TUNGSTEN DUST TRANSPORT IN THE STOR-M TOKAMAK

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Interaction between the STOR-M tokamak (R/a = 0.46/0.12 cm, B_t = 0.65 T, I_p = 22 kA) plasma and the artificially injected tungsten (W) microspheres (dust) has been studied. The STOR-M experiments show that the injected dust particles drift toroidally in the plasma flow direction. When the plasma current direction in STOR-M is reversed, the toroidal plasma flow direction and the dust drift direction are also reversed. Supplemental post-mortem sampling of dust particles in STOR-M indicates a substantial reduction in the sizes of dust particles collected toroidally downstream of the dust drift direction, indicating (a) the effect of dust ablation in plasma, and (b) the dependence of the dust transport properties on the size of the dust. The net force on the dust particles has been interpreted, based on the measured acceleration and the mean diameter of the W-dust in the STOR-M discharges, and compared with the Barnes and Hutchinson/Khrapak ion-drag force models [1]. It has been found that the mean force measured is systematically larger than predicted by either model, though within a factor of approximately 2-3. More detailed analysis is underway to understand the underlying physics for ion-drag, the assumptions made, and applicable limits set for approximations in those models, in conjunction with the measured STOR-M plasma parameters. The STOR-M tokamak plasma with relatively low temperature and density makes it an ideal candidate to simulate the interaction between the plasma and the dust spattered off the first wall in the edge and scrape-off layer (SOL) regions in reactor-grade tokamaks. Understanding the plasma-dust interaction is important to evaluate the transport of dust particles, particularly those containing tritium, in reactors. It is also an important aspect in tritium retention and fuel cycle studies.

1. EXPERIMENTAL SETUP

Dust particles were injected into the STOR-M tokamak from a port on the top of the STOR-M vessel. The injected dust plume drifted downward under gravity and slowly expanded in the horizontal direction as characterized previously [2]. After a delay time τ, on the order of hundreds of milliseconds, when a portion of the plume filled the STOR-M chamber, the STOR-M discharge was initiated. The glowing trajectories of the dust particles in the discharge were recorded using two synchronized fast video cameras (Model: Chronos 1.4) with an 800×800 pixel resolution, corresponding to a 6.6 cm square field of view at the focusing plane. The distance over which dusts was discernible along the line of view of the cameras was $\sim$ 12 cm for both cameras, which covered the central region of the STOR-M plasma of 25 cm in diameter. The exposure time was 1 μs and the frame rate was 2156.3 frames/s. One camera viewed horizontally from the low field side and the other vertically from the bottom into the tokamak, all at the same toroidal location where the dust plume was injected from the top. The plasma flow velocity was measured based on Doppler shift of a spectral line of the C(VI) impurity ions using ion Doppler spectroscopy. The line-averaged electron density ($\sim 5 \times 10^{18}\ \mathrm{m}^{-3}$) was measured using a 4-mm microwave interferometer and the electron temperature (~100 eV) was estimated based on Spitzer conductivity.

2. EXPERIMENTAL RESULTS

Characteristic dust trajectories for a delay time of $\tau = 270$ ms between dust injection and a STOR-M discharge were obtained based on a velocimetry algorithm and the video images recorded by both cameras. Figs. 1a and 1b show particles' trajectories in the vertical-toroidal plane (from the side camera) and the radial-toroidal plane (from the bottom camera), respectively. The trajectories reveal acceleration in the toroidal direction, causing particles to change their direction from the typical free-fall path. Almost no radial dust motion is observed (Fig 2b). Note, the size of the arrowhead indicates the magnitude of the final velocity for trajectory of an identified dust. By inspection one can see that the arrowheads are larger for trajectories determined from the side camera as opposed to those determined by the bottom camera because particles are tracked by the side camera until they disappear (possibly due to ablation), while particles in the bottom camera move out of the cameras view, due to the smaller bottom port acting like a field aperture. For this reason, the average toroidal acceleration of particles computed from trajectories is approximately a factor of two lower for the bottom view compared to the side view.

Plasma parameters were recorded with and without dust injection over many shots. Discharges without dust represents the best possible clean discharge for the day, while the amount of dust present in the vessel increases with the delay time, detrimentally affecting the plasma discharge quality. Approximately 7 -13 ms after STOR-M discharge, an increase in the loop voltage and decrease in plasma current are observed, likely due to detrimental effect of enhanced Bremsstrahlung radiation associated with dust ablation and ionization.

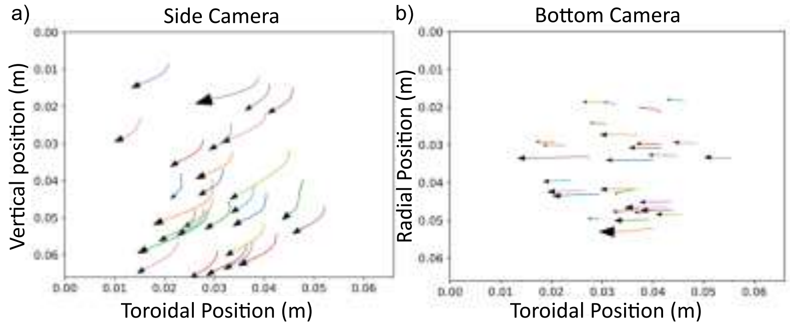

FIG. 1. Characteristic dust particle trajectories reconstructed from video frames captured with a) the side camera and b) the bottom camera. The delay time was $\tau = 270$ ms.

Fig 2 shows the evolution of toroidal plasma flow velocities for the cases without dust injection or with dust injection at delay times $\tau = 250, 270$ ms. The plasma flows mostly in the counter current direction (negative). The plasma flow velocity, with no dust, becomes measurable around 8 ms after current ramp-up phase, which is at least 1 ms before dust appears in cameras, due to the cooler plasma or W-impurities which imped the generation of C(IV), required for IDS measurement in our case. Note, the plasma flow velocity is higher (between 10-13 ms) when more dust is present for $\tau = 270$ ms (red curve) than $\tau = 250$ ms (green curve). After 13 ms, when dust cannot be observed in camera frames, all flow velocities are far more similar, regardless of the amount of dust present initially. This indicates that the ion flow recovers in STOR-M once dust is no longer visible.

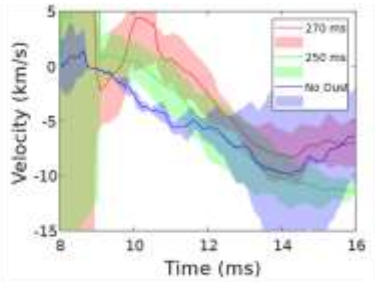

FIG. 2. Mean (solid line) and standard deviation (shaded region) of plasma toroidal flow velocities measured without dust injection and at various delay times. Positive velocity is co-current, in the toroidal direction.

3. DETERMINATION OF THE FORCE ON DUST

The force on dust particles is found to be significant in the toroidal direction, following the toroidal plasma flow in STOR-M. In an additional test, the plasma current was reversed in STOR-M, resulting in the reversal of toroidal plasma flow direction and at the same time the dust drift direction in STOR-M. We also find that when dust is visible in camera frames, it has a distinct effect on plasma parameters and reduces the toroidal plasma velocity. This is strong qualitative evidence that ion-drag force plays a key role in dust dynamics occurring in STOR-M.

Taking the mean acceleration of the dust particles interpreted by the side camera of ~ 4 km/s^2 and multiplying by the average mass of injected dust particles (21 ng), yields a force of approximately 84 nN. Using the measured plasma temperature, density, flow velocity, and the W-dust size, the ion-drag force can also be calculated using Barnes and Hutchinson/Khrapak models [1]. It is found that the observed drag force is 2-3 time larger than those calculated using either model. Efforts are being made to determine whether appropriate modifications are needed when those models are applied to the STOR-M plasma parameters.

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