Comment on “Effects of magnetic field gradient on ion beam current in cylindrical Hall ion source” [J. Appl. Phys. 102, 123305 (2007)]

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It is argued that the key difference in the cylindrical Hall thruster (CHT) as compared to the end-Hall ion source cannot be exclusively attributed to the magnetic field topology [Tang et al., J. Appl. Phys. 102, 123305 (2007)]. With a similar mirror-type topology, the CHT configuration provides the electric field with nearly equipotential magnetic field surfaces and a better suppression of the electron cross-field transport, as compared to both the end-Hall ion source and the cylindrical Hall ion source of [Tang et al., J. Appl. Phys. 102, 123305 (2007)].

The CHT (Ref. 4) features a combination of both EHS and conventional annular Hall thrusters of the so-called stationary plasma thruster (SPT) type. Like the EHS, the CHT (Fig. 1) has a lower surface-to-volume ratio than SPT does and, thus, seems to be more promising for scaling down to low power space applications. The principle of operation of the CHT, which was proposed in Ref. 4, is in many ways similar to that of a typical annular Hall thruster, i.e., it is based on a closed \( E \times B \) electron drift in a quasineutral plasma. The radial component of the magnetic field crossed with the azimuthal electron current produces the axial electric field \( E = -v_x \times B \), which accelerates ions and generates thrust. However, the CHT differs fundamentally from a conventional annular thruster in that the magnetized electrons in the cylindrical design provide charge neutralization of nonmagnetized ions not by not moving axially, but through being trapped axially in a hybrid magneto-electrostatic trap. Comprehensive studies of the CHT with cusp-type and mirror-type magnetic field configurations are reported elsewhere. For the miniaturized low power CHT, the optimal magnetic field configuration was shown to be an enhanced mirror type.

A similar axial trap for the electrons should exist in the mirror-type magnetic configuration of the EHS and the cylindrical ion source of Tang et al. According to Ref. 2 quoted by Tang et al., plasma measurements in the EHS suggest that the ions are electrostatically accelerated along the mirror with nonequipotential magnetic field surfaces toward the source exit, where the magnetic field is weaker. This is in contrast to the CHT, where the magnetic field lines form nearly equipotential surfaces. Indeed, plasma potential measurements in laboratory CHTs (Refs. 4 and 11) demonstrated that there is only an insignificant potential drop along the magnetic field surface closest to the thruster axis between the central ceramic piece and the channel exit. This result has a simple physical explanation. For an isotropic electron velocity distribution function, the spatial distribution of electron density \( N_e \) along the magnetic mirror is independent of the magnetic field. Hence the Boltzmann distribution for the Maxwellian electrons, \( N_e \sim \exp[\exp(x)/T_e] \), where \( \phi(x) \) is the plasma potential profile along the mirror axis and \( T_e \) is the electron temperature. The ion density distribution, which self-consistently affects \( \phi(x) \), is independent of the local magnetic field in a Hall thruster as well, because ions are not magnetized. Thus, from the Poisson equation it follows that the variation of the ambipolar plasma potential along the magnetic mirror should be independent on \( B \). Note that, in general, in a quasineutral plasma immersed in the mirror magnetic field, the momentum balance does not necessarily require the existence of the axial electric field [cf. Eq. (II) by
Fig. 2 demonstrates that for the enhanced magnetic mirror channel geometry and material, geometry and emission properties operate with a higher ionization efficiency and current utilization to the discharge current in these ion sources. However, CHT efficiency is higher, more than 30%–40% at 50–1000 W. Different variations on the CHT design were proposed and tested, including those with and without the short annular part of the channel. The magnetic circuit of the CHT includes a magnetic screen in order to form a favorable profile of the magnetic field, including the magnetic field distribution with a positive gradient. For the larger and higher power CHTs, the cusp-type magnetic field was shown to be the favorable topology. Moreover, the floating and biased segmented electrodes placed on the ceramic channel walls of the CHT can be used to control the plasma flow. Another variation referenced by Tang et al. is the ion source by Zhurin, which appears very similar to the CHT configuration proposed earlier in Refs. 4 and 5, and studied elsewhere. This work was supported by the Air Force Office of Scientific Research.