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* See annex of F. Romanelli et al, "Overview of JET Results",
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ABSTRACT

In the past, the analysis of JET polarimetry measurements were carried out only for the vertical channels using a polarimetry propagation code based on the Stokes vector formalism[1,2]. A new propagation code has been developed therefore for the lateral chords to simulate and interpret the measurements of the Faraday rotation and Cotton-Mouton phase shift in JET. The code has been used to develop a theoretical study to the effect of the input polarization on the eventual quality of the measurements. The results allow choosing the best polarization to optimize the polarimetric measurements for the various experiments.

1. INTRODUCTION

A magnetised plasma is an optically active and birifringent medium. If a laser beam is sent into the plasma, the beam experiences the Cotton Mouton effect [3,4], proportional to the magnetic field perpendicular to the propagation direction, since this is the field which interacts with the birefringence of the medium. The polarization of the beam is subjected also to the Faraday effect, due to the magnetic field parallel to the direction of propagation. The principal interest of these measurements is given by fact that they allow to acquire information on the plasma magnetic fields distribution using internal measurements. The change of the polarization state of an electromagnetic wave can indeed be used to provide indications about the magnetic field distribution, the plasma current and the electronic density. The interpretation of the Faraday rotation and Cotton-Mouton effect measurements is however not a simple task. Suitable propagation codes are required to model the behaviour of the electromagnetic radiation inside the plasma. Such a propagation code has been validated for JET polarimeter vertical channels [1]. The same approach is used in this paper to investigate the effects of the input polarization on the measurements of the lateral channels of JET diagnostic. The initial polarization state of the laser beam is indeed an important characteristic of the electromagnetic radiation sent into the plasma to probe it. The results obtained allow choosing the best polarization to optimize the polarimetric measurements for the various experiments. The analysis presented in this paper is particularly relevant, since JET is the only existing polarimeter with channels of a topology similar to ITER's. The present paper is organized as follows: in section 2 a brief description of JET polarimeter is given; in section 3 a brief description of the propagation code is presented; in section 4 the simulation of the change of polarization state and some results for a significant shot are presented. Finally the conclusions are the subject of section 5.

2. A BRIEF DESCRIPTION OF JET INTERFEROMETER POLARIMETER

The system consists of eight channels, four vertical and four lateral, which measure both the electron density by interferometry and the Faraday rotation angle and Cotton Mouton effect by polarimetry[5]. A Deuterium Cyanide laser at 195μm is split into a probing beam and a reference beam, which is modulated by a rotating wheel at 100kHz. In normal operation, to perform measurements of the Cotton Mouton angle, the initial linear polarization of the input beam is fixed at 45° with respect

to the toroidal field direction. In the case of the lateral views, a second laser, with wavelewngth of 119μm, is used as compensation laser. The initial polarization state of the input laser beam is different for the lateral channels: it is fixed to parallel, linear polarization at 0°, with respect to the toroidal magnetic field. New algorithms have been recently developed to analyse the calibration data of the system [6].

3. THE THEORETICAL MODEL IMPLEMENTED IN THE PROPAGATION CODE BASED ON STOKES FORMALISM.

As is well known [7], the state of polarization of radiation propagating in a magnetized plasma, in the absence of dissipation, is described by the Stokes vector equation [5, 8]:

$$\frac{d\vec{s}}{dz} = \vec{\Omega} \times \vec{s} \tag{1}$$

where the Ω-vector is expressed as:

$$\vec{\Omega} = ka(\Omega_1, \Omega_2, \Omega_3) \tag{2}$$

and the three components are equal to:

$$\Omega_1 = C_1 n_e (B_x^2 - B_y^2);$$
$$\Omega_2 = 2C_1 n_e B_x B_y; \tag{3}$$
$$\Omega_3 = C_3 n_e B_z;$$

where B_x, B_y and B_z are the magnetic field components expressed along the laser beam propagation direction (z), ne is the electronic density (m^{-3}), $C1 = 1.74 \times 10^{-22}$ and $C3 = 2 \times 10^{20}$ are constants calculated for a laser wavelength of 195μm, $Z_p = z_p/ka$ is the normalized coordinate with respect to the vertical position z_p of the i-esim chord, with k the elongation and a the minus radius of the tokamak. In eq. (1) the z-axis, as already said, is the direction of the laser beam propagation, and so the best way of expressing the components of magnetic field is using system of toroidal coordinates. So in this case the radial components (B_r) is parallel to the laser beam direction, while the toroidal (B_t) and poloidal (B_p) components are orthogonal to the propagation direction. Under these assumptions the propagation equations can be written as:

$$\dot{s}_1 = 2C_1 n_e \cos(\alpha) B_p B_t s_3 - C_3 n_e \cos(\alpha) B_r s_2$$
$$\dot{s}_2 = -C_1 n_e (B_t^2 - (\cos(\alpha) B_p)^2) s_3 + C_3 n_e \cos(\alpha) B_r s_1$$
$$\dot{s}_3 = C_1 n_e (B_t^2 - (\cos(\alpha) B_p)^2) s_2 - 2C_1 n_e \cos(\alpha) B_p B_t s_1$$

where it has been assumed that the laser beam is sent into the Torus at an angle (α) with respect to radial magnetic field direction.

2

The polarisation angle (ψ) and the phase shift (φ) then can be expressed in terms of the components of the Stokes vector by the following equations:

$$\frac{s_2}{s_1} = \tan 2\psi \qquad \frac{s_3}{s_2} = \tan \varphi \qquad\qquad (5)$$

RESULTS AND CONCLUSIONS

Starting from the propagation equation 4 and for the geometry of the lateral chords, a solution for the lateral channels can be found. In order to validate the output of the code, a comparison with the experimental Faraday angle has been performed. In order to evaluate the effects of the change of input polarization on the polarimeter measurements, the results of the measurements have been simulated for a relevant shot. In the case of the lateral chords, the laser beam crosses the torus chamber of JET facility with an initial linear polarization at 0° with respect to the toroidal field direction. The developed propagation code is used to simulated the effects of the input polarization on the Faraday angle and the Cotton Mouton Phase shift for eight additional cases, simulating an initial linear polarization state at 1°, 15°, 30°, 45°, 60°, 75°, 85 and 91° with respect to the toroidal field. In our case, channel 7 has been simulated. In the plots of Figure 2,3, 4 and 5, the more relevants simulated input polarization states for the Faraday angle (2) and the Cotton Mouton Phase shift (3) are compared with experimental data for steady state phase of the discharge. The plots show two extremely evident facts:

1) A good agreement between Fadaday angle and numerical simulation is found at polarization state equal to the experimental value(red line) and the recalibrated experimental data (blue line). The Faraday angle (FAR Figure 3) seems not to be much influenced by the change of input polarization of the laser beam up to 30°. Only an increase of the signal appears at steady state for input polarizations between 30° and 75° degree;

2) The Cotton Mouton phase shift (PH Figure 5) shows a higher dynamic range of variation with the input polarization state of the laser beam. Only few degrees are enough to increase the simulated value of phase shift of 4 times. The variation of PH shows a periodic dependece for every quadrant (PH at 1° is equal to PH at 91°). The best agreement between simulations and experimental data (green line) in this case coincides with the polarization state indentical to that of the experimental measurements of the recalibrated Cotton Mouton (blue line).

This change in dynamic range suggests the possibility to use different input polarization states of the polarimeter laser beam in order to optimise the measurements depending on the experimental scenario. For example, in the case of high current experiments, where high variations of the refractive index of the plasma are aspected, probably the best choice of input polarization is 0° as currently done on JET. In other cases, where lower values of the polarimetric signals are expected, a different input polarization state could be tested to optimise the signal to noise ratio of the measurements. Further work are required to perform real measurements with different initial polarisation angle as suggested in this paper.

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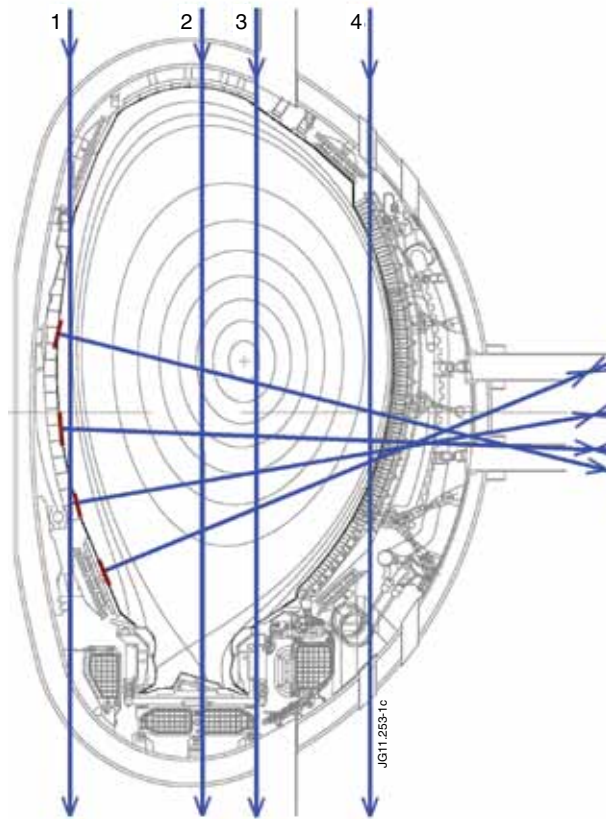[8]. De Marco F and Segre S.E., Optics Communication, **23**, (1977), 125.

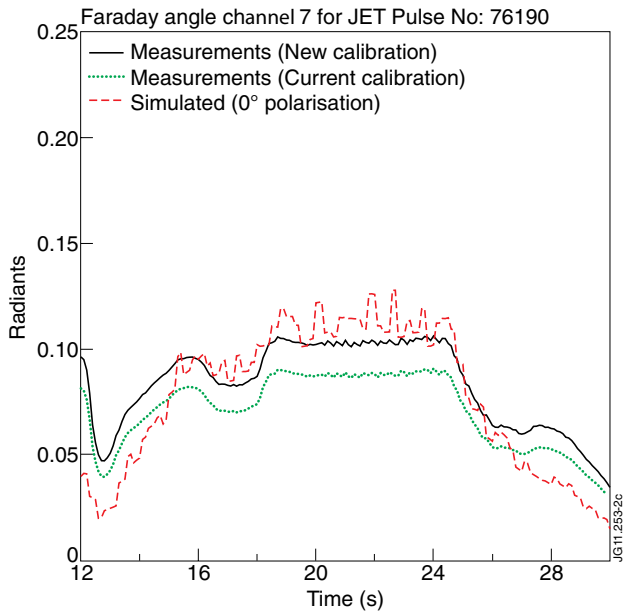*Figure 1: Layout JET interferometer-polarimeter.*

Figure 2. Faraday angles for the steady state phase of the Pulse No: 76190 are plotted. A comparison between the numerical solution (red line) experimental data (green line) and experimental recalibrated data (blue line) is shown.
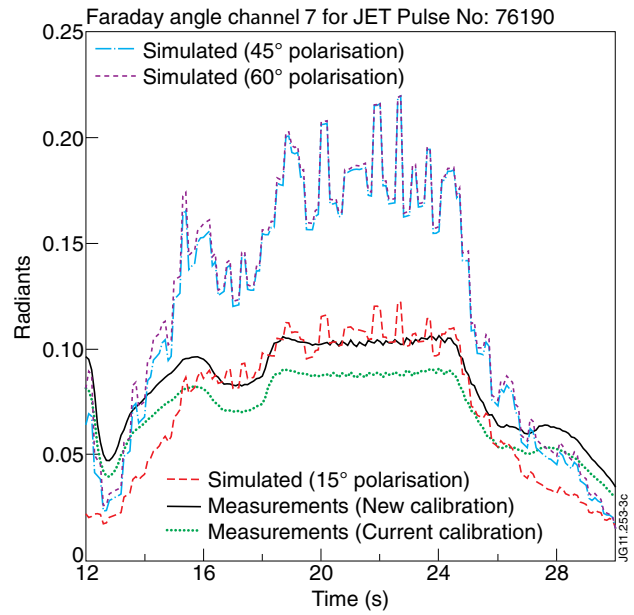

Figure 3: Faraday angle. Simulation of various polarization states of input laser beam are plotted.
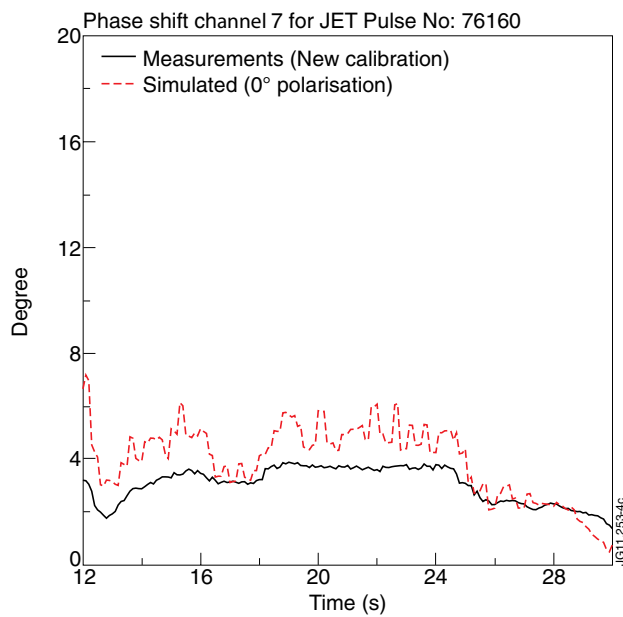

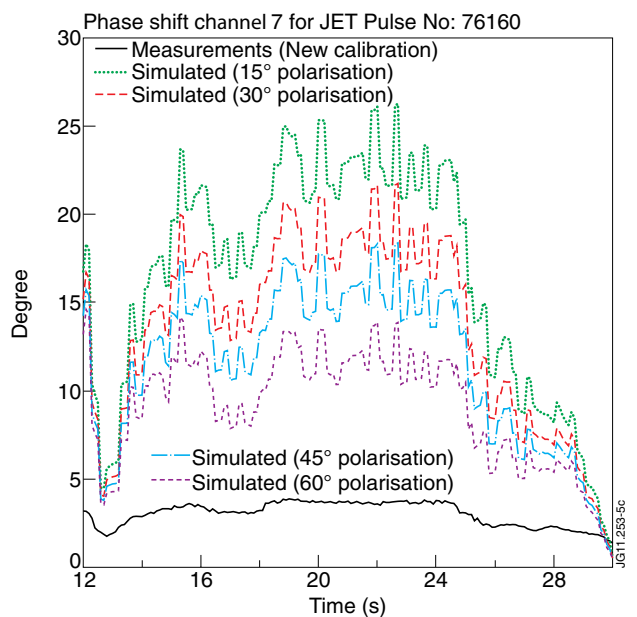*Figure 4: Phase shift. simulation of the relevant polarization state of input laer beam are plotted.*

Figure 5: Phase shift for several simulations of the input polarization state of the laser beam are plotted at stady state. Comparison between the numerical solutions and the experimental recalibrated data (blue line) is shown.