Study of Dust Velocity with Plasma Rotation in KSTAR

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1. Introduction

Study of mobilizable dust particles will be an important issue for future large tokamaks like International Thermonuclear Experimental Reactor (ITER). A simulation suing a commercial finite element code for structural analysis named LS-DYNA has predicted that tungsten dust particle of 0.5 um radius with 100m/s causes noticeable damage to the wall [1]. Moreover, damage to first wall and diagnostics by mobilizable dust particles was reported in KSTAR [2]. In order to strategies for safety issue about mobilizable dust particles, it is important to measure dust velocity experimentally.

In this paper, we report dust velocity distribution using KSTARTV software which can identify the location of dust trajectories in 3D position on CCD image. In addition, relation between dust velocity and plasma rotation is described because ion drag force is dominant forces acting on dust particles.

2. KSTARTV software and Methods

KSTARTV software was developed in KSTAR [3]. This software can estimate the plasma position from toroidally viewed images manually and automatically. Fig.1 shows the interface of KSTARTV software. Well-defined straight line-like trajectories of dust particles recorded by CCD camera are located at in-board or out-board side because they cannot penetrate into the core. Some of dust particles look like location at core. However, those may be wrong information due to 3D to 2D projection. Therefore, the trajectories at in-board side are selected to avoid this problem. Since dust trajectories are recorded during the expose time, by measuring start and end point of the trajectories and angle between them in 3D coordinate, the velocity of dust particles is evaluated.

Size of dust particles is important for a dust velocity. However, we cannot measure the size of dust particles, because the intensity of light from dust particles include both the thermal radiation of dust grain and line radiation of the carbon neutrals and ions in the ablated cloud around the grain [4]. But, we can assume that size of dust particles we measured is range from 2 to 10 um. Results from dust collection in KSTAR [5] show that size distribution of dust particles in KSTAR has two peaks at 0.1 and 2um and is exponentially decreased. Furthermore, the detection limit of the dust by a fast CCD camera is 2um in DIII-D [6]. Therefore, it is not unreadable to assume that size of dust particles we measured is range from 2 to 10 um.

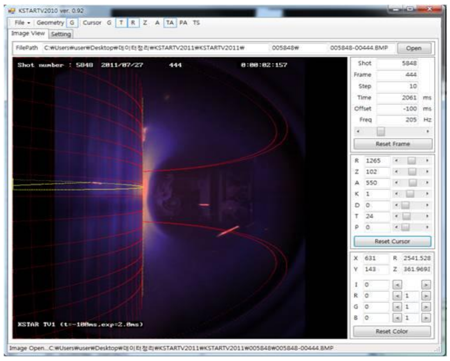

Fig. 1 Interface of KSTARTV software developed in KSTAR.

3. Results

3.1 Dust velocity distribution

Dust velocity distributions have estimated in 2010, 2011 and 2012 KSTAR campaigns (see Fig. 2). Peak, average and Root Mean Square (RMS) velocity in distributions are different due to different campaign goals. Each of campaign goals is ‘Shape & Position control’ in 2010, ‘Exploring H-mode’ in 2011 and ‘Long pulse H-mode’ in 2012. Average and RMS velocities in 2010 campaign are higher than those in other campaigns or similar. This would be an effect of initial dust velocity by plasma shaping and control. When plasma touches the wall, initial dust velocity is fast due to the law of action and reaction. Thus, faster dust particles in 2010 campaign may be generated more than other campaigns. Distributions have shifted toward higher velocity because of enhancement of plasma preference likes edge plasma parameters.

3.2 Reaction between dust velocity and plasma flows

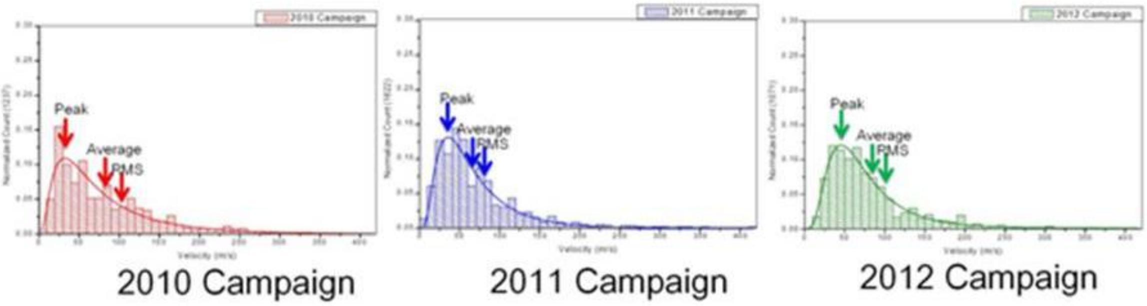

Fig. 2 Dust velocity distributions fitting log-normal distribution in 2010, 2011 and 2012 KSTAR campaigns

Dust particles are exerted by drag, pressure gradient, electromagnetic and gravity forces etc. The most dominant force acting on dust particles is ion drag force among those forces [7].

$$F_{iondrag} = \pi a^2 m_i n_0 |v_p - v_d|(v_p - v_d)$$

Where πa^2 is cross-section, and $v_p - v_d$ the relative velocity between dust particles and plasma flows. Thus, we have experimentally analyzed dust velocity with plasma rotation. Fig.3 shows RMS velocity of dust particles as function of plasma toroidal rotation velocity at edge and pedestal.

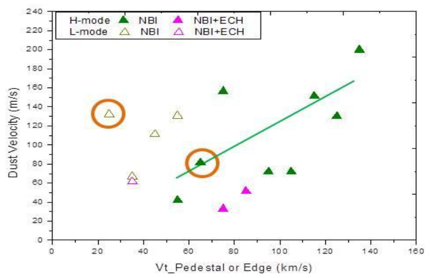

Fig.3. Dust velocity (RMS) as function of plasma toroidal rotation velocity at pedestal or edge in 2012 KSTAR campaign.

Plasma rotation velocity has been measured by Charge Exchange Spectroscopy system (CES). L- and H-mode are separately marked. Moreover, shots of ECH effect are divided. Points in circle are suspected because the sampling number of dust particles is extremely low. Dust velocity is lineally increased with plasma rotation velocity at edge or pedestal. For quantitative analysis, we represent dust velocity as function of stored energy divided by the plasma current.

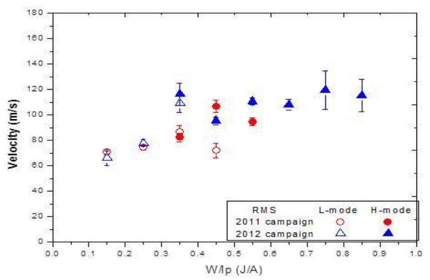

Fig. 4 Dust velocity (RMS) as function of stored energy divided by the plasma current (W/Ip) in 2011 and 2012 KSTAR campaigns.

W of Ip factor is the approximate scaling parameter for plasma rotation velocity [8]. Core and edge plasma rotation velocity from CES data are linearly increased in KSTAR (Not shown here). Relation between dust velocity and W of Ip is clearly showed in Fig.4. This means dust velocity is dependent on plasma flows. Therefore, the increase of the plasma rotation velocity at edge causes increase of dust velocity and probability that dust particles can damage wall and diagnostics.

3. Conclusions

Dust velocity distributions have been experimentally estimated for first time in KSTAR. According to each campaign, distributions have shifted toward higher velocity because of enhancement of edge plasma parameters. Especially, dust velocity is increased with plasma rotation velocity. Nowadays, impact of mobilizable dust particles hardly exists in tokamaks. However, they will be a more critical safety issue particularly for ITER. For more specific study for dust velocity, dust velocity related with other plasma parameter at edge like temperature and density has to be analyzed.

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