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Vector-resolved measurement of a local plasma momentum in a helicon plasma thruster

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Momentum flux in plasmas is one of the fundamental physical quantities dominating the plasma dynamics. In the field of electric propulsion, a force exerted to a propulsion device is often directly measured by attaching it to a pendulum called a thrust balance and sometimes estimated by using a pendulum target located in the plasma plume. In one of the advanced plasma thrusters called a helicon plasma thruster, which consists of a helicon source and magnetic nozzle, it is known that the thrust force is given by the sum of a pressure force (T_s) exerted on a back wall terminating the plasma upstream, an axial force (T_w) exerted on a radial wall, and a Lorentz force (T_B) exerted on the magnetic field due to a plasma-induced electric current [1]. The previous individual measurement of T_w integrated over the wall has implied that the axial momentum is transferred to the radial wall by the ions accelerated axially in the plasma core and lost to the wall [2]. The spatially resolved measurements of the fluxes of both the radial and axial momentum lost to the radial wall, corresponding to the radial and axial forces to the wall, will give new insights into the plasma dynamics and the thruster development, as investigated using a particle-in-cell simulation [3, 4].

Figure 1 shows the schematic diagram of the presently developed momentum vector measurement instrument (MVMI), which is designed to independently and simultaneously measure two different direction components of a force. A momentum detector plate is attached to a rotational arm connected to a pivot, which is further mounted on an axially movable balance structure. When imparting the radial force to the detector, the arm is rotated. Similarly, the stage supported by two flexible plates moves in the axial direction when imparting the axial force to the detector. Then, the two different displacements measured by LED displacement sensors give the radial and axial force by multiplying calibration coefficients relating the displacements to the forces. In order to have these calibration coefficients, two calibration coils are placed very close to small permanent magnets connected to sensitive load cells respectively. Supplying electric currents to these calibration coils induces forces between the coils and the magnets as utilized previously [5]. By simultaneously measuring the output voltage from LED sensors and the load cells, the calibration coefficients can be obtained.

Figure 2 shows the results of calibration bench tests , i.e., the relation between the measured sensor signals (V_r and V_z) and forces (F_r and F_z). In addition, the results show that the presently developed technique gives resolutions of about 10 μN in the radial and axial directions independently, resulting in the application to the spatially resolved measurement of the momentum loss inside the helicon plasma thruster. In the presentation, the detailed design of the MVMI and preliminarily results on the vector-resolved measurement of the local plasma momentum will be shown.

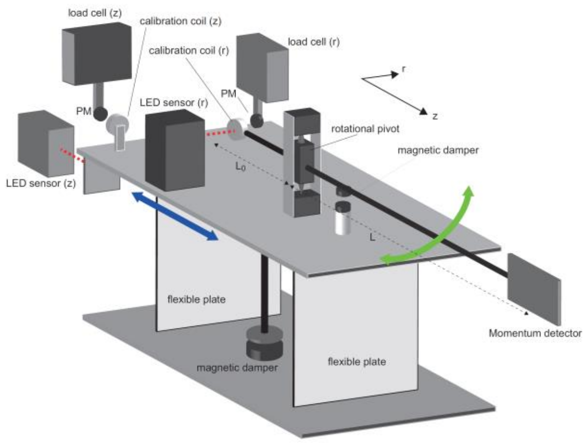

Fig. 1. Schematic of the momentum vector measurement instrument.

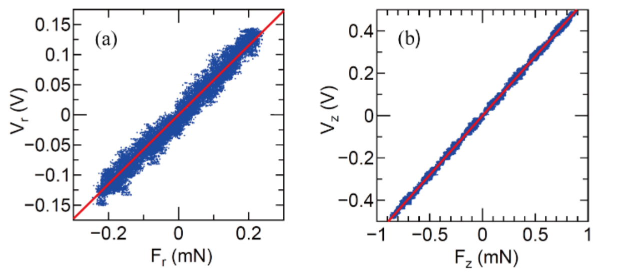

Fig. 2. (a) V_r versus F_r and (b) V_z versus F_z obtained by calibration bench test, together with the fitting lines (red bold lines).

References

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