ANALYSIS OF IMAGES OF THE FTU PLASMAS

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1. Introduction and experimental setup

A TV video system has been recently installed in the FTU tokamak to observe the global behaviour of the discharge evolution. Small size videocameras have been placed inside 3 equatorial ports straight behind the vacuum optical windows, the windows are thermally conditioned to compensate the radiation losses toward the cryogenic vessel and prevent frosting.

The proximity to the plasma and the wide angle optics (~80° field of view) allow observation of a large portion of the plasma with high spatial resolution (~1 mm^2/pixel). The temporal resolution is the standard 25 frames/sec and can be doubled by splitting of the interlaced TV fields. Digitisation of the movies enables reading of the single point brightnesses (the videocameras have been calibrated on their full CCD area ~4×10^5 pixels), and correlation with other diagnostics.

The high image quality of the system is also helpful in assisting plasma operations giving the monitoring of the chamber and toroidal limiter status as well as of irreproducible events such as flying debris, arcs or any structural damage.

2. Typical observations

Data provided by the videocameras are generally consistent with those of other visible multiple line of sight diagnostics (H_α, visible Bremsstrahlung, spectroscopy etc.); nevertheless there are a number of situations in which the higher spatial resolution and field of view offered by the videocameras are essential to understand the observed variations in the brightness of the edge plasma.

Typical image characteristics which depend on the discharge regime (mainly on electron density at fixed plasma current), are reported in what follows.

Low density regimes. Under these conditions the background visible emission is weak and the plasma itself appears largely transparent except for the tiny emission region (a few mm) along the lines of view tangential to the internal region of contact with the limiter.

Figure1 shows the toroidal limiter structure (5 rows × 6 columns of tiles for each of the 12 toroidal sectors) and the portion of the vessel in the view of the videocamera on the horizontal port #5.

The crossed shadow pattern which appears on the limiter surface is regularly observed in this conditions either in white light or through a large band pass H_α filter. The pattern has

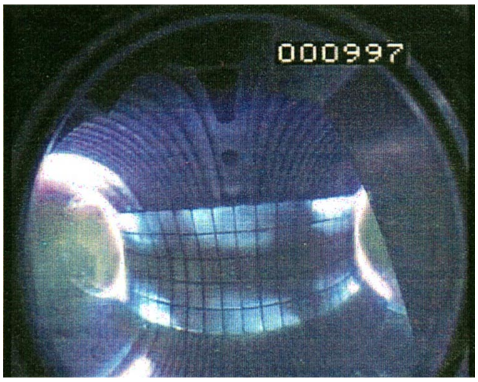

Fig. 1. Shot 12428. Image from Port#5.
$I_p=500\ kA\ n_e=3.5\times10^{19}\ m^{-3}\ B=6\ T$

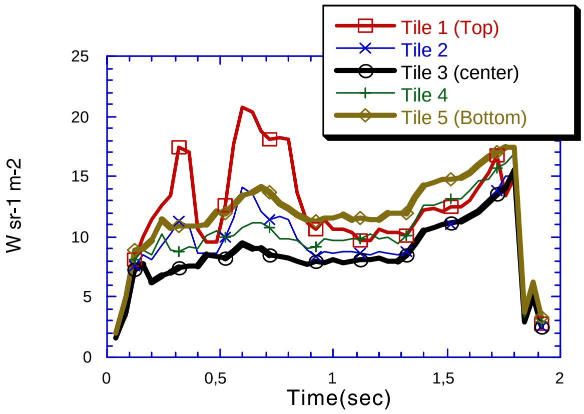

Fig. 2. Shot 12479. Comparison of the brightnesses of tiles on the central column of toroidal limiter sector #5

a toroidal periodicity 1/12th of the major circumference and quantitative measurements of the brightness of individual tiles show that the equatorial tiles are typically a factor 2-3 darker than the top and bottom ones (Fig. 2).

The contrast of this disuniformity is too large to be attributed to local variations of the plasma limiter interaction associated to particle loss at the internal magnetic field ripple (which has the same periodicity as the observed pattern). Conversely, ray tracing computations of edge particle trajectories and their interaction with the saddle shaped limiter sectors in FTU [1] foresee shadowed patterns which are similar to the observed ones.

Knowledge of this shadowing effect helps interpreting the multichordal profiles of H_α and suggests a correction factor 1.1-1.2 on the overall surface averaged hydrogen fluxes deduced from central chord measurements. The possibility that similar corrections be necessary for the Mo flux measurement will be checked by filtering the cameras on the Mo I line.

High density regime. At higher densities the details of the limiter emission are progressively concealed by the higher plasma emission background. These density regimes are mainly characterised by the occurrence of high luminosity bands toroidally symmetric and localised at poloidal angles $2.0 < \theta < \pi$ rad. Specular bands of much lower intensitiy are often observed below the equatorial plane. The most frequent case is reported in Fig. 3 where the band is located at $\theta \approx 2.1$ rad.

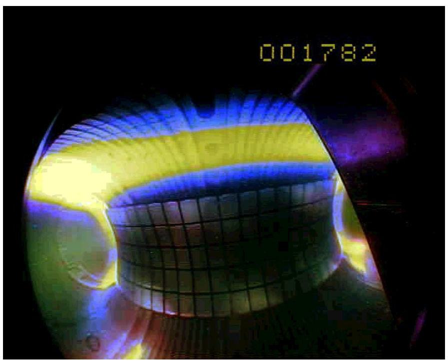

Fig. 3. Shot 12429. $I_p= 500\ kA$, $n_e=7\times10^{19}\ m^{-3}$, $B_T=6\ T$. Toroidal band at $\theta \approx 2.1$ rad.

The angular position of the band is not correlated with the magnetic measurements of plasma position and the gross plasma stability is not visibly deteriorated by the presence of the bands nor by oscillations of their position. Central ($\theta=\pi$) position of the bands have been obtained only in operations with the toroidal limiter alone, while the insertion of an external poloidal limiter apparently prevents the band from developing on the equatorial plane.

It must be noted that, for geometrical vignetting, none of the visible diagnostics in FTU (whose optics lies outside the ports), can detect bands above the toroidal limiter. Indeed, by comparison with the TV images, large variations in the signals from those diagnostics, often observed in stationary discharges, are clearly recognized as fluctuations in the positions of the bands rather than as overall changes in particle fluxes .

Spectroscopic analysis of bands occurring centrally shows that these are associated to increased emission from hydrogen and light impurity lines.

3. Band threshold

A detailed analysis of the movies compared with the main parameters of the discharges shows that the onset and disappearence of the bands is determined by the value of I_p/n_e rather than by the plasma current or density separately. Fig. 4 reports the time evolution of I_p/n_e for the two shots shown above, illustrating the existence of a threshold value below which the band is seen.

An extensive analysis on ~150 shots covering a wide range of the FTU operation space, has also shown (Fig. 5) a dependence of the I_p/n_e threshold on Z_{eff}.

The onset of the bands is not only associated to modification of edge parameters of the discharge, in fact it is found experimentally that they are also accompanied by flattening of the electron temperature profiles with little change on the peripheric values and important reductions of the central values (a few hundred eV) (Fig. 6).

The I_p/n_e threshold condition is also found to correspond to the estimated transition between low and high collisionality regimes in the plasma periphery (evaluated by comparing the electron collision times with the bouncing times for banana orbits).

4. Comparison with Marfes

As already known common Marfes observed when the discharge approaches the density limit, have characteristics similar to those of the bands described above. In fact a detailed

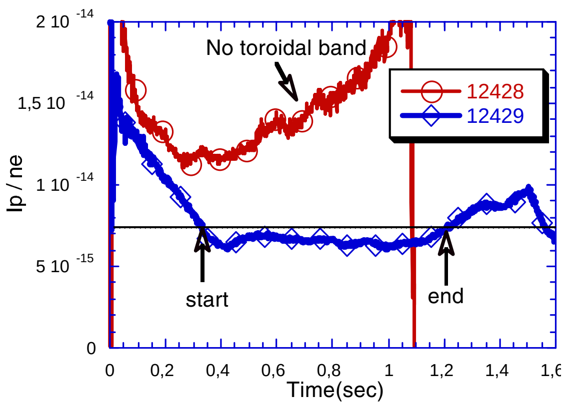

Fig. 4. Time evolution of I_p/n_e. Shot 12428. No band Shot 12429 band for <0.3<t<1.2s

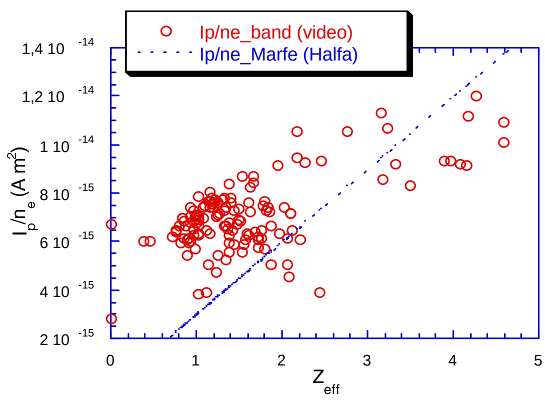

Fig. 5. I_p/n_e vs. Z_{eff} at the threshold for onset of toroidal bands. The dotted curve correponds to the threshold for Marfes deduced by H_α measurements [2,3].

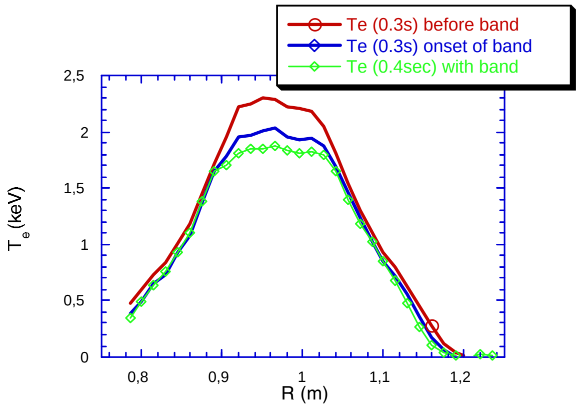

Fig. 6. Shot 12429. Electron Temperature profile variations associated with a toroidal band.

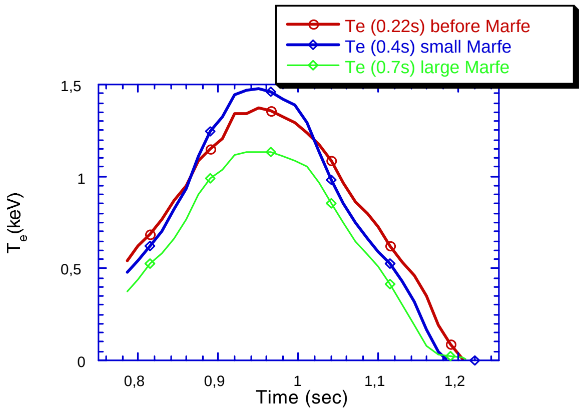

Fig. 7. Shot 12387. Electron Temperature profile variations associated with a Marfe.

comparison has shown that every occurence of a Marfe (as identified e.g. by H_α or bolometry) appears on the videocamera's global view as the evolution of a pre-existing band which is either increasing its intensity and size or just entering the field of view of those diagnostics. The experimental threshold for the two effects depends on the same parameters (I_p, n_e, Z_{eff}) although its absolute value is lower for Marfes. This suggests that there is no real qualitative difference between the two phenomena except for a different size of the plasma regions involved and the different edge temperature drops (Fig. 7). Important differences are observed in the visible and VUV spectra (observable for bands/Marfes at $\theta \sim \pi$) which are dominated in both cases by hydrogen and light impurity lines; the onset of simple bands determines a positive variation on all the spectroscopic lines, while in the case of Marfes impurity line emission decreases leaving the hydrogen feature as dominant.

5. Conclusions

Wide angle observation of the discharges by videocameras have given useful informations not only for machine operation but also as quantitative diagnostic instruments to investigate the plasma and interpret the measurements by other diagnostics operating on less extended angles and number of lines of sight. Disuniformity on the toroidal limiter brightness is found to have the same behaviour as expected from the details of its shape. Toroidal bands of high luminosity are found to be generated when the collisionality of the plasma periphery is high. This is regulated by I_p/n_e ratio and is accompanied by electron temperature profile changes. Marfes appear to generate from the toroidal bands and are characterized by much stronger reductions of the edge temperatures.

References

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[2] G. Apruzzese et al.: *21st EPS Conf. on Contr. Fus. and Plasma Phys.*, Montpellier (1994) Part II, p. 802

[3] D. Frigione et al.: Nucl. Fusion **36**, 11 (1996)