Rotating spoke instabilities in standard and wall-less Hall thrusters: Experiments and PIC simulations

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This work reports on the examination on rotating plasma inhomogeneities, also called rotating spokes, in the discharge of a low-power Hall thruster. Rotating structures have been observed by means of high-speed imaging and time-resolved LIF spectroscopy for two configurations of the thruster: the standard configuration and the wall-less configuration in which the plasma discharge is unbounded. Numerical simulations based on a 3D PIC model support the experiments.

Rotating plasma inhomogeneities are observed in various types of magnetized low pressure plasma discharges created in a crossed electric and magnetic field configuration. Over the past ten years, such structures, often termed "rotating spokes", have been experimentally investigated e.g. in plasma devices like magnetrons and Hall thrusters. There is a great deal of interest in studying rotating plasma structures for mainly two reasons. Firstly, such instabilities seem to be a very general phenomenon in low-pressure plasma discharges of which the origin is not yet fully understood. Secondly, these large-scale low-frequency rotating instabilities certainly play a role in the transport of charged particle. As a consequence, they probably influence both the characteristics and the performances of plasma devices and plasma technologies like thin-film deposition and spacecraft propulsion.

In this contribution we experimentally examine the properties of low-frequency (a few kHz) rotating plasma instabilities in the discharge of the low power ISCT200 Hall thruster. The latter is a versatile 200 W-class Hall thruster using permanent magnets for generating the magnetic field instead of helical magnetizing coils. Two different configurations of the ISCT200 have been employed in this study. The standard (ST) one rests upon a magnetic barrier perpendicular to the cavity walls. The unconventional wall-less (WL) configuration allows to entirely shift the plasma discharge outside the cavity, then eliminating wall processes such as secondary electron emission and sputtering. The two versions, however, share many common features: the channel geometry is the same, walls are made of $BN\text{-}SiO_2$ ceramic, the magnetic field is produced by SmCo magnets, a porous compound serves as propellant gas injector and a heated cathode with a disk-shaped LaB_6 emitter provides the necessary electron current for maintaining the discharge and neutralizing the ion beam. In ST configuration, a ring anode is placed at the back of the channel whereas in WL configuration, a gridded anode with circular holes is placed at the cavity exit plane.

The main objective of this work is to characterize the physics and the dynamics of rotating plasma structures in the E×B discharge of a 200 W-class Hall thruster operating with xenon by means of two diagnostic techniques. High-speed camera imaging has been used to capture the rotating spoke motion and transformation for various thruster operating conditions. Image processing with sophisticated algorithms allows to determine the rotation velocity, direction and frequency, the plasma structure shape and sizes and the mode number.

Time-resolved LIF spectroscopy in the near infrared has been employed to record the temporal evolution of the Xe^+ ion azimuthal velocity component during the rotation of a plasma inhomogeneity. Here, a novel photon counting approach has been developed to enable measurements without externally stabilizing the discharge. The following points will be presented and discussed: the determination of the properties of such structures (velocity, frequency, domain of existence) and correlation with longitudinal instabilities such as breathing oscillations, the impact of the discharge voltage, propellant mass flow rate and cathode heater current on the properties of the rotating spokes, clarifications as to the origin of the rotating inhomogeneities, time evolution of the ion velocity distribution function in the course of a spoke rotation, and finally a critical comparison of the features of rotating structures in conventional and wall-less Hall thrusters. Experimental results are supported by outcomes of numerical simulations carried out with a 3D PIC model.