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Dust tracking techniques applied to the STARDUST facility: First results

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HIGHLIGHTS

- Use of an experimental facility, STARDUST, to analyze the dust resuspension problem inside the tokamak in case of loss of vacuum accident.
- PIV technique implementation to track the dust during a LOVA reproduction inside STARDUST.
- Data imaging techniques to analyze dust velocity field: first results and data discussion.

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ABSTRACT

An important issue related to future nuclear fusion reactors fueled with deuterium and tritium is the creation of large amounts of dust due to several mechanisms (disruptions, ELMs and VDEs). The dust size expected in nuclear fusion experiments (such as ITER) is in the order of microns (between 0.1 and 1000 μm). Almost the total amount of this dust remains in the vacuum vessel (VV). This radiological dust can re-suspend in case of LOVA (loss of vacuum accident) and these phenomena can cause explosions and serious damages to the health of the operators and to the integrity of the device. The authors have developed a facility, STARDUST, in order to reproduce the thermo fluid-dynamic conditions comparable to those expected inside the VV of the next generation of experiments such as ITER in case of LOVA. The dust used inside the STARDUST facility presents particle sizes and physical characteristics comparable with those that created inside the VV of nuclear fusion experiments. In this facility an experimental campaign has been conducted with the purpose of tracking the dust re-suspended at low pressurization rates (comparable to those expected in case of LOVA in ITER and suggested by the General Safety and Security Report ITER-GSSR) using a fast camera with a frame rate from 1000 to 10,000 images per second. The velocity fields of the mobilized dust are derived from the imaging of a two-dimensional slice of the flow illuminated by optically adapted laser beam. The aim of this work is to demonstrate the possibility of dust tracking by means of image processing with the objective of determining the velocity field values of dust re-suspended during a LOVA.

1. Introduction

By the nature of its operation, an experimental nuclear fusion device generates aerosol particulate and flakes that may affect its safety and operational performance. Matter of this type, usually referred to as dust, is produced in fusion devices by energetic plasma–surface interactions, (disruptions and other events) that cause significant erosion. A sizeable portion of the eroded material does not adhere to surfaces and generates dust, which is capable of being re-suspended in case of events like LOVA. Several mechanisms can be responsible for generation of particulate. Possible mechanisms in magnetic fusion systems include blistering and fracturing of deposited layers, generation of reactive species in edge plasmas, arcing, explosive ejection and brittle destruction of surface imperfections, and nucleation of vaporized materials [1]. If a LOVA occurs in a fusion reactor, buoyancy-driven exchange flows take place at breaches of the vacuum vessel (VV) due to the temperature and pressure difference between the inside and outside of the vacuum vessel. The exchange flows may bring mixtures of activated material and tritium through the breaches. Particle sizes

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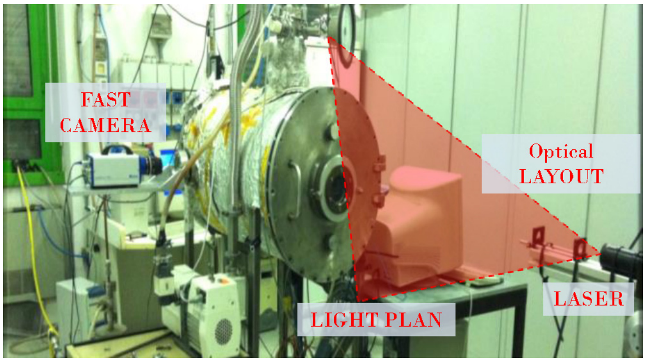

Fig. 1. Experimental apparatus.

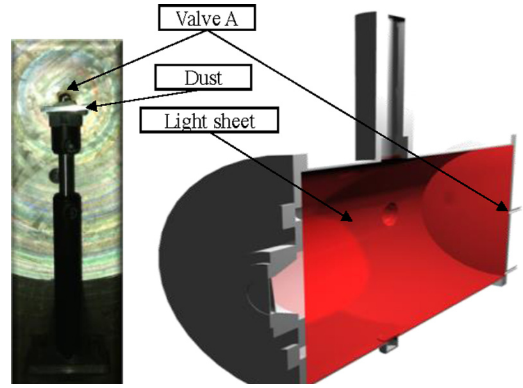

Fig. 2. SS136 placed at the level of Valve A at a distance of 15.5 cm.

are typically small, in the 0.1 micron to 1000 μm diameter range. This particle size raises three separate classes of safety concerns [2]. The first concern is that because of the small diameters, these toxic dusts can be easily re-suspended (the decreasing particle diameter leads to dominance of fluid drag (∼d^2) over gravity (∼d^3) forces, but is important notice that at the smallest of diameters, adhesive forces (∼d) dominate and inhibit resuspension).

The second concern is for personnel occupational safety, since these dusts are breathable sizes [21–24]. The third concern is that these dusts are potentially combustible. Several experimental studies [3–19] demonstrated that the exchange flows depend on number, position, length and shape of breaches, pressure and temperature conditions and type of fluid. Therefore, it is very important to investigate the dust re-suspension characteristics during a LOVA event. The Quantum Electronics and Plasma Physics Research Group of University of Rome Tor Vergata (QEP) has developed an experimental facility, STARDUST, that allows the reproduction of thermo fluid-dynamic comparable to those expected in the vacuum vessel (VV) of nuclear fusion plants like ITER [7–14,16–19]. In this work the QEP in collaboration with the Grupo de Tratamiento de Imágenes (GTI) of Universidad Politécnica de Madrid demonstrate the capability of STARDUST to collect images of dust re-suspended during a LOVA and to obtain information about the velocity field of dust re-suspended. The aim of this work is to demonstrate the possibility to use STARDUST not only to analyze the thermo fluid-dynamic behavior in case of LOVA but also the velocity fields characteristics of dust re-suspended. The experimental set-up and first results of the dust tracking techniques applied to this particular case will be shown.

2. STARDUST-experimental set up

In the previous experimental campaign QEP demonstrate the capability of STARDUST to replicate thermo fluid-dynamic conditions comparable to those expected inside the VV of nuclear fusion plants such as ITER [7,9,11,13,14,16,18,19] and the dust resuspension fraction in case of LOVA [8–10,12,17]. QEP validated the experimental results by means of CFD codes developed in 2D [7–19]. The new experimental set-up allows a high frequency rate images acquisition of dust re-suspended in case of LOVA inside STARDUST VV. The implemented set-up reproduces a sort of Particle Image Velocimetry (PIV), to obtain instantaneous velocity measurements and related properties of particles within the fluids.

Instead of introducing a tracer in the fluid the authors used the compressed air of STARDUST and illuminate this fluid so that dust particles are visible. The implemented experimental apparatus (Fig. 1) consists of a fast camera [30] and a He–Ne Laser (632.8 nm–30 W) with an optical layout (Fig. 1) to limit the illuminated physical region. The optics consists in a cylindrical lens to convert a light beam into a line and a square lens to convert the line into a sheet of light. That sheet illuminates the symmetry plan of the STARDUST VV and the dust placed at the level of Valve A (Fig. 2), used to reproduce a LOVA inside STARDUST at equatorial level [7,9,11,13]. The trigger of the fast camera is synchronized 100 ms before the inlet of air from the flow meter, in order to associate to each frame instantaneous values of: internal pressure, internal temperature, wall temperature and flow rates values automatically collected during the experiment [7–14,16–19]. The dust used previously was SS316 and W [12]. In this experimental campaign the authors used only SS316, with a granulometry from 15 to 45 μm, see Fig. 3 (Scanning Electron Microscopy characterization has been discussed in [12]) due to its brightness and capability to scatter the light compared to W that is a dark dust. The motion of the seeding dust has been used to calculate their speed and direction (the velocity field).

3. Particles detection and tracking

The proposed experimental setup and the fast camera allow dust particles trajectories detection inside STARDUST during a LOVA reproduction; as it can be noticed from Fig. 4(a), they appear as bright spots on a dark background. The goal of the proposed approach is to detect and track the dust particles in the tank to estimate their velocity and direction during the experiment. The proposed approach presented in Fig. 5 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 [25,26] is applied to increase the images' contrast. This step is fundamental. As Fig. 4(a) shows, the raw data provided by the fast camera do not allow to clearly discriminating moving dust particles with respect to the background. Fig. 4(b) illustrates an example of the contrast-enhanced image; as we can see, moving particles definition is enhanced allowing particle detection and tracking. The spatial resolution is approximately 0.0415 cm for each pixel.

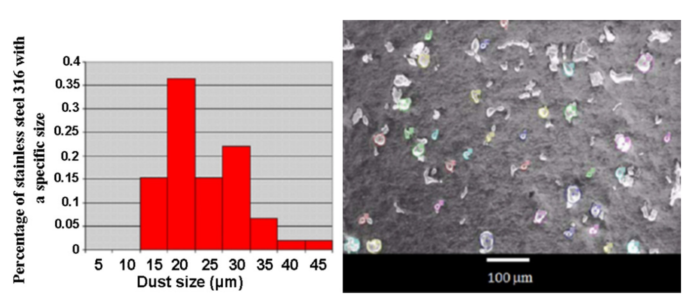

Fig. 3. SEM of stainless steel 316 used inside STARDUST [12].