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Characteristics of the Magnetic Field Profiles Derived from Polarimetric Measurements in RFX

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In this paper we discuss the reconstruction of the plasma magnetic field profiles in the RFX reversed field pinch experiment from measurements of the Faraday rotation angle by a multichannel far infrared (FIR) polarimeter. The RFX FIR polarimeter has been described elsewhere[1,2]. It uses a CO_2-pumped methyl alcohol FIR cavity (λ=118.8μm) and measurements were performed on five parallel chords. The Faraday angle Ψ is related to the plasma parameters by the relation $\Psi = K\lambda^2 \int n_e B_{\parallel} dl$ where K= 2.63 × 10^{-13} rad/T, n_e is the electron density, $B_{\parallel}$ is the component of the magnetic field parallel to the laser beam and the integral is calculated along the propagation path. In RFX the electron density profile is measured by a multichannel CO_2 interferometer toroidally displaced by 30^0 from the polarimeter [3] and the spatial profiles of the poloidal and toroidal magnetic field components B_θ and B_z are calculated accordingly to the μ&p model [4], assuming the spatial profiles of the plasma pressure and of $\mu = \mu_0 \mathbf{j}\bullet\mathbf{B}/B^2$ are known. The μ&p model has been routinely applied to RFX discharges assuming a two-parameter μ profile of the type $\mu(r) = (2\Theta_0/a)[1-(r/a)^\alpha]$; here a is the plasma radius and Θ_0 and α are determined from the experimental values of Θ and F, the pinch and reversal parameters which characterize RFP plasmas. In many cases, the pressure profile has a small influence due to the low value of beta, and it is assumed to be flat (force-free approximation). In this paper we show that introducing the measured Faraday rotation angles as additional constraints it is possible to determine more reliable magnetic profiles. For this analysis the density profile is assumed to have axial symmetry around an axis displaced with respect to the geometrical axis of the vessel. The radius of the plasma column and its displacement δ from the center of the vacuum vessel are determined by interferometric measurements. The magnetic surfaces are also assumed circular but not concentric, their centers being linearly shifted from the magnetic axis position δ_m (given by the polarimeter [5]) and the plasma column axis position δ (given by the interferometer). In the cases considered, both shifts are of the order of 0÷3 cm, with δ smaller than δ_m. To exploit the additional information provided by polarimetric data, a set of more general, three-parameter expressions for the μ profile has been introduced, representing both monotonic and hollow profiles, such as for example:

$$\mu(r) = \frac{2\Theta_0}{a}\left\{1-\exp\left[-\alpha\left(1-\left(\tfrac{r}{a}\right)^2\right)\right]\right\}\left[1+k\left(\tfrac{r}{a}\right)^2\right]. \qquad (1)$$

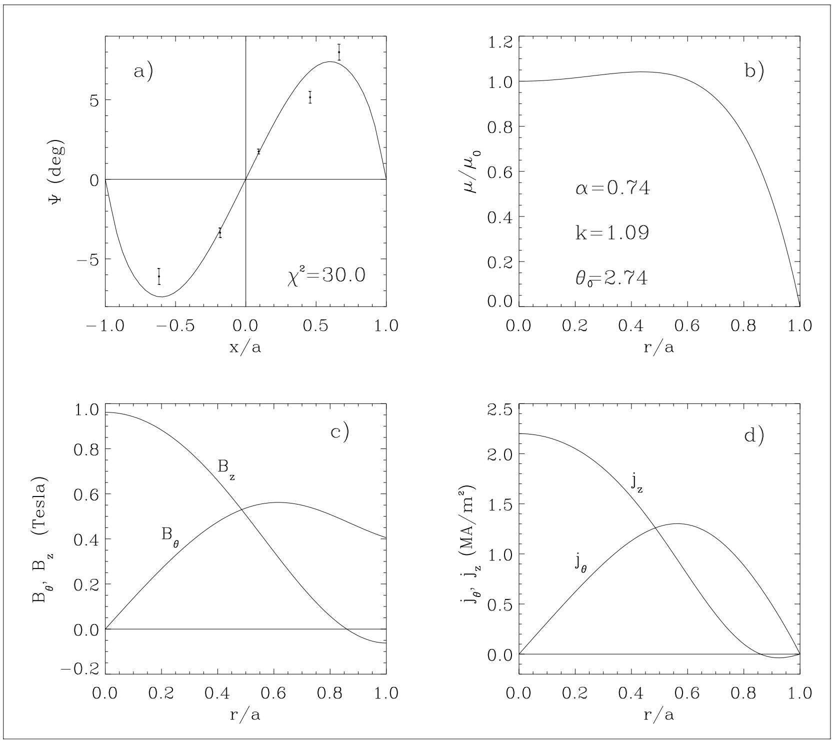

Fig. 1. Best-fit calculations with μ profile given by Eq.(1); a) comparison of the measured Faraday angles (points) with the calculated rotation profile (*x* is the distance of the chords from the center of the plasma column); b) μ profile; (c) poloidal and toroidal magnetic field profiles; (d) current density profiles.

The parameters α, k, ,Θ_0 are then calculated by minimizing the function

$$\chi^2(\alpha,k,\Theta_0) = \sum_i \frac{1}{\sigma_i^2}\left[F_i(\alpha,k,\Theta_0) - \Psi_i\right]^2 \tag{2}$$

where Ψ_i are the measured values of the Faraday angle on the five operating chords, σ_i are the measurement errors (standard deviations) and $F_i(\alpha,k,\Theta_0)$ are the values of the Faraday rotation angle calculated for each chord by the model. The experimental values of the RFP parameters Θ and F measured at the plasma boundary by magnetic diagnostics are imposed as constraints during the minimization. The best-fit minimization has been made with several expressions of the μ-profiles, finding very similar results: in many cases the set of parameters that minimize Eq. (2) corresponds to a hollow μ-profile, giving typically a χ^2 minimum value lower by a factor 3 compared to the conventional monotonic μ-profile used before. As an example, Fig.1 shows the results obtained with the μ-profile of Eq. (1) in a RFX discharge with a 1 MA plasma current (shot n. 14164). The reversal of the toroidal current density near the periphery, observed in Fig.1(d) is related to the assumption of a force-free model.

The best-fit calculation has been repeated at different times of the same discharge, in order to observe the evolution in time of the magnetic configuration. The time interval 11 to 74 ms from the discharge start has been considered, but best results are obtained from 20 ms to 50 ms, where both the polarimeter and the interferometer signals are stronger and less affected by noise. In this shot the results concordantly show an hollow μ-profile from the beginning to

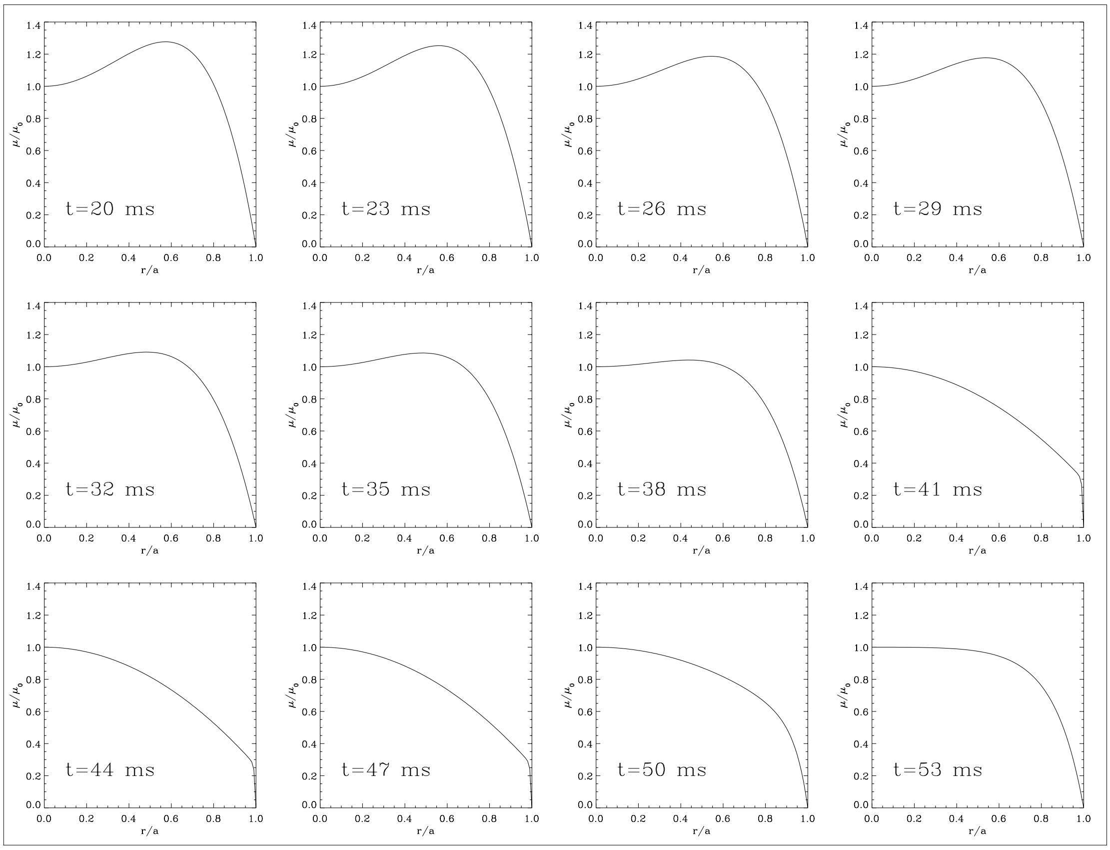

Fig. 2. Time evolution of the μ profile during the plasma shot. Eq.(1) is used

38 ms, then between 38 and 41 ms a sudden change to a monotonic profile is observed, lasting until the end of the discharge (Fig. 2). The electron density profile for this shot is also hollow, but it remains hollow for all the plasma duration. Its particular shape (peaked on the outside and nearly flat in the inner region) is sustained by gas influx from the graphite wall. There is obviously no direct link with the hollow profile of μ. The time evolution of main plasma parameters is reported in Fig. 3, together with the times chosen for the best-fit calculations. The μ-profile evolution may be explained in terms of a diffusion process of the magnetic field in the plasma: initially the current density is more peaked in a peripheric region of the column and then it penetrates inside the plasma with a characteristic diffusion time. Simulations have been done solving the resistive diffusion equation, using the reconstructed magnetic field profiles. The observed time evolution is consistent with a global diffusion time of the order of $\tau \approx 200$ ms, which agrees with the one calculated on the basis of a uniform Spitzer resistivity ($\eta \approx 4\div5$ x10^{-7} Ω•m). It is also observed that the sudden change to a monotonic μ profile at about 40 ms is accompanied by a sudden fall of the electron density. This particular behaviour of the electron density is dominated by the presence of a phase and wall-locked mode in the plasma column [6]. In the first 40 ms the mode is localised in a fixed toroidal position not far from both the polarimeter and interferometer

positions, giving a persistent interaction with the wall, which produces a large particle influx. Consequently, the electron density becomes very high. Then, the locked mode suddenly changes its toroidal position and starts rotating under the drive of an external m=0 magnetic perturbation [7]. As a consequence, the local gas influx and the electron density decrease. These results show that the FIR polarimeter is an effective tool to study the magnetic field dynamics in RFX. In particular, in non perturbative way, it provides evidence of details of the μ profiles, such as the hollow shape already observed by perturbative internal probes in previous RFP experiments [8]. It has also been shown that the diagnostic is sensitive to changes due both the magnetic field diffusion and the locked mode dynamics of RFX plasmas.

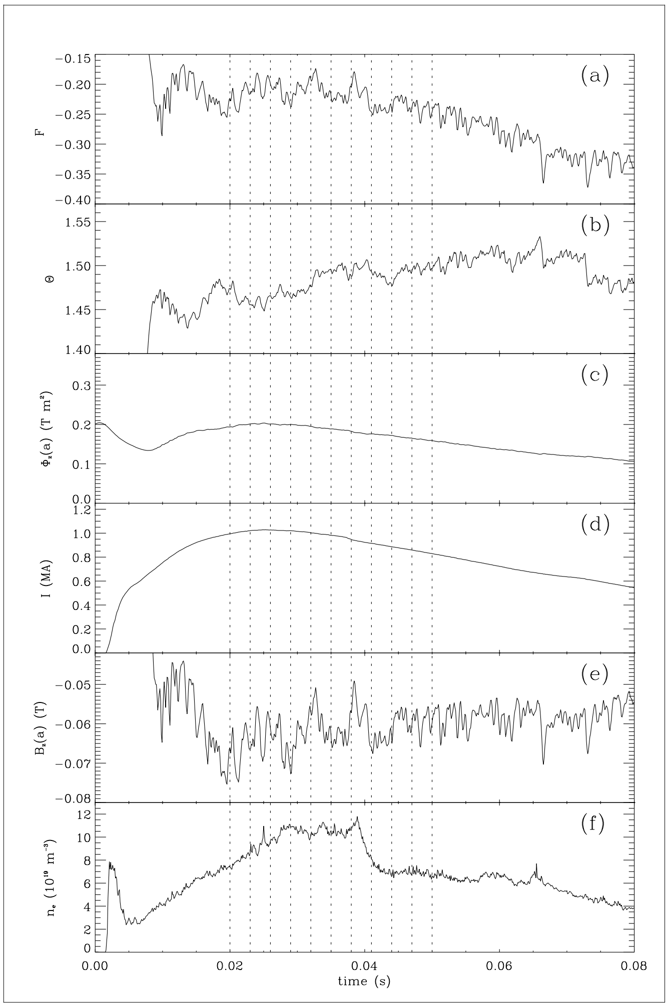

Fig. 3. Time evolution of some plasma parameters: (a) F, (b) Θ, (c) toroidal magnetic flux, (d) plasma current, (e) toroidal magnetic field at the wall, (f) electron density.

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