33rd EPS Conference on Plasma Phys. Rome, 19 - 23 June 2006 ECA Vol.**30I**, P-5.107 (2006)

Integration of the new reflected channels of the Tore Supra polarimeter for current profile analysis

D. Elbèze, C. Gil, F. Imbeaux

Association EURATOM-CEA, DSM /DRFC, Cadarache, 13108 St Paul lez Durance France

Introduction

Precise knowledge of safety factor *q* profile is required for the analysis of fusion experiments, since it is a key parameter for plasma performance. At Tore Supra, a FIR interferometer – polarimeter diagnostic is routinely used to determine electron and current density profiles by the way of the refraction and the Faraday effect of two sub-millimetre beams (119 and 195 µm) crossing the plasma. The inversion of the polarimetric integrated measurements to obtain the current profile and then the *q* profile needs an accuracy of 0.06° and a large number of lines of sight in order to obtain a reliable profile shape [1]. Since 2005, five new nearly horizontal reflected chords have been installed to improve the spatial resolution of the five nearly vertical already existent ones. Figure 2 shows the positions of the chords. This new system has been designed for long pulse operations, including actively cooled components. Its geometry is very close to the expected ITER polarimeter and thus, the associated post-processing issues are similar.

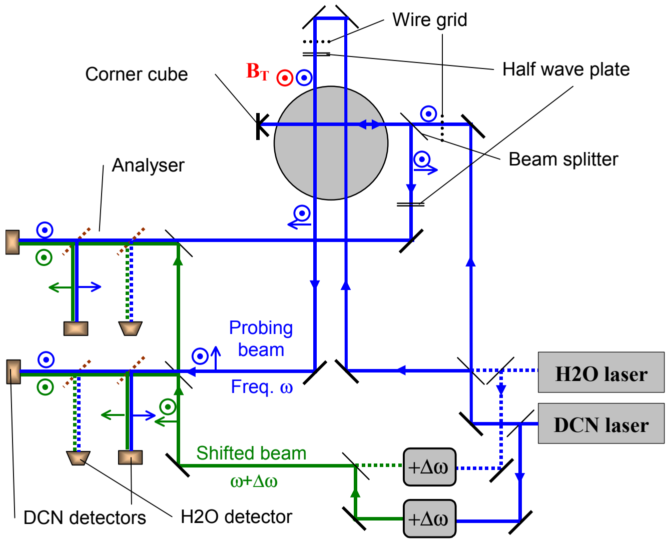

Fig. 1 – The Tore Supra interfero-polarimeter

Reflected chord main characteristics

Internal actively cooled corner cube mirrors reflect the beams of the new chords on themselves, which thus cross twice the plasma. Then, kapton films are used to separate the reflected beams from the incident ones. In order to be effective, the calibration half-wave plates are located after the beam splitters [2].

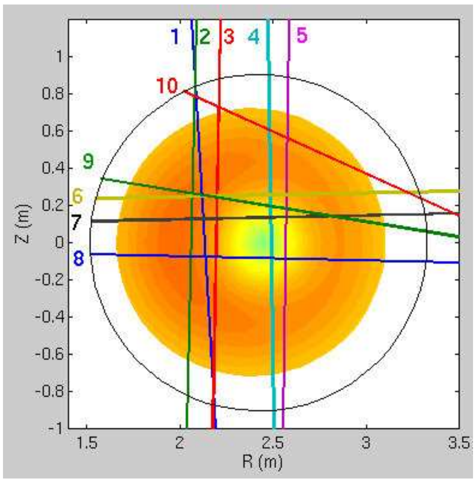

Fig. 2 – Position of the traversing and the reflected chords.

Cotton-Mouton effect

The interferometer measures the phase shift of the wave when crossing the magnetised plasma. The measured phase shift is the integral along the line of sight of the electron density n_e: $\Delta\Phi = C_1\lambda\int n_e dl$, where C_1 is a constant and λ, the wavelength. The polarimeter principally measures the Faraday rotation angle of the wave polarisation: $\alpha_F = C_2\lambda^2\int n_e B_{//} dl$ where C_2 is a constant and $B_{//}$, is the propagation parallel component of the poloidal magnetic field, B_p. But the polarimetric angles are also affected by the Cotton-Mouton effect which makes elliptic the polarisation and which is sensitive to the square of the magnetic field $B_\perp$ that is perpendicular to the propagation: $\varphi_{CM} = C_3\lambda^3 \int B_\perp{}^2 n_e dl$. So, as long as beam polarisation is linear and parallel to the total magnetic field, it does not become elliptic. But, due to the Faraday effect, the polarisation direction rotates and, then, becomes elliptic. The phenomenon increases as the wave is propagated and as the electron density is high (figure 3). Because the toroidal magnetic field is larger than the poloidal one, the incident polarisation of the Tore Supra polarimeter beams is toroidal in order to be nearly parallel to the total field and this minimises the Cotton-Mouton contribution [3]. Notice that the polarimetric angles of the reflected chords, which cross twice the plasma, are more sensitive to the Cotton-Mouton effect and must be corrected in the inversion and reconstruction codes because of the 0.06° needed accuracy.

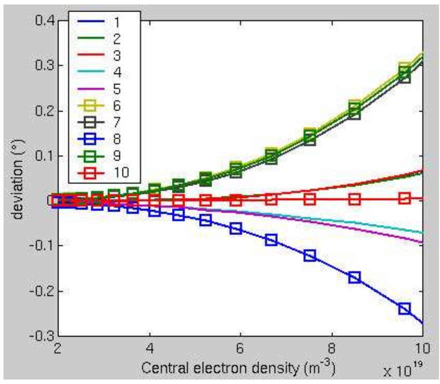

Fig. 3 - Cotton-Mouton effect in degree on the polarimetric angles vs central electron density

Ripple effect

The toroidal magnetic field, B_T, is produced by a discrete number of coils and thus is slightly modulated between the coils. This modulation geometrically induces that B_T is not perpendicular to the poloidal field B_p except in the middle of two toroidal coils for reason of symmetry. Then, due to this ripple effect, $B_{//}$ is not deduced from B_P only and the polarimetric measurements can be significantly modified in particular at Tore Supra where the ripple can reach up to 5%. Because the traversing chords are positioned in a poloidal plan at the middle of two toroidal coils, the B_T poloidal projection is very small and B_p is not modified. But it is not the case for the new reflected chords, which are situated in a poloidal plan, which has a 3.5° angle with the middle plan (figure 4). In this plan, the B_T ripple significantly modifies $B_{//}$ in particular at the low-field side (figure 5). The ripple effect is negligible at the high-field side and this dissymmetry increases the deviation on the polarimetric angles. Thus, if the chords were vertical, the B_T ripple at the top of the plasma would compensate for that at the bottom. Figure 6 shows, for different values of the toroidal magnetic field,

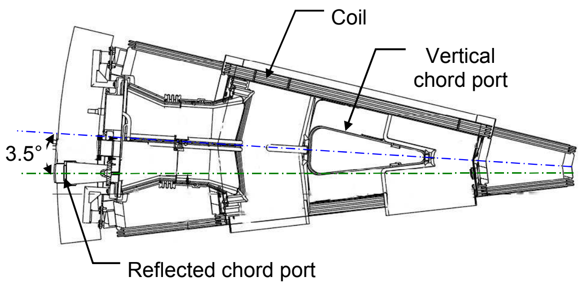

Fig. 4 – Top plan of chord port implantation

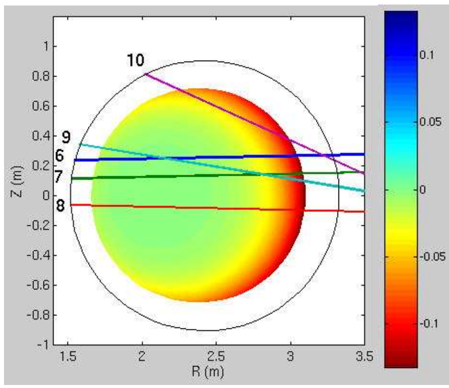

Fig. 5 – B_T poloidal component (in T) due to the toroidal ripple in the incident plan of the reflected chords

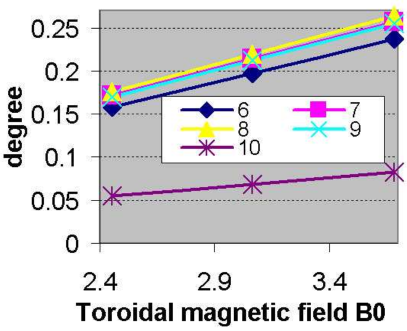

Fig. 6 – Ripple correction to polarimetric angles of reflected chords

the ripple induced deviations to the polarimetric angle, which are not negligible for the reflected chords and must be corrected in the inversion and reconstruction codes. In a same way, for ITER polarimeter, if the corner cube mirrors are not strictly at the middle between two coils, the ripple effect should be taken into account in the polarimetry inversion.

Current profile evaluation

The current density, and then the q profile, can be estimated in real time or just after the pulse by the measures of the polarimetry, the interferometry and the magnetic diagnostics. For real time, we use the Brüssau and Soltwisch technique using the normalised Faraday angles, A_i, of two vertical chords to find the current density profile peaking, $piqj$. The peaking is calculated for two chords i and j situated on both sides plasma centre by polynomial regression: $piqj = f_{pol}\left(\mathrm{A}_i - \mathrm{A}_j, R_{ci} - R_{cj}, R_{ci}{}^3 - R_{cj}{}^3\right)$ where $\mathrm{A}_i = C\dfrac{a}{I_P R_0'}\dfrac{R_{ci}\alpha_i}{nl_i}$, $R_0' = \sqrt{R^2 - a^2}$ and R the major radius, a the minor radius, I_p the total current, R_{ci}, the i-chord major radius, α_i the polarimetric angle, nl_i line electron density [4]. We extend this method for multiple horizontal chords and determinate the new coefficients of the regression for the four first reflected chords (the last one is too external). We do not need to use two chords because the non-cylindrical effects (Shafranov shift) are integrated along a horizontal chord: $piqj = f_{pol}\left(\mathrm{A}_i, \rho_i, \rho_i{}^3\right)$ where $\mathrm{A}_i = C\dfrac{aR}{I_P R_0'}\dfrac{\alpha_i}{nl_i}$ and ρ_i, the normalized minor radius.

As we can see figure 6, the real time calculated minimum of q deduced by $piqj$ is very similar with that obtained by polarimetry inversion. Thus, the combination of one couple of traversing chords and four single horizontal ones give more confidence in the evaluation of the current density peaking and an indication of the minimum of q can be estimated in order to observe significant changes of the current profile.

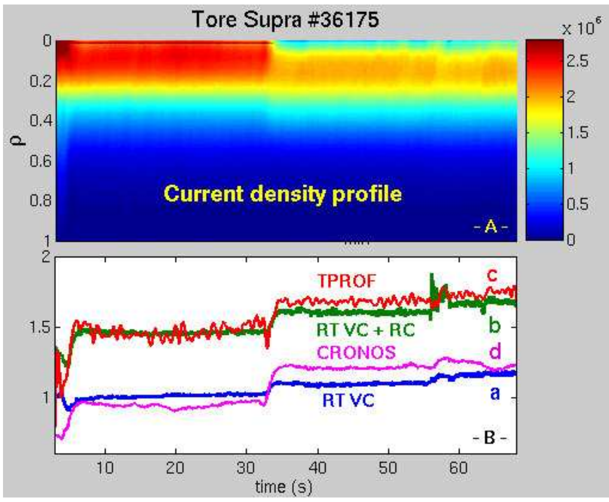

Fig. 6 – A - Current density profile given by CRONOS code and- B - Evaluation of the minimum of the safety factor q a) in real time with the traversing chords only, b) in real time with the new chords, c) by TPROF inversion with the ten chords, d) given by CRONOS code

Comparison with CRONOS reconstruction

The polarimetry measurements are used to validate the current profiles obtained using the integrated modelling code CRONOS. Using the current profile deduced from current diffusion and a prescribed electron density profile, CRONOS recalculates the polarimetric angles that should be measured by the diagnostic.

Chord	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
$\lvert\alpha_{F\_CRONOS}\rvert - \lvert\alpha_{F\_meas}\rvert$ (°)	-0.10	-0.13	-0.03	0.00	-0.21	0.37	0.61	0.25	0.04	-0.05
$nl_{CRONOS} - nl_{meas}$ ($10^{19}m^{-2}$)	0.03	-0.01	0.01	0.03	0.05	0.16				-0.05

Tab. 1 – Discrepancy of CRONOS reconstruction for the absolute values of polarimetric angles and for line electron density- Tore Supra shot 36175

Notice that when the difference between *nl* measurements and CRONOS reconstructions is high (i.e. chord 6 in table 1), the difference on polarimetric angles is great as well.

Plasmas with high fraction of Lower Hybrid current drive (~80%) are routinely produced in Tore Supra. The current density profile depends thus strongly on the LH power deposition. We investigate below the sensitivity of polarimetric measurements to possible variations of the LH driven current density profiles j_{LH} (Fig. 7).

A small change of the central value of j_{LH} (#1 on Fig. 7) is barely detectable, only chord 4 sees a significant change. Conversely, changes of j_{LH} corresponding to cases #2 and #3 (Fig. 7) induce detectable variations of the polarimetric angles measured essentially by the new chords, which are tangent to the rho = 0.1 – 0.3 surfaces. Therefore the recently added lines-of-sight should help in detecting relative variations of the core current density profile in the non-inductively LH driven plasmas of Tore Supra. Absolute comparison of polarimetric angle to their simulated value (using a given current profile) remains difficult. Discrepancies remain, which may be due to uncertainties in the density profile used for the reconstruction. This issue of absolute comparison between simulation and experiment will be investigated in future work.

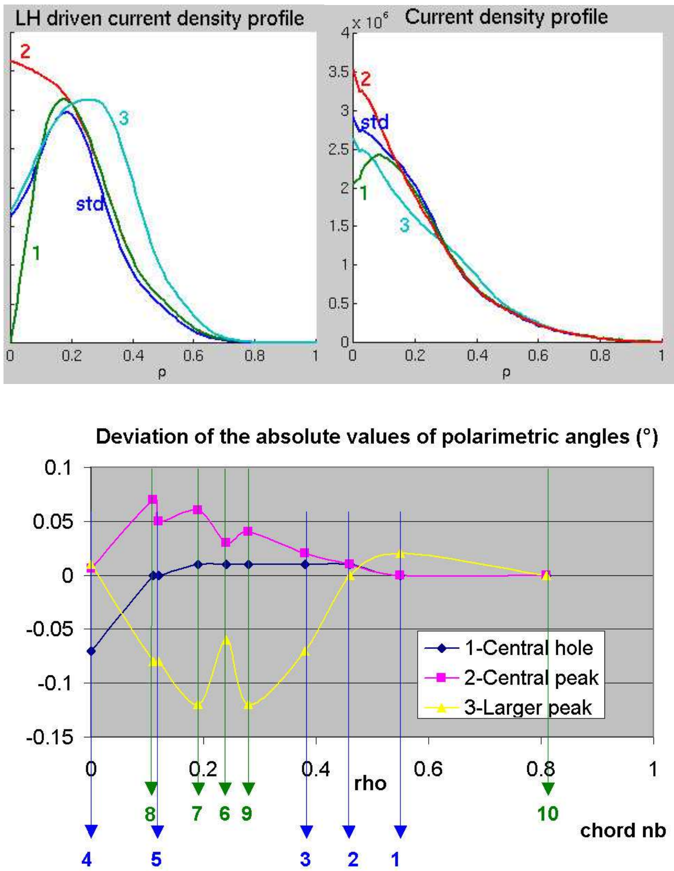

Fig. 7 – Different shapes of LH driven current density profile used in CRONOS code and deviation of the absolute values of polarimetric angles in degree for various shapes of LH driven current density profile

Conclusions

Because the reflected beams cross twice the plasma, the Cotton-Mouton alteration to the polarimetric measurements can be significant (up to 0.3° at Tore Supra and much more for larger and density higher plasma). Because the polarimetry incidence plan does not locate at the middle of two magnetic coils, the toroidal ripple modifies the polarimetric measurements (up to 0.3°). Then, the inversion and reconstruction codes using the polarimetric angles have to take into account the Cotton-Mouton effect and the ripple of the toroidal magnetic field. The new set of measures not only improves the spatial resolution and the measurement inversions but also allows us to evaluate the value of the minimum of *q* and contributes to validate the results of current diffusion simulations.

[1] T. Aniel et al, Proc. EPS 2002

[2] C. Gil et al, SOFT 2000

[3] L. de Pasqual, priv. Com. CEA 2004

[4] W.D. Brüssau, H. Soltwisch, IPP, 1985