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Study of Plasma density profiles evolution using the new scanning interferometer for FTU

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Introduction.

In order to improve the diagnostic performances in the Frascati Tokamak Upgrade (FTU) for the advanced scenario experiments, a new scanning interferometer was installed. More than 30 chords through the observation port have been obtained, with a substantial increase of the spatial resolution for density profiles. The scanning time was 12 kHz (density profiles every 42 µs) in the 2004 campaign. Now a more reliable oscillator is used that provides a density profile every 62.5 µs (scanning frequency 8 kHz). The diagnostic has been developed by the "Consorzio RFX" [1] and was implemented during the first FTU shut down in 2004. In the following, we will present some measurements made during the 2004 and first part of 2005 experimental campaigns, to show the diagnostic capability of the instrument.

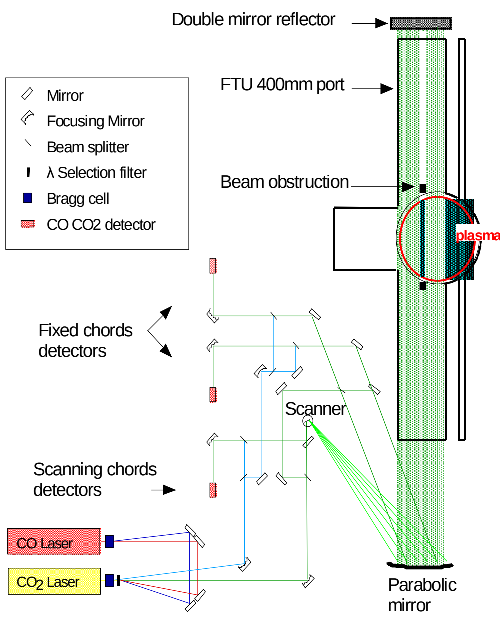

***Fig. 1** Scanning interferometer schematic view: an oscillatina mirror scans the beam.*

The scanning interferometer.

A "two colours" interferometer uses two different lasers to compensate the mechanical vibration contribution to the phase. The density is obtained by the phase difference of two interferometers ($n_e \sim \lambda_1\phi_1 - \lambda_2\phi_2$). In this case CO_2 laser (10 W, λ = 10.6 µm) is used for the measurement, while a CO laser (1 W, λ = 5.5 µm) is used to compensate vibrations. The wavelength choice was dictated by the attainment of very high densities (> of 10^{21} m-3) with multiple pellet injection. Due to an obstruction in the middle of the port, two different scanning beams have been used to cover the full width of the port; other fixed chords play the role of density reference measure. During the optical path (fig.1), both laser beams are split and recombined in order to obtain three fixed chords and two scanning ones. The central fixed chord is also used to give real-time density for feedback during the FTU discharge. The two colours are modulated at 40 and 30 MHz respectively with two Bragg Cells, in this way their signals can be detected with the same photoconductive detector and split electronically. The innovative technique is the “scanning beam” system: a tilting mirror placed at the focus of a parabolic one used to scan the laser beams within the vertical port [2]. The scanning is made by a small mirror (6x4 mm) mounted on a rotor that oscillates at its electromechanical resonant frequency. After crossing the plasma, the beam is reflected by the “roof-top” retro-reflector, made by two rectangular flat mirrors forming a right angle. The beams are collected by the same parabolic mirrors and reflected back on the tilting mirror; in this way the deflection is completely cancelled. The scanning chord signal is split via software in spatially separated chords, using the voltage control signal of the tilting mirror rotor to locate chord positions. A potential disadvantage of the scanning system is the not simultaneity of the measurement for the different elaborated chords. This approximation is acceptable for most of plasma phenomena that typically occur at a time scale much longer than the scanning time. The number of independent line-average density data depends on the ratio between scan amplitude and beam diameter (~ 1 cm); the number of equivalent chords typically varies from 28 to 34 depending on the scan amplitude. The typical noise is of ~ $2x10^{18}$ m^{-2}. Anyway a great attention has been paid in studying any possible error sources, as the effect of the magnetic field on the scanner or as the non complete compensation of the phase difference induced either by the rotation of the scanning mirror or by the vibration of the roof top mirror. Actually with the 12 kHz scanner, we do have an effect of the poloidal magnetic field on the scanner that changes the scan amplitude without being detected by the voltage reference signal. As consequence an error in the reconstructed position of the chords is induced and the profiles result distorted. An insertion of thin rod at fixed position in the scan (enough thin to avoid phase loss but visible on signal amplitude) can give a measurement of the beam position in the time. However we preferred to change the scanner with an 8 kHz one, which is not sensitive to the

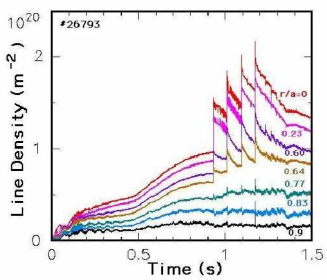

Fig. 2 *Lines integrated measures in a multipellet discharge 26793.*

magnetic field. Vibrations due to an incomplete overlap of the two colours are not perfectly compensated, even in the best alignment. As far as this error is reproducible in time, as the defective cancellation of the deflection, it can be subtracted using data before discharges. More severe is the effect of the tilt of the rooftop mirror, stuck directly to FTU port that can have amplitude up to 1 mrad. The tilt can be measured by the interferometer itself, from the difference of the vibrations at the extremes of each scan, so that a correction can be tried. The correction procedure compares the computed tilt, before and after the discharge, with the computed density. As the plasma density is zero, the computed value is the error induced by the imperfect compensation of the mechanical movements. The two quantities are strictly correlated so that its contribution to the phase during the plasma can be computed and subtracted. However a residual systematic error up to ~ 5×10^{18} m^{-2} could be present in the data in worst cases. An attempt to compensate the tilt movement by the feedback system is under implementation. It is important to note that this error is not inherent to the scanning interferometer but depends on the choice to use a roof top mirror fixed to the port to obtain high spatial resolution.

Measures of density profile.

Data have been produced routinely during the two experimental campaigns of 2004 and 2005 in different FTU scenarios as plasmas with internal transport barriers obtained with LHCD and ECRH, and PEP regimes. Here we present examples of measurements in pellet injection campaigns, where large and fast density variations occur. In fig. 2 some chords (line integrated density evolution) of the interferometer during the injection of 4 pellets are shown. Fast rise is observed in all central chords and fast passing of the pellet can be observed as spikes on the peripherals ones. In figure 3 the comparison with the Thomson Scattering (TS) is reported. Density from TS in FTU, do not have a stable calibration so

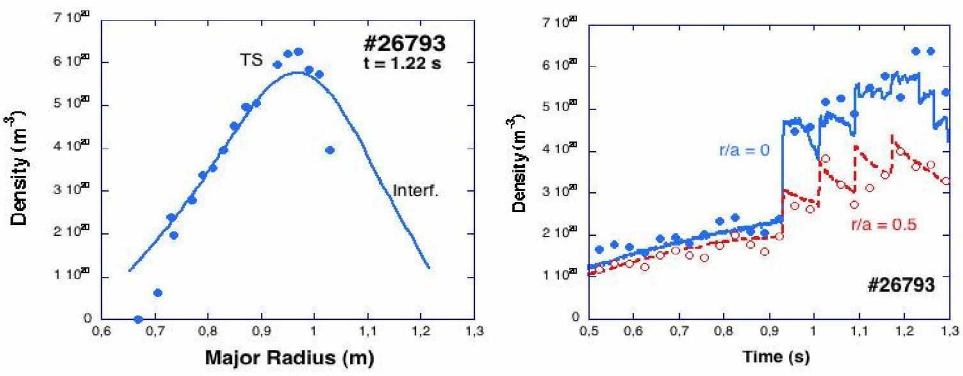

Fig. 3 *timing density evolution, the blue line is the measure by Thomson scattering*

that data need to be recalibrated shot by shot. The comparison should be considered as time behaviour and not in absolute value. The time evolution (fig 3a) for a central chord (full) and for a peripheral chord (dashed) is shown together with TS (dots) data (calibration at 0.9 s). A comparison of the profile at 1.22 s is shown in fig 3b. Data can be considered in good agreement. During pellet injection from high field side, with penetration time smaller than the scan time, the profile inversion has been performed and shown in fig 4. The integrated line profiles are shown in fig 4a and the contour plot of the inverted profiles in fig 4b. During the penetration the density peak moves inward with a velocity of 150 m/s that is compatible with a pellet speed of 200-300 m/s.

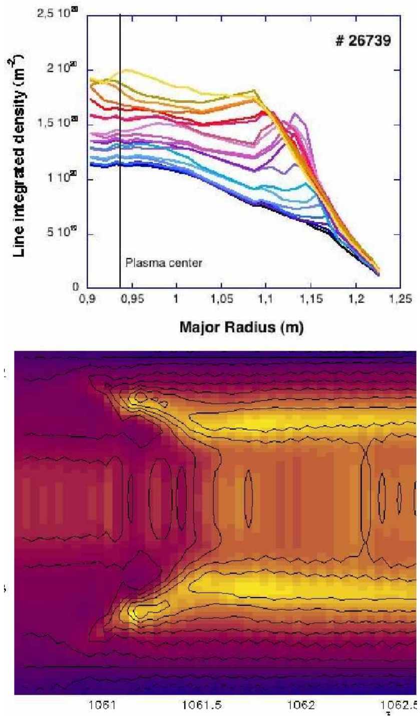

Fig. 4 *Profiles during pellet ablation. a): Density line integrated profiles; b): Density contour plot.*

When the pellet is completely ablated the density peak remains unchanged during this time scale and diffuse slowly with typical diffusive time. Two inversion methods to obtain the real density profile have been used up till now; both are performed assuming the density as function of the poloidal magnetic flux (Φ). For most of the density profiles the Cormack technique [3] is used, where an expansion in polynomials allows an immediate profile inversion; while in some cases (as that in fig.4b) an asymmetric Abel inversion algorithm which uses the line integrated data without any fitting results more effective [4].

Conclusions.

A spatially fast scanning two colours interferometer has been installed in FTU and is routinely working since spring 2004. More than 30 radial chords can be produced with a time resolution of 62.5 µs, and 1 cm of spatial resolution. Detailed density profiles are routinely produced.

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