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The Visible Intensified Fast Camera with Wide-Angle View of JET ITER-Like Wall Experiment

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INTRODUCTION

The JET wide-angle view Fast Camera [1] has been upgraded with an image intensifier for light amplification and a filter wheel in order to allow the system for spectroscopic plasma imaging filtering atomic lines. The objective was to track fast events down to the microsecond range without filtering and to image atomic emission at a speed so as to resolve Edge Localised Modes (ELM), disruptions, pellet injection or plasma breakdown.

1. EXPERIMENTAL SET-UP

A visible light beam collected from the infrared wide-angle view endoscope is split into three lines that go to two operation cameras and to our Fast Camera system, after passing through the filter-wheel and being reflected by different mirrors. This light splitting together with the small collection mirror inside the endoscope makes a relatively poor light flux onto our camera system. Moreover, the golden-coated mirrors in the endoscope have a reflectivity of less than less than 95% for wavelengths over 650nm and a strong decay below 60% under 500nm. This unfavourable light transmission in the visible to the Fast Camera system, together with our objective to use atomic line filters, lead us to the conclusion of installing an image intensifier. A Fast Camera in TJ-II (CIEMAT) demonstrated a successful operation with an image intensifier (Hamamatsu C9548-03BL) since a few years [2]. The coupling of an image intensifier to a fast camera is not trivial in fusion devices, since relatively high light intensity fluxes are captured continuously for a long time period of typically some seconds. To obtain a linear response a two-stage intensifier is chosen, the first one being a standard GEN II image intensifier with Multi-alkali photocathode operating at minimum voltage, the second being step a GEN I tube. A discussion of the performance regarding the balance between light amplification and image quality degradation and the linearity of the response curves can be found in [2]. Unfortunately, since electrons are accelerated in vacuum in the GEN I tube, it is sensible to magnetic fields larger than a few tens of mT, this limit being much smaller than those in the JET Fast Camera environment (up to 0.1T, mainly perpendicular to tube direction). Further concerns were the strong acceleration forces and the possible radiation damage. The intensifier was modified by the supplier to slightly increase the space around the tube for magnetic shielding and to strengthen the mounting of the attachment holder. Calculations made with the ANSYS code predicted that a 10 mm iron cylinder around the tube would shield the magnetic field to values below 10mT inside. This was confirmed experimentally with permanent magnets producing fields of 0.08T and at a calculated distance from a field coil of TJ-II. In parallel, the optical support structure was modified keeping the weight increase within the acceptable limits and the filter-wheel (with 5 position), mirrors and beam-splitters were mounted. The control and acquisition software of filter-wheel and intensifier was adapted to the JET environment. Finally, the system was aligned and focused and the intensifier was operated successfully during the last days of the JET with carbon wall. Comparison of two similar plasmas of filtered CII light from the divertor, with and without image intensifier, showed an increase by factor of 30 in the signal to noise ratio.

2. SOME RESULTS UND DISCUSSION

The Intensified Fast Camera has captured videos routinely from beginning 2012 in experiments such as ELM studies, ELM pace making with pellets, Beryllium erosion, Disruption mitigation and plasma breakdown. An example of ELM divertor dynamic analysis is presented in Figure 1, corresponding to Pulse No: 82582, t = 13.565s. The camera was running at 50000 frames per second and 5 µs exposure time without filtering. Figure 1a shows a superposition of a CATIA model with one camera frame where three characteristic emission regions are visible (I, O and U). Figure 1b shows the pre- and post ELM emission, with the inner (I) and outer (O) divertor emission regions. Figure 1b is a frame corresponding to the ELM, where a new region appears at the left (region U) that seems to be in the far scrape-off layer, on the upper edge of the divertor tile. Figure 1d shows the time evolution (vertical co-ordinate) of the intensity along the yellow arrow and 1e the time evolution of the mean intensity of regions I, O and U. Before the ELM most part of the emission comes from inner (I) and outer (O) target, than the U-region evolves and becomes dominant during the ELM to finally disappear again. Although not visible in the shown scale, the first strong intensity increase comes from region U, about 100µs before that of regions I and O. We believe that this kind of imaging analysis can help in understanding the physics of ELMs.

A second example shown in figure 2 is the Be II (527nm) emission (Pulse No: 81984) during an ELM. The time evolution of the mean intensity values of the upper inner limiter region LIM and the divertor DIV (marked in the image with ellipsis) is presented in the left figure. The intensities were qualitatively compared with the signal of the inner divertor Be II photon flux monitor (same line) and very similar time behaviour is observed. Note that the low light level when using the Be II filter imposes relatively long exposure times (400µs) at high intensifier voltage (800V) and image quality is rather poor, but the frequency is enough to resolve ELMs. Depending on plasma configuration, the Be-emission can be also observed at the outer limiters. This 2-dimensional imaging analysis allows the exact allocation and extension of the main beryllium sources, else not possible with discrete chords.

The Fast Camera is also playing an important role in the pellet ELM pace-making experiments. The typically millimetre sized ELM-pacing pellets are relatively small to cause remarkable perturbation of the JET plasma, therefore it is difficult to diagnose them. These pellets (LFS injection, v=150m/s) are near to the threshold of the pellet ELM triggering and only the fast camera system can detect which of them triggered an ELM: the wide tangential view permits to see the LFS pellet ablation region and simultaneously the outboard limiters where the ELM filament produces hot spots [3]. For these experiments, 10-20 thousend frames per second and 10µs exposure time has given reliable movies to assist the pellet ELM pace-making studies. KL8 has been operated during massive gas injection of argon with an Ar II filter (611nm) in order to characterise the gas penetration during the disruption process. A complex filamentary structure can be observed from the start of the injection throughout the whole disruption. As the plasma cools down during the current quench the emission moves towards the plasma centre indicating temperatures of a few eV.

As mentioned before, the image intensifier is sensible to magnetic field so that above a magnetic threshold, image rotation and translation appears. Fortunately, these movements are in theory detectable and one can correct them. Right now an algorithm called phase correlation and the masked version of this algorithm [4] combined with a so-called sub-pixel precision algorithm was tested on the camera images. These algorithms are working quite well on translation detection, but haven't got the sufficient precision to detect and correct the rotation of the images. Other algorithms are in development and under testing.

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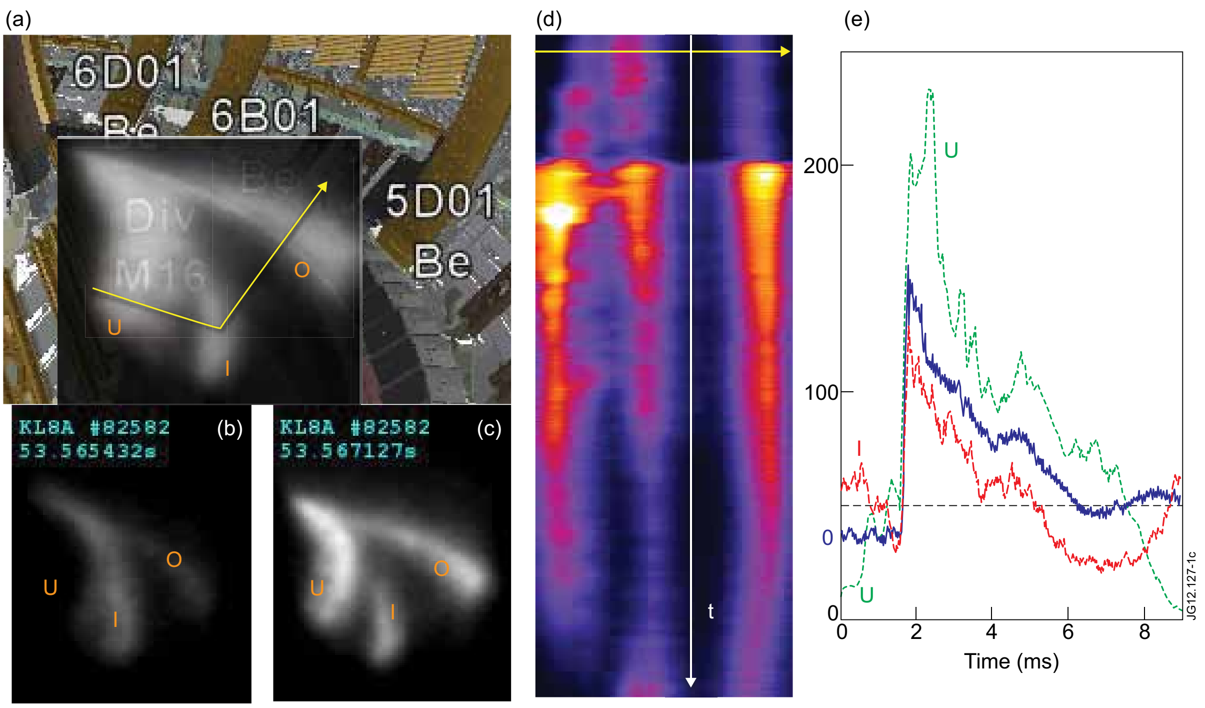

Figure 1: ELM dynamics study (see text for figure explanation).

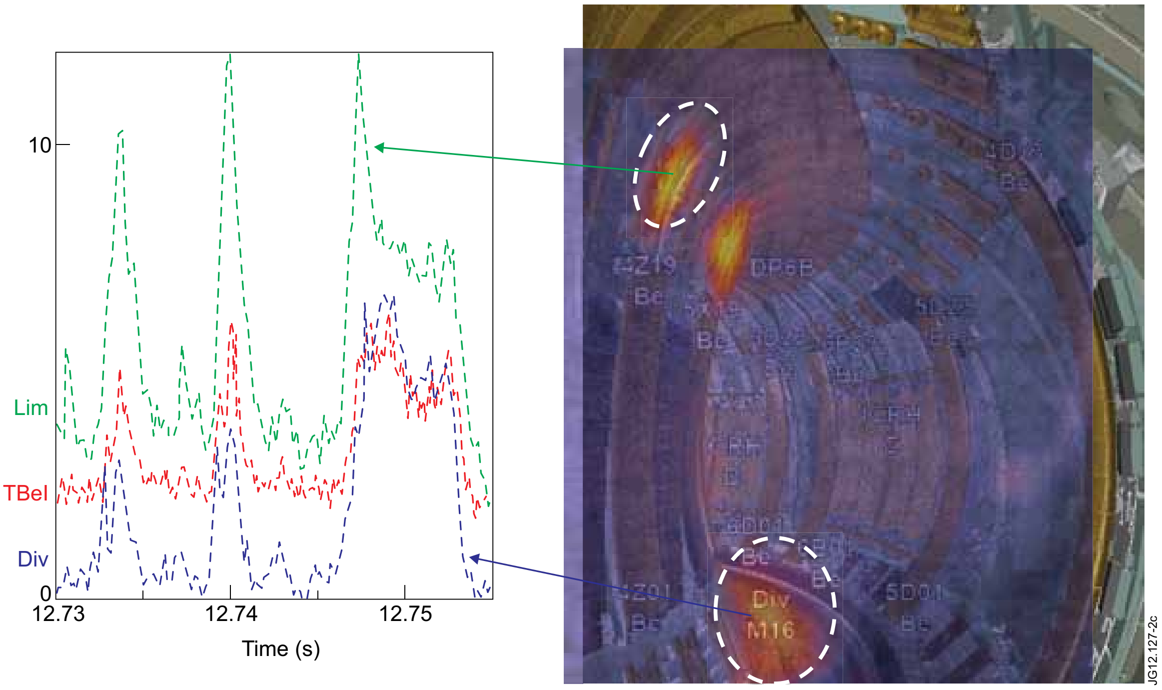

Figure 2: Beryllium emission image and time evolution