for the effect of the plasma horizontal shift, has also been included.

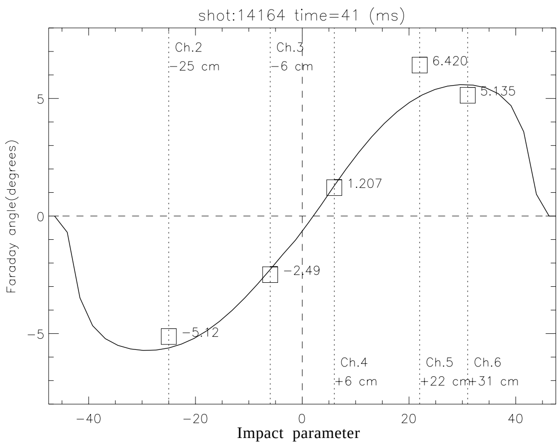

Fig.3 *Simulated Faraday rotation profile (continuous line) and experimental measurements.*

The agreement is good, with respect to the assumed current density profile for steady-state conditions. From Fig.4, where the measured values of the Faraday angle and the interpolation of the simulated ones are plotted versus the product I_p n_e for a central and an external chord, it can be deduced that, at higher densities and plasma currents, the signals on the external chords seem to be systematically lower than the simulation results, whereas the signals of the internal chords are well matched by the model. Preliminary investigations of this subject seem to indicate that, in several cases, a current density parameterisation different from the one foreseen by the monotonic μ profile may be necessary to simultaneously fit all the chords [8]. The relevance of the required modifications of the profile on the configuration stability analysis will have to be considered with great attention, for both steady state and transient phases.

The Faraday rotation profile during transient phases

Since the μ&p model is obtained solving the equilibrium MHD equations at steady state, it is a poor approximation during transient phases. The polarimetric measurements have been analysed during the start-up and the ramp-down of the configuration. In order to compare the experimental data with the model, a parameter quantifying the quality of the fit (QF) has been introduced with the following definition:

$$QF = \frac{1}{N}\sqrt{\sum_{i=1}^{N}\left(\frac{\left|\Psi_{pred}\right|_i - \left|\Psi_{real}\right|_i}{\left|\Psi_{real}\right|_i}\right)^2} \qquad (2)$$

where ψ_{real} are the experimental data and ψ_{pred} the results of the aforementioned code.

Lower values of this parameter correspond to a better agreement between the experimental points and the calculated Faraday rotation angle profile. As can be seen in Fig.5 where this parameter is analysed statistically, the discrepancy between experiment and model increases at the start-up with respect to steady state. On the other hand, the agreement between the measured and the calculated values improves during the ramp-down of the plasma current, when it is reasonable to assume the configuration to be nearer to the relaxed state foreseen by the model.

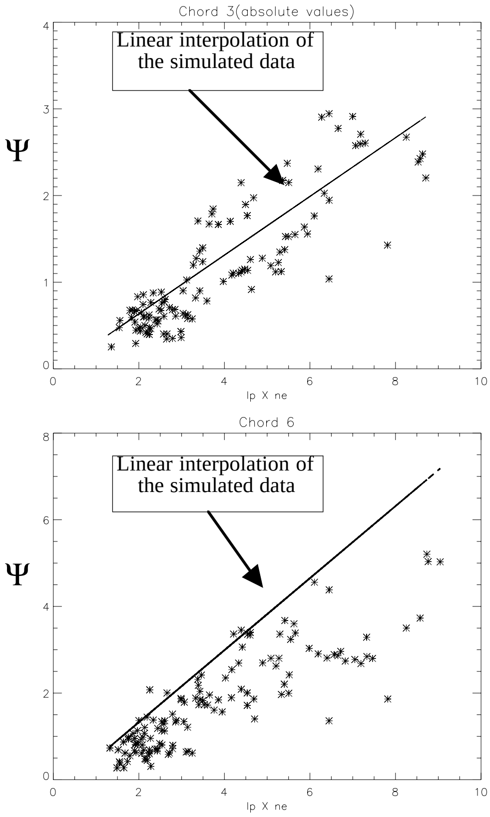

Fig.4 *Scaling of the Faraday rotation angle with the product of plasma current and electron density at steady state (asterixs indicate the experimental points).*

This analysis of the transient phases was conceived as a preliminary study of the important subject of the improved confinement regimes. In the RFP configuration indeed the improved performances, in terms of energy confinement, are obtained only transiently. These improvements are mainly achieved with Pulse Poloidal Current Drive (PPCD) [2], which consists of modifying the current density profile of the plasma via an externally induced variation of the toroidal flux. The positive results of this technique are believed to be due to a stabilisation of the dominant tearing modes, whose induced magnetic stochasticity is considered to be responsible for the poor energy confinement time of the RFP configuration. This interpretation of PPCD would profit very much from a direct measurement of the internal poloidal field variations during the transient phase.

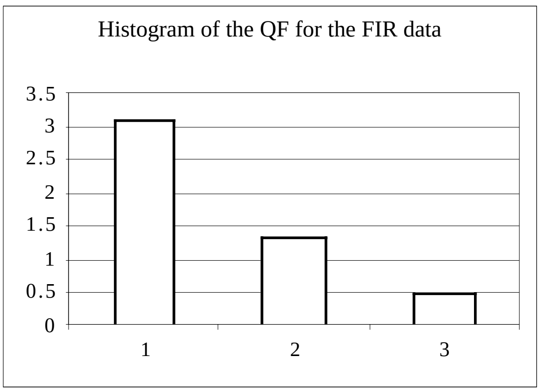

Fig.5 *Trend of the QF parameter at Start-up(1), Steadystate (2), and Ramp-down(3).*

At the moment the RFX polarimetric data base is too small to draw any definitive conclusion on this topic but, as shown in Fig.6, during PPCD the Faraday rotation profile is remarkably different from the one before and after this phase. This indicates not only that the current density profile is affected by PPCD but also that the polarimetric diagnostic is able to detect the modifications, within the limits of its time and spatial resolution.

Conclusions

The RFX polarimeter, operating on 5 of its 6 chords, has given satisfactory results, which have proved that a diagnostic based on the measurement of Faraday rotation can be applied to this magnetic configuration. The first data have demonstrated that such a diagnostic has the potential to provide essential information about some of the most important topics of present day research in this field. The polarimeter provides essential measurements for operation of an RFP, but also helps in understanding the conditions leading to improved confinement regimes (PPCD). Some positive indications have also been collected in advanced regimes, such as the Quasi Single Helicity states (QSH) [3]; the diagnostic has indeed shown results in agreement with the external magnetic measurements for the cases in which this state, dominated by a single unstable mode, was realised experimentally. It is therefore reasonable to expect that the polarimeter could provide important measures of the magnetic configuration associated with such states. In addition, the diagnostic is also sensitive to the so called locked mode, which is a static perturbation of the plasma column believed to be due to the phase locking of the main helical instabilities. Indeed, when the locked mode is located in front of the diagnostic or passes by it, the measurements are affected and the QF is seen to increase in the outer chords, showing a degradation of the agreement between measured and calculated data as expected. In conclusion a systematic use of this diagnostic in the RFP should provide some very useful information on the most important RFP research topics, which involve the plasma current profile and the ensuing magnetic field topology.

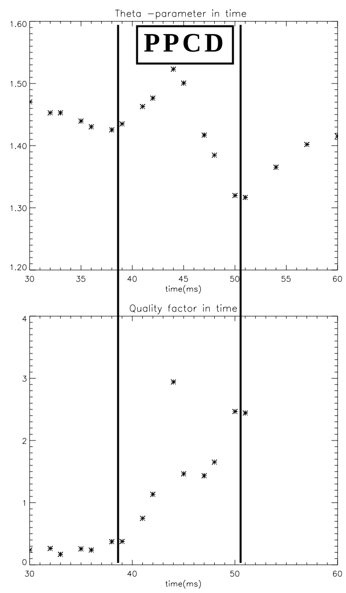

Fig.6 *Evolution of the quality factor QF during PPCD (for the theta parameter we adopt the usual definition* $\Theta = B_\theta(a)/\langle B_\phi \rangle$*).*

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