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Three-dimensional Numerical Investigation of Electron Transport with Rotating Spoke in a Cylindrical Anode Layer Hall Plasma Accelerator

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Comment on "Three-dimensional numerical investigation of electron transport with rotating spoke in a cylindrical anode layer Hall plasma accelerator" [Phys. Plasmas 19, 073519 (2012)]

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The oscillation behavior described in [Tang *et. al*, Phys. Plasmas **19**, 073519 (2012)] differs too greatly from previous experimental and numerical studies to claim observation of the same phenomenon. Most significantly, the rotation velocity in [Tang *et. al*, Phys. Plasmas **19**, 073519 (2012)] is three orders of magnitude larger than that of typical "rotating spoke" phenomena. Several physical and numerical considerations are presented to more accurately understand the numerical results of [Tang *et. al*, Phys. Plasmas **19**, 073519 (2012)] in light of previous studies.

Oscillations are an important aspect of Hall thruster behavior as they influence cross-field electron transport and, correspondingly, thruster efficiency. The “rotating spoke”, originally observed by Janes and Lowder[1] in 1966, has attracted recent interest in both the cylindrical[2–5] and annular[6,7] configurations of the Hall thruster. A recent paper by Tang *et. al*[8] presents numerical studies of an azimuthally rotating electron density perturbation which is claimed to be the rotating spoke oscillation. In this comment, we address two features of the numerical study in Ref.[8]. First, the rotation speed and frequency are too large to be described as the rotating spoke without further justification. Experimental observations of the rotating spoke are in the kHz range, whereas the numerical results in Tang *et. al*[8] describe a 12.5 MHz oscillation. Second, the simulation results fall short of modeling self-sustained Hall thruster operation due to the lack of an electron source and the short time duration.

The so-called “rotating spoke” is a low-frequency azimuthal oscillation observed in both cylindrical and annular Hall thrusters[1–3,6,7,9]. It was originally observed using azimuthally separated electrostatic probes[1] and more recently detected using high-speed camera imaging[2,3,6]. Experiments have operated across a variety of thruster configurations, sizes, and operating parameters including magnetic field geometry, gas type and flow rate, and discharge voltage (see Ref.[6] for a parametric study in the annular Hall thruster geometry). The experimentally-observed rotation velocity has been on the order of 10^3 m/s, ranging from 500 m/s in Ref.[6] to 7×10^3 m/s in Ref.[1]. In contrast, Tang *et. al*[8] observe a rotation speed of 10^6 m/s - three orders of magnitude larger than the experimental observations. The large discrepency in rotation speed and frequency requires additional justification to be described as the rotating spoke instead of oscillations more commonly observed in the MHz range[10–16].

One reason for classifying the observed rotation in Ref.[8] appears to be the difference between the azimuthal rotation speed and the $\mathbf{E}\times\mathbf{B}$ drift speed. The 10^6 m/s rotation in Tang *et. al*[8] is 37% of the $\mathbf{E}\times\mathbf{B}$ speed with $B = 175$ Gauss and $E = 470$ V/cm. For comparison, Ellison *et. al* observe a 2×10^3 m/s rotation which is 10% of the $\mathbf{E}\times\mathbf{B}$ speed using $B = 850$ Gauss and $E = 20$ V/cm. To rule out mere $\mathbf{E}\times\mathbf{B}$ rotation, the location where the electric field is measured is important, and it is unclear from Figure 4 in Ref.[8] that 470 V/cm is an appropriate estimate of the electric field near the electron cloud. Also, without a rigorous understanding of the rotating spoke mechanism the scaling with the $\mathbf{E}$

× **B** speed is not the only relevant measure. The experimental rotation speeds are also near the ion sound speed and ion thermal velocity, for instance, which do not scale with the **E** × **B** speed. The similar time scales have led several authors to suggest the rotating spoke is related to ionization phenomena[1,3,5,6,17], and until a better theoretical understanding is established, it's important to keep these parameters in mind.

Aside from the rotation speed discrepency, the simulation of Tang *et. al*[8] lacks a cathode electron source and is shorter than the time required for the initial plasma distribution to extinguish. Consequently, the observed rotation is not likely to model the self-sustained plasma discharges studied during experiments, but instead the transient relaxation of an initial distribution of particles. The non-neutral plasma observed in Ref.[8] cannot persist in steady state because the excess charge will be forced to the electrodes by the perturbed electric field. A more rigorous study investigating the rotating spoke should include several milliseconds of sustained plasma to resolve ionization-relevant time scales for evaluating the rotation mechanism.

Overall the present oscillation in Ref.[8] appears distinct from the rotating spoke. For one, the variety of experimental configurations in which the rotating spoke has been observed have measued kHz-scale frequencies with rotation velocities on the order of 10^3 m/s. In contrast, the 12.5 MHz rotation observed by Tang *et. al* requires justification beyond comparison with the **E** × **B** speed to be connected with the rotating spoke. Further separating the numerical results from the experimental observations is the absence of a self-sustained discharge in the numerical model.

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