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Models Comparison for JET Polarimeter Data

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** See annex of M.L. Watkins et al, "Overview of JET Results ",*
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ABSTRACT.

A complete comparison between the theory and the measurements in polarimetry was done by using the Far Infrared Polarimeter at JET. More than 300 shots were analyzed, including a wide spectrum of JET scenarios in all critical conditions for polarimetry: high density, high and very low fields, high temperatures.

This work is aimed at the demonstration of the robustness of the theoretical models for the JET polarimeter measurements in the perspective of using these models for ITER like plasma scenarios.

In this context, an assessment was performed on how the line-integrated plasma density along the central vertical chord of FIR polarimeter could be evaluated using the Cotton-Mouton effect and its possible concrete use to correct fringe jumps of the interferometer.

The models considered are: i) the rigorous numerical solution of the Stokes propagation equations, using dielectric tensor evaluated from JET equilibrium and Thomson scattering [1,2]; ii) two types of approximated solutions [2,3] and iii) the Guenther empirical model [4] that considers the mutual effect between Cotton-Mouton and Faraday rotation angle. The model calculations have been compared with polarimeter measurements for the Cotton-Mouton phase shift.

The agreement with theory is satisfactory within the limits of experimental errors [3].

1. THE JET POLARIMETER SYSTEM

The JET polarimeter, even if sharing the FIR interferometer optical path, takes independent measures by employing different processing electronics and using polarimetric optical principia [1]. In fact the polarization of an electromagnetic wave passing through the plasma changes producing Cotton Mouton and Faraday rotation effects. In particular the Cotton Mouton phase shift angle is related to the plasma behavior similar to a birifrengent medium. This paper presents calculations of Cotton-Mouton angle using different models and compare them with the entire set of available JET polarimetric measures, which includes a wide range of plasma conditions.

2. SOLUTION OF STOKES EQUATIONS (RIGOROUS SOLUTION)

We can briefly consider the three components [1,2] of the Stokes vector $\vec{S}$ when the laser beam is propagating along a vertical chord (z axis) in a poloidal plane. The components of $\vec{S}$ can be expressed in terms of ellipticity (χ), related to the Cotton Mouton phase shift angle (Φ), and Faraday rotation angle (Ψ), through the following equations: $S_1 = \cos 2\chi \cos 2\psi$, $S_2 = \cos 2\chi \sin 2\psi$, $S_3 = \sin 2\chi$ while the propagation of polarization is defined by the Stokes equation:

$$\frac{d\vec{S}}{dZ} = \vec{\Omega} \times \vec{S},\ \ \vec{\Omega} = \vec{\Omega}(n(z, t), \vec{B}).$$

The $\vec{\Omega}$ vector depends upon plasma parameters: the components in the Stokes space are: $\Omega_1 \propto n_e B_t^{\mathbf{2}}$, $\Omega_2 \propto n_e B_r B_t$, $\Omega_3 \propto n_e B_z$; where $\vec{B}$ is the magnetic field whose components for Tokamak configuration are r for radial, t for toroidal and z for vertical, and n_e is the electron density.

If it is supposed, as in the present paper that the two effects are not mutually interacting, and using the definition of the Stokes vector it is possible to obtain simple relations for Faraday rotation (Ψ) and Cotton Mouton phase shift (Φ) angle: $S_2 / S_1 = \tan 2y\ meas$, $S_3 / S_2 = \tan f\ meas$.

In particular case of JET, for each vertical chord, the two measurements of Faraday rotation and Cotton Mouton angle can be expressed respectively as follows:

$$\Delta\Psi \approx \lambda^2 \int n_e B_{p\|} dz, \quad \Phi \approx \lambda^3 B_t^2 \int n_e \, dz.$$

3. APPROXIMATED SOLUTIONS: TYPE 1, TYPE 2 AND EMPIRICAL MODEL

Defining the quantities $W_i = \int_{z_0}^{z_1} \Omega_i (z)dz$ in the hypothesis $W_i << 1$ a simple approximation to solve [2] the equation of propagation is found to be $W_3 = C_3 \int n_e B_{\|} dz = -1 \tan 2\psi$ and $W_1 = C_1 \int n_e B^2{}_T dz = \tan \phi$. In this approximation, called Type I, the Cotton-Mouton phase shift angle results proportional to the line integral of plasma density. To check JET polarimeter data, a first task was to extract the line-integral density from the Cotton-Mouton measurement and to compare it with the one delivered by the other two diagnostics operating at JET: LIDAR Thomson Scattering (TS) and FIR interferometer. The figures 1(a), and 1(b) show that the agreement is very good. Moreover comparing the two graphics we can roughly estimate the error bar associated to the polarimeter density measures, it results of the order of $\approx 2\ 10^{19}\ m^{-2}$, 0.5×10^{19} larger with respect to the LIDAR TS resolution. The proportionality coefficient C_1 resulting is lightly overestimated (0.0019) respect of the expected one (0.0018).

Introducing the relation [2,3] $\Omega_3 > \Omega_1 >> \Omega_2$, that is almost always verified in tokamak configuration plasmas, the solution to the Stokes equations can be found: $s_1 = -\sin W_3$, $s_2 = \cos W_3$ and $s_3 = \int_{z_1}^{z_2} \Omega_1(z')\cos W_3 (z')dz$. It means that Faraday rotation effect is much larger than the Cotton-Mouton, this model is called Type 2 approximation.

Finally, if α is the measured Faraday rotation angle, ϕ_{CM} the measured Cotton-Mouton phase shift angle and ϕ the pure Cotton-Mouton angle, the differential equation $d\phi = d\phi_{CM} - (\sin 2\phi / \tan 2\psi)\, d\alpha$ gives the correction applied to the measured Cotton-Mouton to obtain the pure Cotton-Mouton angle. This is the so called empirical model [4],

4. MODELS COMPARISON

The figure1(c) shows the comparison between Cotton-Mouton experimental data from polarimeter vs rigorous numerical solution, while the figure 1(d) shows the experimental data vs Type 1 solution. The data for all the models are calculated from EFIT equilibrium together with density taken from LIDAR TS. In figure 1(e), the impressive accordance between Type 1 versus Type 2 model indicates that both are good approximations and that the assumptions done for Type 2 model are correct. For the Empirical model we have to distinguish two cases: the general case is shown in figure 1(f), i) it is observed a worse approximation for the most part of measures respect of other models, ii) nevertheless if it is considered a selected sub-set where the difference in terms of density is less then one fringe jump for high density measures, the model applied gives better results [5].

5. FRINGE JUMPS CORRECTION

In fig.2.a an example of attempt to correct JET interferometer fringe jumps by using polarimeter data is shown for the central chord #3 shot #61049. At JET a post processing software operates from many years in order to counter the problems of the fringe jumps but with limitations, in fact several fringe jumps are slipped. This work is under development at present, in fact using polarimetry not all the signals result recoverable due to different reasons, for example the timing resolution of polarimeter is lower than interferometric signal, so the presence of more fringe jumps in a restricted interval of time can cause elaboration problems.

CONCLUSION

A wide statistical analysis, more than 300 JET shots covering a wide range of plasma conditions, leads to the comparison of all the existing models for polarimetry. Polarimeter measures result reliable and in accordance with models.

Cotton Mouton phase shift can provide information on the line integral density also using approximated solutions and it can be used to correct interferometer fringe jumps.

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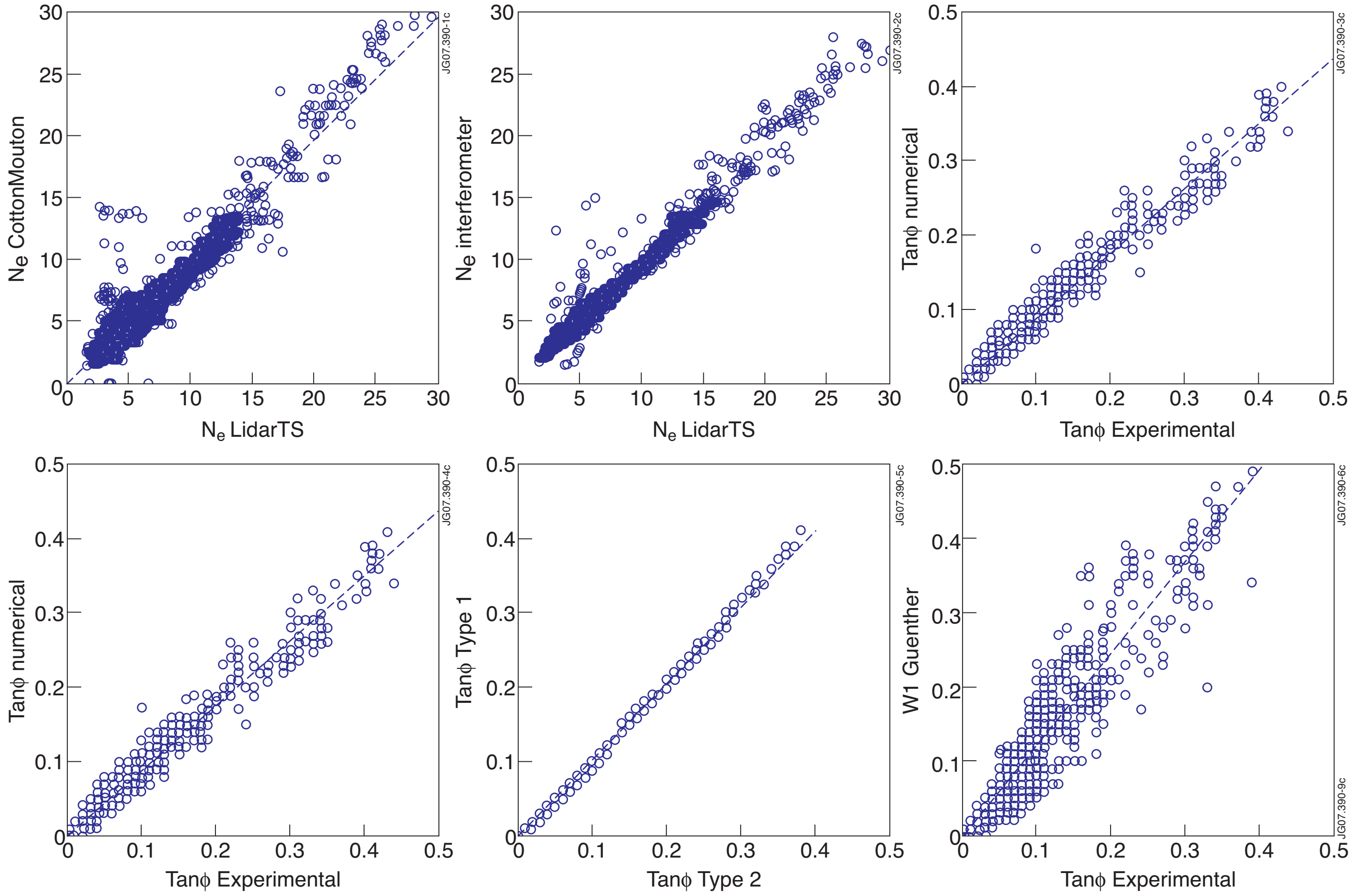

Figure 1: From left at high, (a) electron density comparison between LIDAR TS and polarimeter measurements, the density is expressed in $10^{19}m^{-2}$; the resolution is scarcely lower respect of the interferometer ones (b). At right (c) the tangent of Φ measured by polarimeter versus numerical solution: it is almost identical to the figure (d) of the Type 1 approximation. In figure (e) Type 1 versus Type 2 solution has an impressive accordance. Figure (f) the Empirical model is in general worse than the others ones.

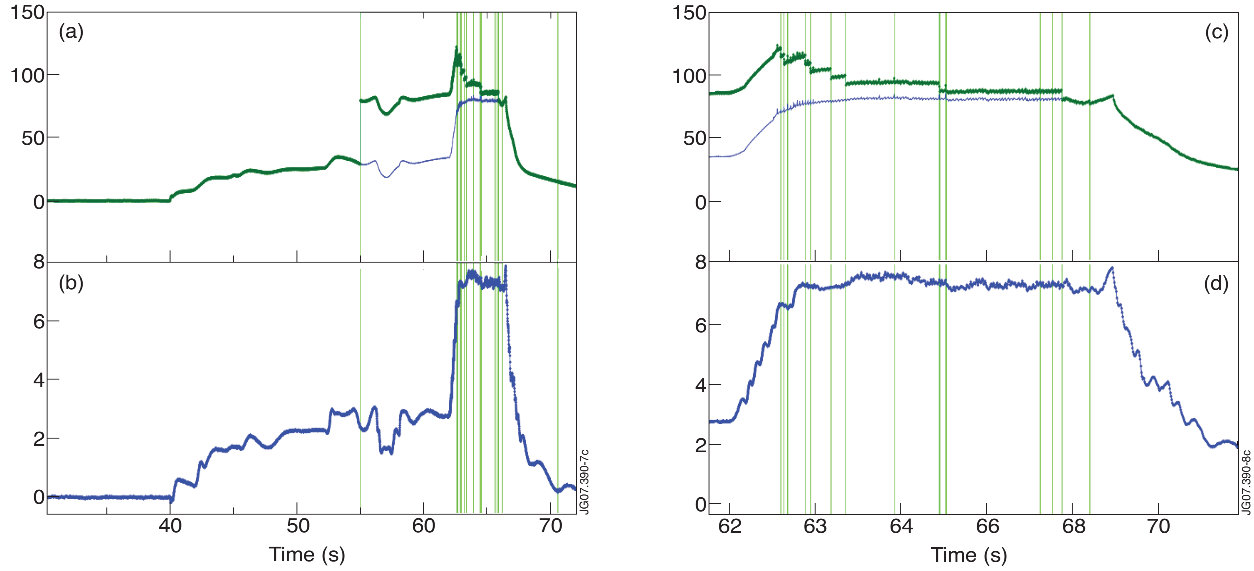

Figure 2: At left figure (a) electron density signal from interferometer: dark green line from JET ppf signal, blue is the same signal but with the correction of the polarimetry. At low, figure (b) signal from polarimeter is the blue line, all the verticals light green lines indicate possible fringe jumps resulted comparing with the interferometric signal (fig(a) at high). Subsequent controls return only ten real fringe jumps, the most evident is at 15s, enlarging the imagine (figures (c), (d)) less evident fringe jumps are corrected in the interval 22-28 secs.