Journal of Nuclear Materials 390–391 (2009) 100–102

Contents lists available at ScienceDirect

Journal of Nuclear Materials

journal homepage: www.elsevier.com/locate/jnucmat

Investigation of temporal evolution and spatial distribution of dust creation events in DITS campaign using visible CCD cameras in Tore Supra

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ARTICLE INFO

PACS:
52.25.Vy
52.70.Kz

ABSTRACT

Images of wide-angle visible CCD cameras contain information on dust creation events (flaking) that occur during plasma operations. Due to the interaction with plasma, flakes entering into the plasma left straight line-like visible traces behind in the images. Analyzing these traces by image processing, the temporal evolution, spatial distribution, and statistics on dust creation events in DITS campaign in Tore Supra were obtained.

1. Introduction

In fusion research, large numbers of various diagnostics are employed for scientific data acquisition. CCD cameras are operational tools which provide many kinds of information in wide ranges of spectra from UV to IR. Scientific analysis of signals including various image processing gives valuable information on a particular shot as well as long term evolution of the signals during a campaign, e.g., DITS (Deuterium Inventory in Tore Supra) campaign in Tore Supra (TS). In TS visible CCD images (352x288 pixels), various events were identified: 1. Very small events (1–3 pixels) caused by the neutron/X-ray impact on the camera CCD array, 2. Thin trajectories, typically up to 800 pixels, rather straight lines that are attributed to dust particles flaking into the plasma because of their kinetic motion, 3. MARFE-like, light emission from large areas (more than 1000 pixels) located usually at high field side (HFS) often associated to major disruption of the plasma column. Dust particles in fusion devices were observed by (fast) CCD cameras [1–3]. An image processing method for the extraction of data related to dust particles using visible CCD cameras is developed and tested in TS and in Asdex Upgrade (AUG) [4]. In this paper, we will present the temporal evolution and the spatial distribution of dust creation events (DCEs) in TS during DITS campaign. More information on DITS campaign will be reported by Pegourie [5]. We have restricted our image analysis in this paper to thin trajectories which shows well-defined straight line behaviour and kinetic motion. Images containing large blobs and MARFE-like events were automatically excluded from the analysis.

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0022-3115/$ - see front matter © 2009 Published by Elsevier B.V.
doi:10.1016/j.jnucmat.2009.01.120

2. On the dust creation events in DITS campaign

2.1. Temporal evolution analysis

Fig. 1 shows the overview of the number of events per second (NEPS) – the total number of events divided by total plasma operation time in the given shot – as a function of total plasma operation time in whole DITS campaign. Blue closed squares indicate the NEPS in normal shots, while red closed circles represent disruption shots. From Fig. 1, two different phases were shown. Note that, the plasma parameters are all fixed in the first phase. At the beginning of the first phase (operation time up to $\sim$13800 s), the NEPS of normal shots increases exponentially from 0.2 to 4.29 with a mean value of 2.2 events per second. The NEPSs of disruption shots has much higher value than that of normal shots and they are scattered in wide range with an average value of 10.52 events per second which indicates massive flaking during these shots. Due to the large numbers of disruptions at the end of the first phase, the plasma operation scenario had to be changed (lower the input power level and slower ramp up). After changing the plasma operation scenario, the NEPS decreased dramatically down to a level of 1.25 events per second at the beginning of the second phase (operation time 13 800–18 000 s) with a mean NEPS in the second phase has a value of 2.7 events per second, which is similar to that in the first phase (2.2 events per second). However, NEPS increases, again, as a function of plasma operation time with almost the same tendency as in the first phase. The results indicate an important consequence on the long pulse and long term identical plasma operation.

2.2. Spatial distribution analysis

Fig. 2 show normalized contour plots (64 level between 0 and maximum value, divided by total plasma operation time) of

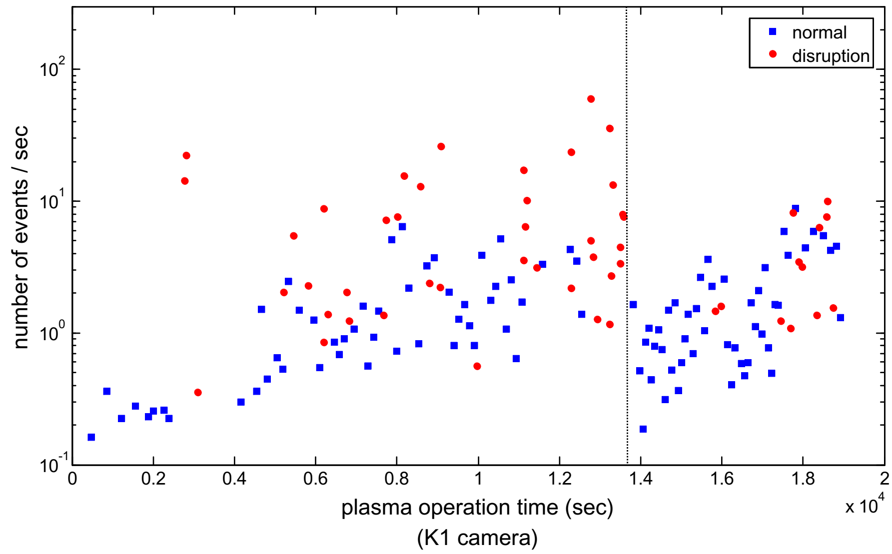

Fig. 1. Number of events per second as a function of total plasma operation time in DITS campaign.

integrated images, over 260 000 frames of DITS campaign. Although the information on individual flaking events is lost due to the integration, the spatial distribution of the flaking events were identified by comparing with a reference frame of CCD image of TS shown on the left in Fig. 2. First of all, a broad distribution of low number of events (blue) on the Toroidal Pumped Limiter (TPL) and lower part of the HFS inner wall is from the result of the random flaking events. On the other hand, several localized heavy flaking patterns on the TPL were identified. These areas are likely to be the deposition dominant zones. Note that the count numbers in contour plot, especially at spatial locations far from the camera, have been weighted due to the smaller spatial resolution caused by the use of wide-angle optics: The larger the distance is, the smaller the spatial resolution is. Furthermore, due to the perspective of the CCD camera, due to the 3D to 2D projection, events occur at the edge of the HFS inner wall (label A in Fig. 2) cannot be distinguished where they are originated from. Care must be taken for the interpretation of these events.

2.3. Statistics on DITS campaign from contour plot

Contour plot provides information on spatial distribution of the flaking events in TS. For more detailed analysis, additional matrices representing each in-vessel component, defined as 352 × 288 with 1 for region of interest (ROI, e.g. TPL) and 0 for elsewhere – are multiplied. Table 1 shows the statistics on the DITS campaign. As it is already identified in the contour plot in Fig. 2, about 71% of flaking events were from the TPL observed by K1 camera. On the HFS inner wall, 13.7% of events are observed. 'Other' indicates the areas excluding Outboard Limiter (OL), TPL, and the HFS inner wall. About 15.1% of events were found in these areas. Most of the events in 'other' areas are concentrated on the edge of the HFS inner wall. Note that a large observation area results much higher number of events, simple comparison of numbers in statistics may mislead the results. Thus, the average number of events per pixel (NEPP) which is corresponding to the spatial density of the events is used. NEPP at the HFS inner wall is about 1.421, and that at the TPL is about 29.71.

2.4. Extrapolation: total count numbers in TS

CCD cameras installed in TS have limited observation volume. Thus, it is of interest to extrapolate the results to the entire TS vacuum vessel. To achieve the extrapolation, factors for each component have to be considered.

1. The TPL observed by K1 camera is about 27.8% of entire TPL.
2. Area of HFS inner wall observed by K1 camera is 1/6 of entire HFS surface.
3. Area of Low Field Side (LFS) outer wall observed by K1 camera is 1/9 of entire LFS surface.
4. OL and 5 antenna protections.

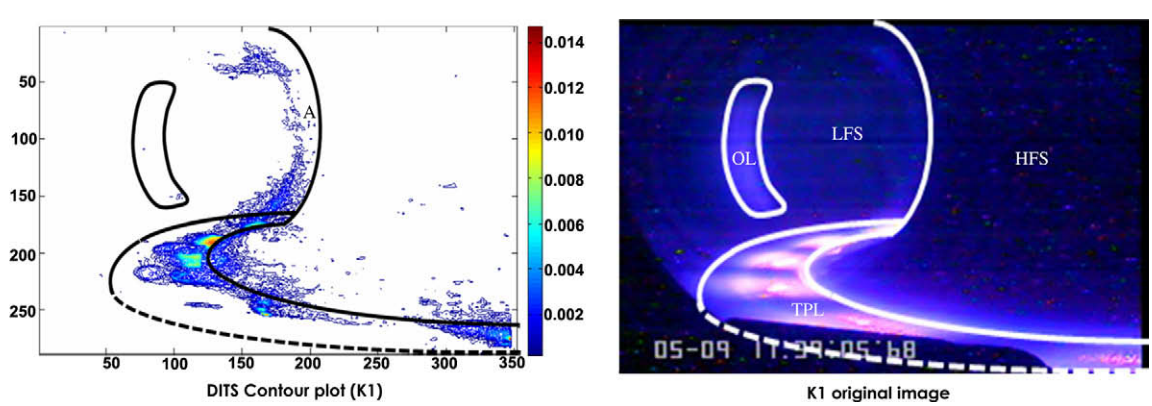

Fig. 2. DITS normalized contour plot of flaking events detected by K1 camera which indicates the spatial location of flaking events. Axes numbers in contour plot indicate the pixel numbers of the CCD array.

Table 1
Statistics on total number of events in DITS campaign.

Location		Total count number in contour	Total count number/pixel (density)	%
K1 camera	Outboard limiter	21	0.006	0.005
	HFS inner Wall	57 353	1.421	13.671
	TPL	298 754	29.706	71.213
	Other	63 391	1.452	15.110
	Total	419 519	4.300	100

Table 2
Extrapolation of total number of events based on DITS campaign.

Location		Total count number in contour	Factor	Total count number (extrapolation)	%
K1 camera	Outboard limiter	21	6	126	0
	HFS inner Wall	57 353	6	344 118	17.3
	TPL	298 754	3.6	1 075 514	54
	Other	63 391	9	570 519	28.7
	Total	419 519	–	1 990 277	100

Table 2 shows the extrapolation of the statistics for DITS campaign. The extrapolation shows slight different results from the statistics directly obtained by contour plot: the total count number at TPL is about 54%, about 17.3% at HFS inner wall, and about 28.7% at other places by K1 camera.

3. Discussion

The long term temporal evolution of flaking events observed in TS during the DITS campaign indicates an important issue on the 'long pulse and long term identical plasma operation'. Analyses of the long term temporal evolution of DCEs in TS 2006 campaign (∼1000 shots) and in AUG 2007 campaign (∼200 shots) show that the DCEs at the beginning of both campaigns decrease exponentially as a function of plasma operation time with proper wall conditioning and cleaning discharge (not shown here, will be published in a forth coming paper). On the contrary, the number of events during the DITS campaign increases exponentially without wall conditioning and cleaning discharge in-between. These reveal that such plasma operations may cause series of problems of heavy flaking of dust particles. Furthermore, from the spatial distribution analysis, it is found that the flaking events may not randomly occur, but from localized areas in vessel, e.g. from the TPL, especially deposition dominant zones. Such areas have to be carefully monitored and their status has to be traced carefully.

4. Summary

The long term temporal evolution and the spatial distribution of the dust creation events in DITS campaign were analyzed by means of CCD image analysis developed in TS. CCD cameras are already installed in fusion devices observing plasma operation and huge amount of image data are available. This opens a possibility to utilize CCD camera observation as a new diagnostic based on image processing. The main result of the image processing shown in this paper demonstrates the potential ability of the technique for the in-situ in-vessel dust study.

Acknowledgements

Authors thank J. Winter, P. Ghendri, and E. Tsitrone for valuable discussions and helpful comments on the development of image processing method.

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