*34th EPS Conference on Plasma Phys. Warsaw, 2 - 6 July 2007 ECA Vol.**31F**, P-5.114 (2007)*

First Results of Fast Ion Loss Detector in the TJ-II Stellarator

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Introduction. The confinement and losses of fast ions in stellarator devices is an active research field because of its paramount importance for the future of this magnetic configuration as an alternative to tokamaks as a fusion reactor. A new diagnostic has been installed in the TJ-II stellarator for quantifying fast ion losses close to the plasma edge. Due to the optimum sensitivity of our design, the purpose of this detector is not only to monitor the fast ions originating from NBI, but also to be capable of detecting the suprathermal ion population present in the TJ-II, as in other devices, when the plasma is created and heated by RF techniques. This TJ-II suprathermal population has been detected and studied by spectroscopic techniques and recently reported [1]. A detector of this kind can record ions difficult to measure with charge-exchange neutral spectrometers or spectroscopic diagnostics viewing the plasma along perpendicular or tangential views; since ions drifting outside of the plasma along paths not connecting with the exterior are not necessarily seen by such diagnostics.

Since the final goal of this study is to determine the energy and pitch angle distribution functions of the ions impinging onto a phosphor screen and to display these distributions in absolute scale; we have developed, in parallel to TJ-II measurements, an experimental setup to perform basic studies on the response of this screen in the energy range of interest ($E \leq 35$ keV), with the aim of unfolding the distribution from the phosphor luminescence image.

The paper is organized as follows. First, a brief description of the diagnostic design, as well as the originalities of its capabilities are presented. Second, the luminescent response of the screen used, measured in a lab setup, is presented. Finally, the first results obtained in TJ-II plasma discharges will be shown and discussed within the physics of fast particles in stellarator devices.

Experimental. The TJ-II flexible heliac [2] has been operated during these measurements with a maximum ECR power of 600 kW, and in a few discharges with a co-injected NBI beam with an absorbed power of 300 kW. Simulations predict that fast-ion losses could reach 30% of the injected power, [3] and [4], and they are extremely localized in the poloidal plane, this being the reason why, in this initial phase, our goal has been to perform detector tests mainly with ECRH discharges. In addition, our detector is located not to record the prompt losses of the NBI fast ions, in contrast to other designs that are aimed exclusively for this type of ions.

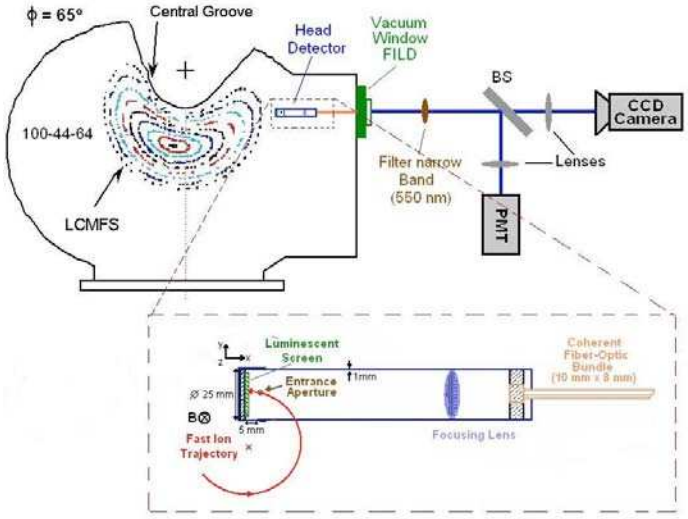

Fig. 1. Experimental setup sketch of FILD. The last closed magnetic flux surface (LCMFS) and the optimal position for detecting co-injected fast ion loss are represented.

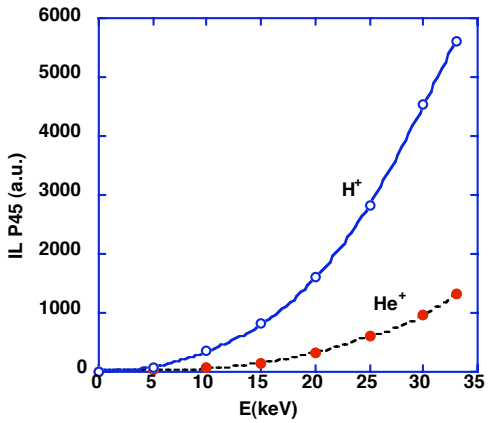

Fig. 2. Ionoluminescent response of P45 to H and He ions accelerated to energies of TJ-II fast loss ions (≤35 keV) in the lab setup.

The TJ-II fast-ion loss detector (FILD) is based on the ionoluminescence of a granular luminescent screen as used in other designs [5]. The phosphor, P-45 (Y_2O_2S:Tb), was chosen for this initial phase because of its good sensitivity. The FILD acts as a magnetic spectrometer where incident fast ions disperse onto the scintillator with hit points that depend on their gyroradius and pitch angle. In Fig. 1 we show the schematic representation of the FILD experimental setup. The unique features of the design include: a) the flexibility to position the head arising from the use of a coherent fibre optic bundle (8 mm x 10 mm collection area and 90 cm long) for relaying the ionoluminescent image from the plasma edge to outside of the vacuum chamber, b) the possibility to orientate the entrance aperture to sense ions coming from opposite toroidal directions and c) the ease of extraction from the device for modification or maintenance. For this initial experimental phase the total filtered luminescent light is guided to a single photomultiplier (temporal resolution) in order to have a fast fiducial signal of the screen response to the TJ-II plasma ions. Simultaneously, the image of the screen

luminescence is relayed to a cooled sensitive CCD camera (spatial resolution) operated in single shot mode. Both data are needed to ensure that the luminescence signal is substantially due to ions impinging onto the screen after passing through the 1.5 mm collimating hole located in the head of the movable optical probe, and that any background caused by other types of exciting agent are negligible; i.e. the phosphor screen could respond in principle to photons, electrons and ions (E > 1 keV). However, the analysis of the temporal behaviour of the ion detector trace, under very different types of discharges and its correlation with the traces of radiation diagnostics in different spectral ranges: visible, VUV, soft X-ray and hard X-rays, allow us to exclude such radiations as contributing to the signal delivered to the photomultiplier detector sensing the FILD of TJ-II plasmas. The latter point must be emphasized, since in contrast to other devices the detector exhibits a significant response in TJ-II plasmas heated by only ECR.

Phosphor screens similar to those used in the FILD were studied in a lab setup where they were bombarded by different kind of ions (H^+, He^+ and Ar^+). These ions are produced by a commercial ion source, with energies in the same range as those expected in the TJ-II plasma experiment, from 1 to 35 keV. See Fig. 2. This flexible experimental setup, where up to 6 luminescent screens can be studied successively, and where the ionoluminescence, catodoluminescence and photoluminescence can be alternatively studied, provides an excellent test bed to study the influence of different mechanisms and the luminescent spectra at different ion energies, necessary to back up the development of the FILD. It is important to emphasize here the importance of these results for interpreting the luminescence of this type of screen used to detect fast ions at the plasma edge and for guiding the selection of the optical filter incorporated to these detectors.

Experimental results. The detector has been operateded during this commissioning phase mainly in ECRH discharges, and with two detectors simultaneously: a) with a single channel photomultiplier collecting the whole phosphor emission excited by the plasma ions and transmitted by the coherent bundle, b) collecting the luminescent image by a single shot highly sensitive CCD camera. Its response was studied under different magnetic configurations with ECRH in hydrogen and helium discharges; and for a few discharges with NBI.

The most original aspect of our results is that we obtained an excellent signal with solely ECRH. To illustrate its behaviour in this type of discharges we show in Fig. 3, the global response of our detector in an ECRH discharge sustained during the whole duration by a

gyrotron, whereas the second one delivers a 50 ms pulse approximately centered in the discharge. The FILD trace responds clearly to the microwave injected power, what is herein interpreted as being due to the generation of ions by RF heating, with energies > 1 keV, since this energy is the luminescence material threshold to respond to protons. Its rapid rise with the microwave heating perturbation, precludes that it can be due to the rise of radiation which has a different behaviour, as shown in Fig. 3, where three relevant traces of this experiment are depicted together. If we could exclude that electrons are reaching the phosphor screen, then these ions should correspond to the suprathermal population associated with ECRH heating that has already been studied in TJ-II by spectroscopic means [1].

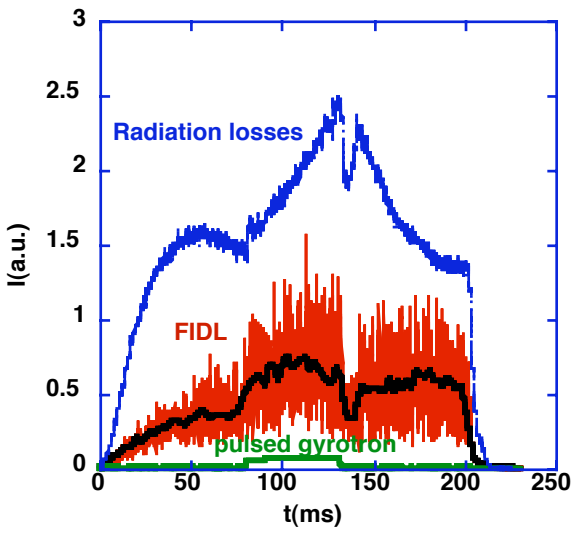

Fig. 3. Typical detector trace in an ECRH discharge where one of the gyrotrons was pulsed.

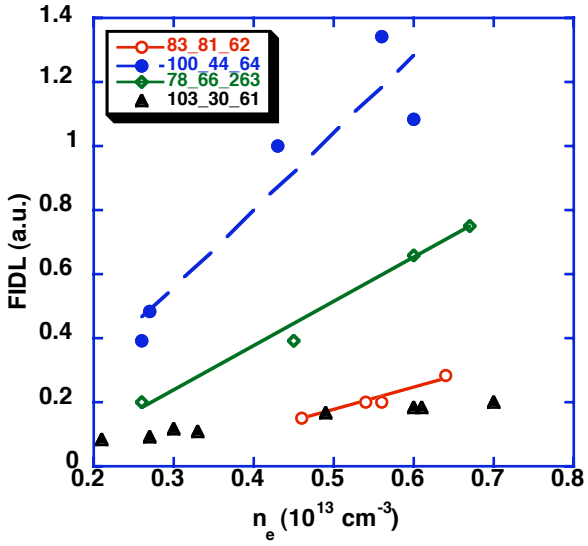

Fig. 4. Detector signal response for a fixed position as a function of n_e and magnetic configuration.

The FILD trace in a typical ECRH discharge exhibits a monotonic increases with time, reaching a plateau close to the end of the discharge at ~150 ms. In Fig. 4, we plot the maximum signal of the detector for discharges with different plateau densities and for different magnetic configurations of TJ-II. The operation of this detector mainly in ECRH discharges of TJ-II plasmas proves that there exists a relevant population of suprathermal protons with energies above 1 keV with a temporal behaviour specific of this ion population which will be studied in the next future.

References

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