EFDA–JET–CP(07)04-14

J.A. Alonso, P. Andrew, A. Neto, J.L. de Pablos, E. de la Cal, H. Fernandes, J. Gafert, P. Heesterman, C. Hidalgo, G. Kocsis, A. Manzanares, A. Murari, G. Petravich, L. Rios, C. Silva, P.D. Thomas and JET EFDA contributors

Fast Visible Camera Installation and Operation in JET

Fast Visible Camera Installation and Operation in JET

J.A. Alonso[1], P. Andrew[2], A. Neto[3], J. L. de Pablos[1], E. de la Cal[1], H. Fernandes[3], J. Gafert[4], P. Heesterman[2], C. Hidalgo[1], G. Kocsis[5], A. Manzanares[1], A. Murari[6], G. Petravich[5], L. Rios[1], C. Silva[3] and P.D. Thomas[2] and JET EFDA contributors*

JET-EFDA, Culham Science Centre, OX14 3DB, Abingdon, UK

[1]*Asociación EURATOM-CIEMAT, Avenida, Complutense 22, 28020 Madrid, Spain*
[2]*EURATOM-UKAEA Fusion Association, Culham Science Centre, OX14 3DB, Abingdon, OXON, UK*
[3]*Associação EURATOM-IST, Avenida, Rovisco Pais, 1049-001 Lisbon, Portugal*
[4]*Max-Planck IPP, Boltzmannstrasse 2D-85748 Garching, Germany*
[5]*EURATOM-HAS Association, KFKI-RMKI, P.O.Box 49, H-1525 Budapest-114, Hungary*
[6]*Consorzio RFX-Associazione EURATOM ENEA per la Fusione, I-35127 Padova, Italy*
** See annex of M.L. Watkins et al, "Overview of JET Results ",*
(Proc. 21 st IAEA Fusion Energy Conference, Chengdu, China (2006)).

Preprint of Paper to be submitted for publication in Proceedings of the
International Workshop on Burning Plasma Diagnostics, Villa Monastero,Varenna, Italy.
(24th September 2007 - 28th September 2007)

ABSTRACT.
This article is a summary of the measurements of the recently installed wide-view fast visible camera in the Joint European Tokamak JET. Here we limit ourselves to a description of the different phenomena and leave for forthcoming articles a more extensive analysis of every phenomenon.

1. CAMERA SYSTEM AND TECHNICAL ISSUES

A fast visible Photron APX-RS camera has recently been installed on JET. The camera is located near the equatorial plane of octant 8 and is looking through an endoscope designed for infrared imaging [1]. It uses a CMOS detector with a maximum recording speed of 250kHz and a minimum exposure time of 1 us. In the present set-up a commercial camera lens and no filters are used. The camera was tested against high radiation fluxes and rapidly varying magnetic fields. The integrated neutron fluence in the camera position after four months of operation is in the range of 4×10^{10} n/cm^2. So far there is no evidence of permanently damaged pixels. Several disruptions were recorded the camera withstanding field variations of up to 4T/s.

2. OBSERVED PHENOMENA AND FIRST ESTIMATIONS

2.1 ELM PHYSICS AND PLASMA-WALL INTERACTION

The fast camera has proven to provide useful information to study different fusion plasma relevant issues including plasma wall interaction, ELMs and disruption physics. Figure 1 shows the expulsion of macroscopic particles from the wall after the occurrence of an ELM.

Some 6 ms after the sudden radiation increase caused by an ELM, a shower of solid fragments is seen to come out of an outer wall poloidal limiter and seem to be accelerated in the toroidal co-current direction (that is also the direction of the parallel plasma flows for this configuration). These particles can be seen for 50ms.

ELMs are commonly seen in the images as a sudden increase of radiation. For high power type-I ELMs like the one in figure 2, an associated filamentary structure can be observed as in other machines [2], [3]. In the high frequency recording of an ELM in figure 4, a helical interaction pattern can be seen on the wall within 40 us following the onset of the ELM (the associated D_α rise). This kind of interaction pattern has also been seen with infrared cameras in JET [4]. It should be noted that an ELM impact can produce localized particle desorption from the wall elements. These particles are transported parallel to the magnetic field and can also be seen as filamentary structures (figure 4, third and fourth frames) which are thus different from the ELM own structure.

2.2 ELM RADIAL / PARALLEL DYNAMICS

Very fast framing can be achieved if the active part of the detector is reduced. Images in figure 3, show a 100 kfps frame sequence of the divertor during an ELM. The radiation increase starts very close to the strike points (figure 3). The D_α rise progressively reaches further divertor positions up to the limiters shadows. Two possible causes of this delayed arrival have been identified as the

radial decay of the parallel flow because of the SOL temperature profiles [4] and the intrinsic ELM radial velocity. The relative importance of these two factors is under investigation.
From figure 3 it is apparent that the volume light emission from inner divertor is stronger that that of the outer, consistently with the measured higher neutral density. An intensively radiating cloud localized in between the strike points is seen after the impact of some ELMs and appears to rotate in the toroidal direction (figure 3.a).

2.3 PLASMA DISRUPTIONS

During disruptions (figure 5) the plasma detaches from the divertor as the current is lost and high particle fluxes are directed to the wall. MHD activity can also be seen as fillamentation. In the course of a disruption a highly radiating MARFE-like ring could be seen which travels from the upper plate, where it formed, to the equatorial plane in the HFS in ~5ms, where it keeps radiating for ~32ms. After this time the plasma terminates violently.

CONCLUSIONS AND FUTURE PLANS

The recently installed fast visible camera in JET has produced the first results. Several physical phenomena like particle expulsion from the wall, ELM filamentation, MARFE formation and disruptions have been observed. The apparent toroidal rotation velocities of the structures during ELMs and disruptions were estimated from the images to be in the order of 10km/s. ELMs can be seen to reach the first wall less than 40μs after the start of the light rise giving, for a typical wall clearance of 40mm, radial propagation velocities in the range of 1 km/s. More extensive analysis of the individual phenomena, here only briefly described, will be carried out in future articles. Investigations of the pellet-plasma interaction will also be studied by making use of the camera system capabilities.

The study of lower intensity phenomena, like the continuous plasma wall interaction and the generation and dynamics of impurities, requires a higher signal level. Image intensifiers are being tested for its possible installation on JET fast imaging system, which would allow the use of interference filters so as to investigate these and other phenomena. Image analysis techniques for optical flow estimation, spatial-temporal structure detection and IR/visible data merging are under development [6].

REFERENCES

[1]. E. Gauthier et al, Proc. of the 17th PSI Conference, Heifei, China 22-26/05/2006

[2]. A. Kirk, H.R. Wilson *et al.*, Phys. Rev. Lett. **92**, 245002 (2004)

[3]. R. J. Maqueda, R. Maingi, *et al.*, J. Nucl. Mater. 363-365, (2007)

[4]. P. Andrew *et al.*, 34th EPS Conference on Plasma Physics, Warsaw 2007.

[5]. R. Pitts*et al.*, Nuclear Fusion **46** (2006) 82

[6]. S. Hong, A. Murari *et al.*, 34th EPS Conference on Plasma Physics, Warsaw 2007.

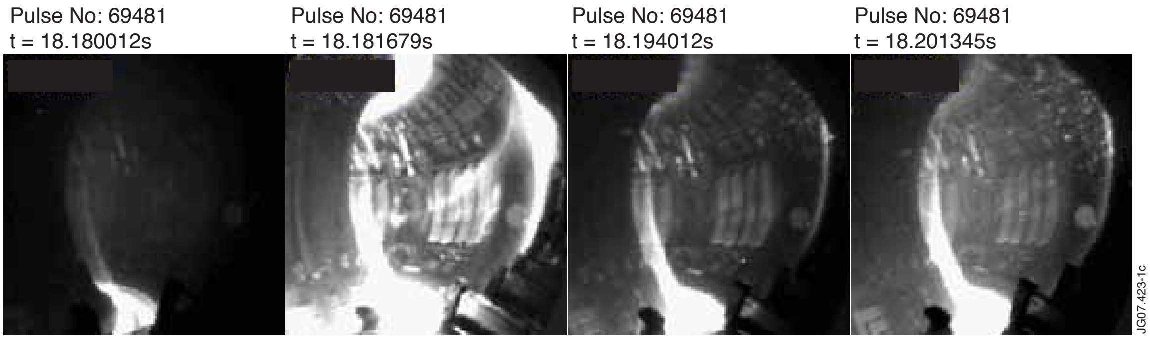

Figure 1: Particle expulsion from a poloidal limiter. Images are taken at 3 kfps with 166 us exposure time.

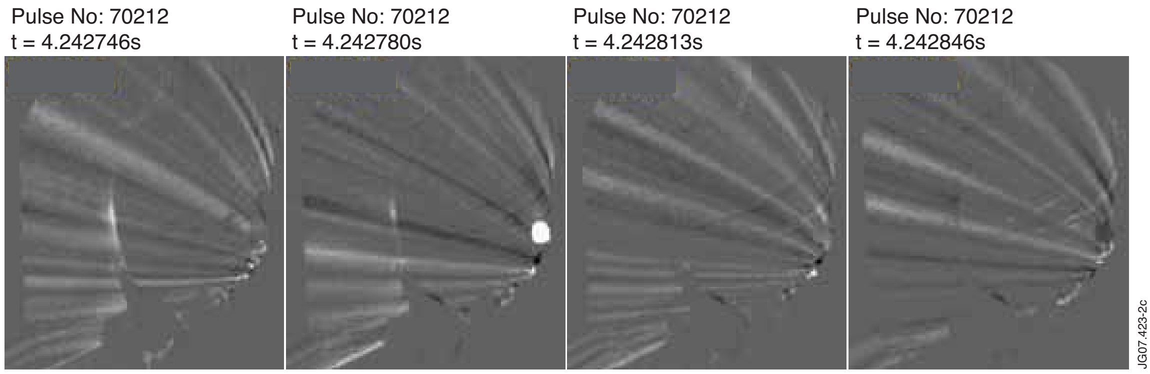

Figure 2: Filament development during an ELM (30kfps, 25μs exp. time). The background images (calculated as the pixel median over 500μs) has been subtracted from the original frames to highlight the filamentary structure.

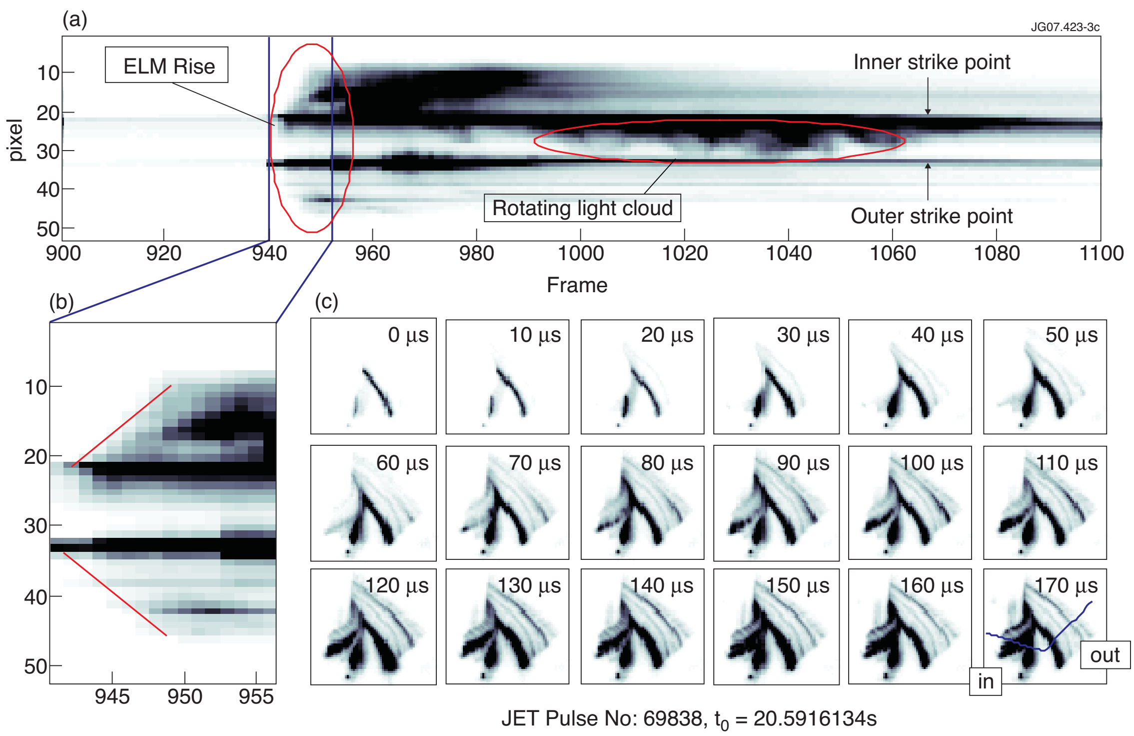

Figure 3: (a) Time trace of the pixels on the blue line in the last frame of (c) -approx. in a poloidal section. The radiation onset shows a delayed arrival to the ELM energy flux to the different divertor positions. (b) Close-up of the ELM rise. (c) Sequence of the divertor at the ELM onset (@ 100kfps 9μs exposure).

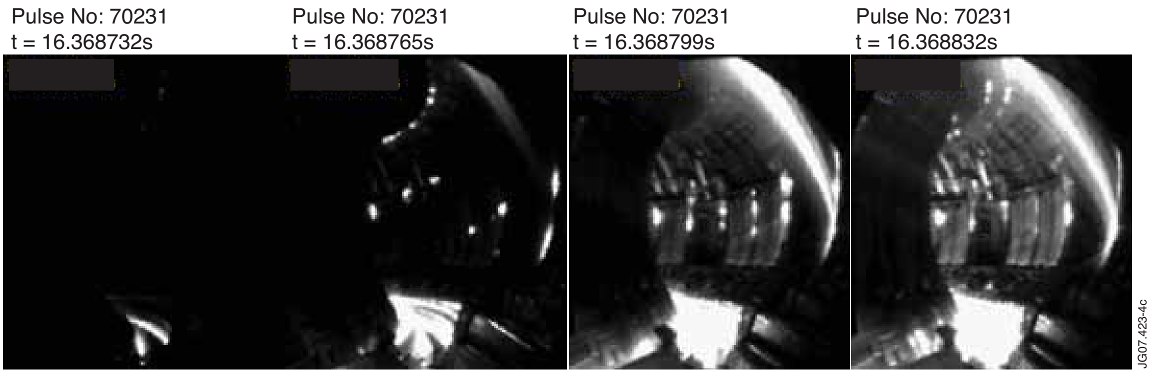

Figure 4: ELM onset and interaction with the wall (@ 30 kfps 25 us exposure). A helical wall-interaction pattern can be seen less than 40μs after the start of the D_α rise.

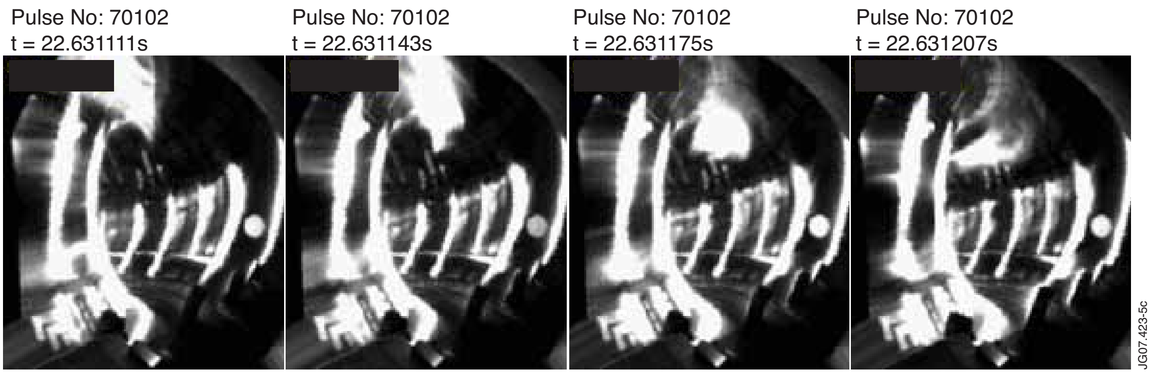

Figure 5: JET interior during a plasma disruption (@ 30 kfps, 25μs exp. time). The magnetic configuration is largely lost and the plasma interacts strongly with the inner and outer walls. A light cloud is seen to move toroidally in the counter-current direction . It moves ~90deg in the toroidal direction in the lapse of 3 frames. For R=3m this gives ~4×10^4 m/s.