Optical Techniques to study the dust resuspension problem in case of LOVA: Comparison of results obtained with PIV and Shadowgraph

Andrea Malizia[1], Massimo Camplani[2], Michela Gelfusa[1], Luca Antonelli[1,3], Francesco Barbato[1], Maria Del Vecchio[1], Maria Richetta[1], Luis Salgado[2,4], Carlo Bellecci[1] and Pasqualino Gaudio[1].

[1]*Associazione EURATOM-ENEA, Department of Industrial Engineering, University of Rome "Tor Vergata", Via del Politecnico 1, 00133 Rome, Italy*

[2]*Grupo de Tratamiento de Imágenes, E.T.S.I de Telecomunicación, Universidad Politécnica de Madrid, Spain*

[3]*Université Bordeaux 1, CNRS, CEA, CELIA (Centre Lasers Intenses et Applications), UMR 5107, F-33405 Talence, France*

[4]*Video Processing and Understanding Laboratory, Universidad Autónoma de Madrid, Spain*

Corresponding author : Andrea Malizia, PhD. malizia@ing.uniroma2.it

1 Introduction

The various type of Plasma Material Interactions are one of the main cause of dust creation inside tokamaks [1-4]. A small facility, Small Tank for Aerosol Removal and DUST (STARDUST), [1-12, 19] was set up to perform experiments concerning the dust mobilization in a volume with the initial condition similar to those existing in ITER VV.

The dust velocity and direction values under LOVA experimental simulation have been analyzed by the mean of two optical techniques:

1. Particle Image Velocimetry, used for dust type: Stainless Steel (SS316) [6];
2. Shadowgraph used for tungsten (W). [6]

In the present paper the two experimental set-up and the preliminary results will be discussed.

2 Method and materials

2.1 *PIV experimental set-up*

Particle image velocimetry (PIV) is an optical method generally used for flow visualization. It is used to obtain instantaneous velocity measurements and related properties of dust (or more in general particles) in fluids. With this aim the fluid is seeded with tracer particles (dust, in our case) which, for sufficiently small dimensions, are assumed to faithfully follow the flow dynamics The motion of the seeding particles is used to calculate speed and direction (the velocity field) of the flow being studied.

2.2 *SHADOWGRAPH experimental set-up*

SHADOWGRAPH is a technique generally used for flow visualization too. It employs an expanded collimated beam of light that illuminates a fluid. If the region crossed by the light beam shows a disturbance, the refractive index could change and the individual light rays are refracted and bent out of their original path. This causes a spatial modulation of the light-intensity distribution with respect to the original intensity on the screen. The resulting pattern is a shadow of the refractive index field prevailing in the region of the disturbance. As in the PIV technique, SHADOWGRAPH has not been employed in order visualize the fluid itself but rather the particles (tungsten dusts) mobilized by the flow fluid.

3 Experimental results

The PIV and SHADOWGRAPH experimental set-up used for the experimental campaign are illustrated, respectively, in [18] and [20]. The Figure 1 and 2 showed the resolution of images (in a pre-processing phase) obtained, respectively, with PIV and Shadowgraph.

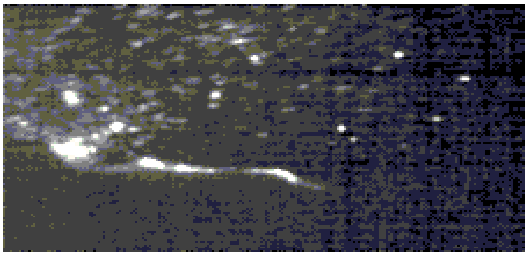

Fig.1 Image of SS316 with PIV

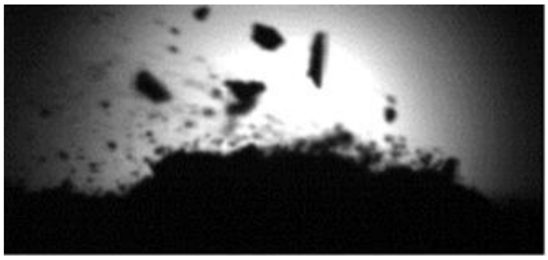

Fig.2 Image of W with SHADOWGRAPH

The computer vision approach proposed for SHADOWGRAPH consists of two main steps: particle detection (PartDet) and tracking (PartTrack). The use of the shadowgraph technique guarantees high contrast images allowing for particles detection moving inside STARDUST without a pre-processing phase. The obtained high contrast images are used to build a stable background model of the scene before the experiments have started, this model is then use to accurately identify, in each frame, the particles present in the tank. In particular, the background model is based on the Mixture of Gaussian (MoG) background model presented in [13]. In the work presented in [14], dust particle detection is performed with a similar approach. In particular, a per-pixel background model is obtained by estimating a temporal median of the pixel values; however, they generate a large number of erroneous detections due to camera noise that, in our case, is still present also in the high contrast images. The resulting foreground binary image is presented in figure 3 (that represent a different temporal frame than figure 2). As it can be noticed, the proposed approach guarantees a good detection accuracy of the moving particles in the tank. The obtained foreground connected regions are filtered by considering their area in order to identify the small moving particles.

Fig.3 Detected dust particle

For each iteration, the predicted positions and the detected particles position are then associated by considering their closeness in the image plane. The Hungarian algorithm [15] is employed in order to solve the assignment problem, allowing to track the same particles along the frames. The proposed approach for images elaboration obtained with PIV consists of three main steps: Pre-processing (imgProc block) to improve the image quality and ease particle detection and tracking (PartDet and PartTrack blocks). During the pre-processing step histogram equalization [16, 17] is applied to increase the images' contrast. This step is fundamental because the resolution of images obtained with PIV is lower than the one obtained with SHADOWGRAPH (see Figure 1 and Figure 3 and [18,20]) The rest of the approach is quite similar to those adopted for SHADOWGRAPH.

For both the experimental-set up described above, the sequence analyzed consist of 4000 fps simulating a LOVA at 300 Pa/s (27 l/min of flow rate).

The temporal range analyzed is from:

- 0,0744 to 0,11 seconds after the beginning of air inlet for PIV with SS316 (see table 1 for the values collected inside STARDUST in this temporal range);

Time (s)	$T_{wall\ mean}$(K)	T_{env} (K)	P_{in} (Pa)	FR (lit/min)
0,0744	280,13	280,46	170,92	3,18
0,11	282,13	280,46	191,83	4,68

Table 1 Experimental data collected inside STARDUST *

- 0,0754 to 0,1604 seconds after the beginning of air inlet for SHADOWGRAPH with W (see table 2 for the values collected inside STARDUST in this temporal range);

Time (s)	$T_{wall\ mean}$ (K)	T_{env} (K)	P_{in} (Pa)	FR (lit/min)
0,0754	278,19	280,24	172,35	3,16
0,1604	285,17	281,33	200,82	4,74

Table 2 Experimental data collected inside STARDUST *

* _Tables - Legend:_

- *1st Column : Time (in second) after the beginning of air flow inlet*
- *2nd Column : Mean value of wall temperature (in Kelvin) measured by thermocouples*
- *3rd Column : Mean value of STARDUST internal environment temperature (in Kelvin) measured by thermocouples*
- *4th Column : Internal pressure inside STARDUST (in Pascal)*
- *5th Column : Flow rate of pressurized air flowed inside STARDUST (Liter/minute)*

By data images techniques the velocity values of dust particles mobilized have been calculated considering a time step of 0,005 seconds (25 frames). The results are shown in Figure 3 for PIV and Figure 4 for SHADOWGRAPH.

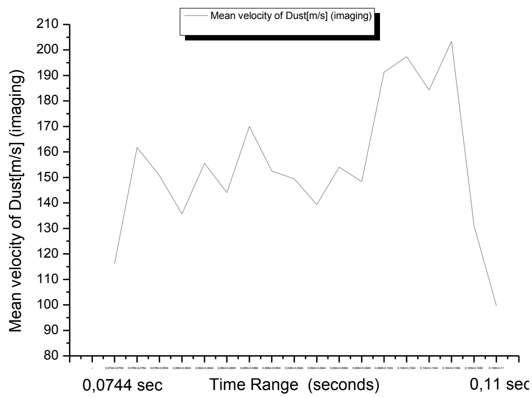

Fig.1 SS316 Velocity values measured at the beginning of air flow inlet

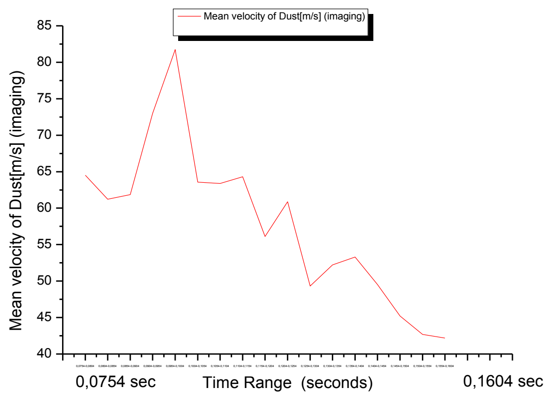

Fig.2 Tungsten Velocity values measured at the beginning of air flow inlet

4 Conclusions

The authors have investigated the dust mobilization inside STARDUST reproducing a LOVA and then they have analyzed the velocity values and directions of SS316 and W. It has been demonstrated that with the two optical techniques (PIV and SHADOWGRAPH) it is possible investigate the dust behavior (of both the dark dusts like W and the bright dust like SS316) during a LOVA experimental simulation. The main evidences are: a)There are both a better resolution and contrast of images with Shadowgraph compared to those obtained with PIV. b) A Reduction of computational time during the computer vision with the images obtained with the SHADOWGRAPH. c) It is necessary to increase the field of view inside STARDUST by introducing new windows. d) It is necessary to create an inlet of the air from the divertor region in order to reduce the direct impact of air on the dust. e) It is necessary to compare the velocities with those recovered with lower pressurization rates.

References

[1] Gaudio, P., Malizia, A., Lupelli, I. "Experimental and numerical analysis of dust resuspension for supporting chemical and radiological risk assessment in a nuclear fusion device" (2010) International Conference on Mathematical Models for Engineering Science - Proceedings, pp. 134-147

[2] A. Malizia., I. Lupelli, M. Richetta, M. Gelfusa, C. Bellecci, and P. Gaudio. Safety analysis in large volume vacuum systems like tokamak: experiments and numerical simulation to analyze vacuum ruptures consequences. Hindawi Publishing Corporation, Advances in Materials Science and Engineering, Volume 2014, Article ID 201831, 30 pages, http://dx.doi.org/10.1155/2014/201831

[3] Benedetti, M., Gaudio, P., Lupelli, I., Malizia, A., Porfiri, M.T., Richetta, M. "Large eddy simulation of Loss of Vacuum Accident in STARDUST facility" (2013) Fusion Engineering and Design, . 88 (9-10) , pp. 2665-2668

[4] M.Benedetti, P.Gaudio, I.Lupelli, Malizia A., M.T.Porfiri, M.Richetta (2011). Influence of Temperature Fluctuations, Measured by Numerical Simulations, on Dust Resuspension Due to L.O.V.As . International journal of systems applications, engineering & development, vol. 5; p. 718-727, ISSN: 2074-1308

[5] Bellecci, C., Gaudio, P., Lupelli, I., Malizia, A., Porfiri, M.T., Quaranta, R., Richetta, M. "Validation of a loss of vacuum accident (LOVA) Computational Fluid Dynamics (CFD) model" (2011) Fusion Engineering and Design, 86 (9-11), pp. 2774-2778.

[6] Bellecci, C., Gaudio, P., Lupelli, I., Malizia, A., Porfiri, M.T., Quaranta, R., Richetta, M. "STARDUST experimental campaign and numerical simulations: Influence of obstacles and temperature on dust resuspension in a vacuum vessel under LOVA" (2011) Nuclear Fusion, 51 (5), art. no. 053017.

[7] Bellecci, C., Gaudio, P., Lupelli, I., Malizia, A., Porfiri, M.T., Quaranta, R., Richetta, M. "Loss of vacuum accident (LOVA): Comparison of computational fluid dynamics (CFD) flow velocities against experimental data for the model validation" (2011) Fusion Engineering and Design, 86 (4-5), pp. 330-340.

[8] Benedetti, M., Gaudio, P., Lupelli, I., Malizia, A., Porfiri, M.T., Richetta, M. "Scaled experiment for Loss of Vacuum Accidents in nuclear fusion devices: Experimental methodology for fluid-dynamics analysis in STARDUST facility" (2011) Recent Researches in Mechanics - Proc. of the 2nd Int. Conf. on FLUIDSHEAT'11, TAM'11,Proc. of the 4th WSEAS Int. Conf. UPT'11, CUHT'11, pp. 142-147.

[9] Bellecci, C., Gaudio, P., Lupelli, I., Malizia, A., Porfiri, M.T., Quaranta, R., Richetta, M. "Experimental mapping of velocity flow field in case of L.O.V.A inside stardust facility" (2010) 37th EPS Conference on Plasma Physics 2010, EPS 2010, 2, pp. 703-706.

[10] P.Gaudio, Malizia A., I.Lupelli (2010). Experimental and Numerical Analysis of Dust Resuspension for Supporting Chemical and Radiological Risk Assessment in a Nuclear Fusion Device. In: Conference Proceedings - International Conference on Mathematical Models for Engineering Science (MMES' 10). Puerto De La Cruz, Tenerife, 30/11/2010 - 30/12/2010, p. 134-147, ISBN/ISSN: 978-960-474-252-3

[11] Bellecci, C., Gaudio, P., Lupelli, I., Malizia, A., Porfiri, M.T., Quaranta, R., Richetta, M. "Characterization of divertor influence in case of LOVA: CFD analysis of stardust experimental facility" (2009) 36th EPS Conference on Plasma Physics 2009, EPS 2009 - Europhysics Conference Abstracts, 33 E1, pp. 266-269.

[12] C. Bellecci, P. Gaudio, I.Lupelli, Malizia A., M.T.Porfiri, M. Richetta (2008). Dust mobilization and transport measures in the STARDUST facility. In: EPS2008 Proceedings, 35th EPS Conference on Plasma Physics. Hersonissos - Crete - Greece, 9 - 13 June 2008, vol. ECA Vol.32, p. P-1.175

[13] Stauffer, C., & Grimson, W. E. L. Adaptive background mixture models for real-time tracking. IEEE Conference on Computer Vision and Pattern Recognition , pp. 246–252, 1999.

[14] Boeglin, W. U., Roquemore, a L., & Maqueda, R. (2008). Three-dimensional reconstruction of dust particle trajectories in the NSTX. The Review of scientific instruments, 79(10), 10F334. doi:10.1063/1.2965001

[15] J. Munkres, "Algorithms for the Assignment and Transportation Problems", Journal of the Society of Industrial and Applied Mathematics, 5(1):32-38, 1957

[16] A.Murari, M. Camplani B.Cannas, D.Mazon, F.Delaunay, P.Usai, J.F.Delmond and JET EFDA Contributors, "Algorithms for the automatic identification of MARFE and UFO in JET database of visible camera videos". IEEE transaction on Plasma Science. Vol 38 - 2. page 3409-3418 2010.

[17] R.C. Gonzalez, R.E. Woods, Digital Image Processing, Addison Wesley, 1992.

[18] A. Malizia et all (2014). "Dust tracking techniques applied at STARDUST facility : first results. Fusion engineering and design, ISSN: 0920-3796, doi: 10.1016/j.fusengdes.2014.01.014

[19] I. Lupelli, P. Gaudio, M. Gelfusa, A. Malizia, I. Belluzzo and M.Richetta (2014). Dust tracking techniques applied at STARDUST facility : first results. Fusion engineering and design, ISSN: 0920-3796, doi: 10.1016/j.fusengdes.2014.03.064

[20] P. Gaudio, A.Malizia et all (2013). Shadowgraph Technique applied to STARDUST facility for dust tracking: first results . In: Proceedings ICFDT 2013 Conferece. INFN- Frascati, 25-27 Novembre 2013.