33rd EPS Conference on Plasma Phys. Rome, 19 - 23 June 2006 ECA Vol.**30I**, P-2.093 (2006)

Evidence of dust in FTU from Thomson Scattering diagnostic measurements

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Abstract

The FTU Thomson scattering diagnostic has been used to measure the density and size of dust particles following plasma disruptions. A dust density of the order of 10^7 m^{-3} has been found. The Rayleigh approximation was used to determine the particle size, which is of the order of 0.1 μm and less.

Introduction

The presence of dust in tokamaks may directly affect both the safety and the operations of fusion devices [1], [2].

Diagnostic systems based on laser light scattering can be used to understand the production and dynamics of dust during plasma discharges, a fundamental need highlighted by the ITER design. We analyze laser scattering signals observed by the Thomson Scattering (TS) system, installed in FTU (Frascati Tokamak Upgrade), that suggest the presence of dust particles formed after a disruption. The TS diagnostics in FTU uses two Nd:YAG lasers (1.5 J pulse energy, 10 ns pulse width, 1064 nm wavelength, repetition rate 30 Hz each) to measure the electron temperature and density profile along a vertical chord. The detection system consists of 19 polychromators, each of them being provided with 5 spectral channels. Four channels are used during the discharges to measure Thomson scattered light; the last one is used for alignment and the spectral transmission of its filter is centred at the laser wavelength. Therefore, this channel can be used to detect elastic light scattering, which might be due to the presence of dust particles [3]. Indeed, elastic scattering signals have been

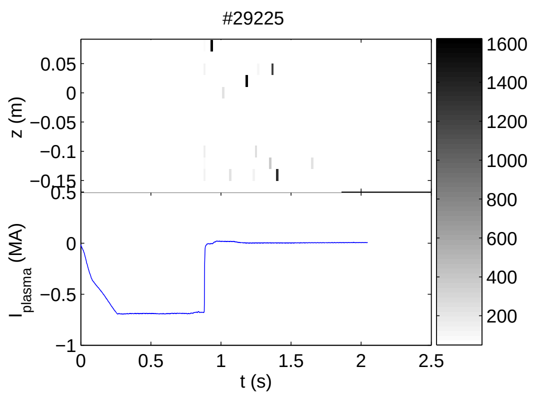

Figure 1: *Intensity of the signal in counts from channels at the laser wavelength together with the plasma current signal, showing no dust is present before the disruption.*

often observed in FTU after disruptions and can last more then one second after the end of the discharges (Fig. 1).

Experimental results

A dust particle is recognized when the signal gets above a given treshold, this has been conservatively fixed to a multiple of σ_d where σ_d is the standard deviation of the signal before the disruption.

A database has been made with 1322 discharges. Only 7% of the discharges doesn't have any dust following a disruption, even though for a large majority of the discharges (70%), the dust is detected in less than 10% of the about 30-60 laser pulses following a distruption (Fig. 2).

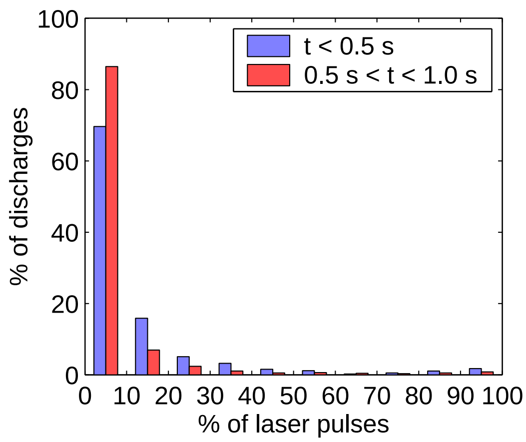

Figure 2: *Percentage of discharges versus percentage of laser pulses detecting a dust particle*

The dust content following a disruption is decreasing with time, this can be seen by comparing the number of dust particles in the first 0.5 s after a disruption with that found between 0.5 s and 1.0 s (Fig. 2).

Given a laser radius of the order of $r \simeq 0.2$ mm, the scattering volume is about $V_{scat} \simeq l\pi r^2$ where l is the length of the scattering volume ($l = 0.02$ m). The average dust content is about $n_{dust} \simeq 0.05/V_{scat} = 2\times 10^7$ m^{-3}, assuming from figure (2) that a dust particle is hit every 20 laser pulse.

The Mie Scattering theory should be employed in order to analyze the particle size, even if it is strictly valid only for spherical particles. Useful formulas can be found in [5] and in [6]. Data for metallic particles can be found in [7]. The FTU limiter is made of Molibdenum so metallic particles are expected to be produced after a disruption.

Tungsten dust of submicron size has been recently detected on tungsten samples exposed in the FTU scrape-off layer, near to melted zones [8].

The perpendicular scattering cross section σ for a small particle (Rayleigh approximation) is given by:

$$\sigma = \left(\frac{2\pi}{\lambda}\right)^4 a^6 \frac{n^2-1}{n^2+2} \cong \left(\frac{2\pi}{\lambda}\right)^4 a^6 \qquad (1)$$

Where a is the particle radius and λ the wavelength of the light, and n is the refraction index.

The scattered power depends not only on the particle size but also on the local laser power density, which is not constant across the laser beam diameter. The observed signal is:

$$S = KE\sigma \tag{2}$$

Where E is the local power density, K is a proportionality factor, and σ is the particle cross section. The probability distribution function of the scattered signal is then:

$$P_s(S) = \frac{1}{K}\int_{E_{\min}}^{E_{\max}} P_e(E)P_\sigma(S/KE)\frac{dE}{E} \tag{3}$$

Where $P_\sigma(\sigma)$ is the particle cross section distribution function, and $P_e(E)$ is the probability distribution function of the laser power hitting the particle. For a gaussian beam it is equal to:

$$P_e(E) = \frac{1}{\log R}\frac{1}{E} \tag{4}$$

where $R = E_{\max}/E_{\min}$ and $E_{\min} < E < E_{\max}$. $E_{\max}$ is the peak power density of the laser beam while $E_{\min}$ is a lower cutoff. If the particle distribution follows a decreasing power law, or at least a tail in the distribution follows a power law, then the scattered power still follows a power law with the same slope. This can be easily seen assuming:

$$P_\sigma(\sigma) = \frac{\alpha - 1}{\sigma_0^{1-\alpha}}\sigma^{-\alpha} \tag{5}$$

And then by the use of (3):

$$P_s(S) = S^{-\alpha}K^{\alpha-1}\frac{\alpha - 1}{\sigma_0^{1-\alpha}}\int_{E_{\min}}^{E_{\max}} P_e(E)E^{\alpha-1}dE \tag{6}$$

providing that $S > K\sigma_0 E_{\max}$. Given a power law distribution the slope can be obtained from the experimental data by the following formula [9]:

$$\alpha = 1 + \frac{n-1}{\sum_i \log(x_i/x_{\min}) + n_{\mathrm{sat}}\log(x_{\mathrm{sat}}/x_{\min})} \tag{7}$$

Where $x_{\min}$ is where the power law tail starts, x_{sat} is the value at which the signal gets saturated, and n_{sat} are the number of saturated values. The signal intensity in each channel has been analyzed for all the discharges. The tails of the experimental data are distributed as a decreasing power law (Fig. 3).

The σ has been obtained using an average power density given by the energy of the laser pulse divided by its diameter. The detectors has been calibrated using Raylegh scattering in hydrogen, the beam diameter has been measured with a CCD detector and a lens of known focal length.

The measured cross section is inside what is expected for the Rayleigh scattering, so applying (1) we can obtain the distribution of particle radii (Fig. 3).

Conclusions

Dust has been observed after disruptions in more than 90% of the discharges, the dust density tends to decrease with increase time delay from disruption.

The particle size distribution seems to follow a decreasing power law, the non flat profile of the laser power density cannot change its slope.

The particle size is less than 0.1 μm in agreement with sample exposure experiments.

We haven't still used the information on the broad spectrum channels that usually see the Thomson scattering light. More information could be extracted from this diagnostic.

The feasibility of active experiments by introducing dust of known size in the machine are under evaluation.

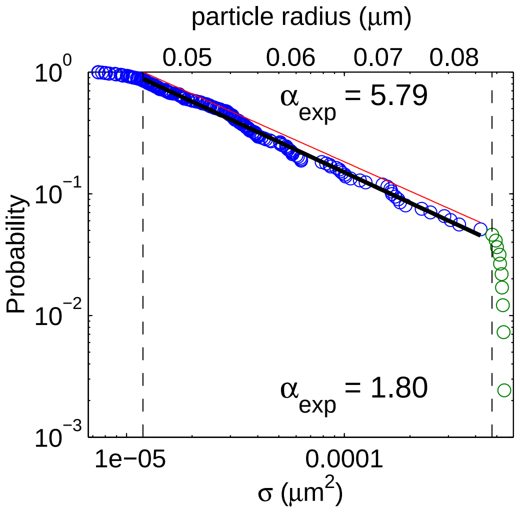

Figure 3: *Experimental cumulative distribution function of particle cross sections and radii using the Rayleigh approximation in the central spectrometer.*

The effects of magnetic fields on particle dynamic will be considered in future.

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