Electrostatic Thruster with Swirl Acceleration Characteristics

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Abstract: Applied-magnetic-field thrusters which have an annular anode and a hollow cathode on the center axis exhibited linear thrust dependence on the product of a discharge current, applied magnetic field and anode inner radius. The associated coefficient is determined by the thruster configuration, in particular, that for propellant injection and applied magnetic field pattern.

Nomenclature

$\bar{B}$	=	magnetic field at coil/magnet center
E_i	=	mass averaged ion kinetic energy calculated from measured thrust
F	=	thrust
J_d	=	discharge current
R_a	=	anode inner radius
V_d	=	discharge voltage

I. Introduction

CATEGRIZATION of propellant acceleration mechanisms in electric propulsion has been done as to "electrostatic," "electromagnetic" and "electrothermal" accelerations. In electromagnetic acceleration, a

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Lorentz force is produced from the interaction between a discharge current and an applied or a self-induced magnetic field. Regardless of the source of the discharge current, either the ions or electrons, the Lorentz force is transferred to heavy particles, ions and neutrals. The momentum transfer processes from the electrons to the ions can be done not only through Coulomb collisions but also through an electric field due to local charge separation. In the latter case, the mechanisms of ion acceleration are equivalent to those of the electrostatic acceleration.

In Ref. 1, we reported that a thruster of electrostatic acceleration type exhibited a thrust performance of electromagnetic acceleration. It is difficult to distinguish these acceleration types. In this paper, we report electrostatic/electromagnetic acceleration characteristics of three thrusters, all of which utilize the inner surface of an annular anode and a hollow cathode set on the thruster center axis.

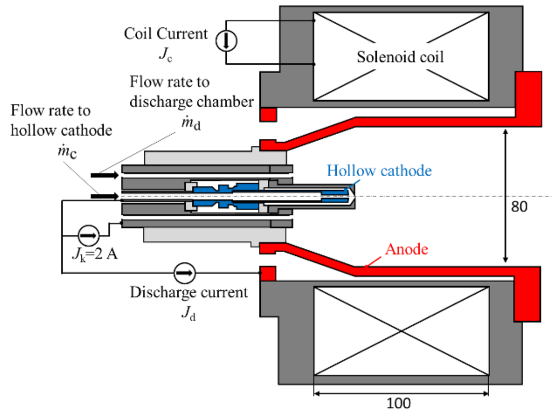

Figure 1. Schematic illustration of Type I.

II. Thruster Configurations

We examined the thruster characteristics of three steady-state electric thrusters as follows:

A. Type I

Figure 1 shows the schematic illustration of the thruster, Type I.[2] This thruster was designed as an applied-field, magneto-plasma-dynamics (MPD) thruster. Is has a annular anode made of copper. It has two cylindrical parts which are connected by a conical transition. Argon is used as the propellant, being injected from the insulator back plate and the hollow cathode on the center axis. The electrodes are connected to a constant current power supply. Using a solenoid coil, a slowing diverging magnetic nozzle is formed..

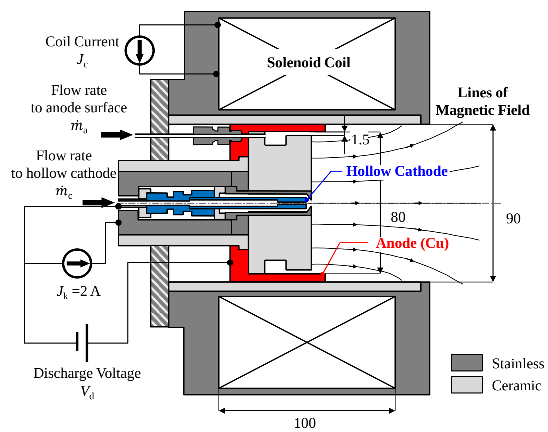

Figure 2. Schematic illustration of Type II.

B. Type II

Figure 2 shows the schematic illustration of the thruster, Type II.[1] The thruster has many common features as of Type I: It utilizes the inner surface of an annular anode; a hollow cathode is set on the center axis; a slowly diverging magnetic field is applied by using a solenoid coil. However, only a short cylinder is exposed to the discharge zone as the elective anode; the electrodes are connected to a constant voltage power supply as an electrostatic thruster; the propellant, xenon, is injected along the anode inner surface after a 1.5-mm-thick annular slit.

C. Type III

Figure 3 shows the schematic illustration of the thruster of Type III. It has a similar electrode configuration as of Type II. Yet, the magnetic filed is applied by using a ring permanent magnet, thereby having a cusp in the downstream zone of the electrodes. The strength of the magnetic filed is varied by using different magnet materials. As in Type II, a short cylinder is exposed to the discharge zone as the elective anode; the electrodes are connected to a constant voltage power supply. The propellant, xenon, is injected along the anode inner surface after a 1.5-mm-thick annular slit.

III. Trust Characteristics

A. $J_\mathrm{d}\bar{B}R_\mathrm{a}$ Dependence

Figure 4 summarizes thrust dependence on $J_\mathrm{d}\bar{B}R_\mathrm{a}$. Surprizingly, in each thruster, the thrust, F, is fit to a linear dependence on $J_\mathrm{d}\bar{B}R_\mathrm{a}$. This dependence is equivalent to that obtained in Fradkin et al.'s rigid rotator model.[3] In their model, the plasma of the propellant is assumed to act as a rigid rotator that experiences a torque produced by a Lorentz force due to the interaction between the discharge current and the applied magnetic field.

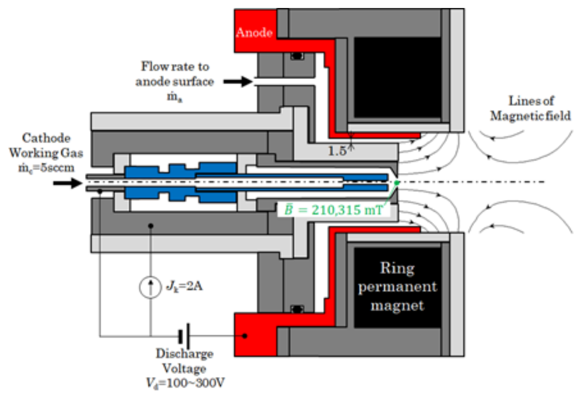

Figure 3. Schematic illustration of Thruster III.

Those thrust performances are fit to the following equation:

$$F = \alpha J_\mathrm{d}\bar{B}R_\mathrm{a} \qquad (1)$$

where the value of the coefficient, α, should be determined either from a theoretical model or fitting to experimental data. The value of α that is obtained from the Fradkin et al.'s model equals $1/\sqrt{2}$. The value of α can also be obtained by assuming electrostatic acceleration. In this case, the value is not limited by the above one.

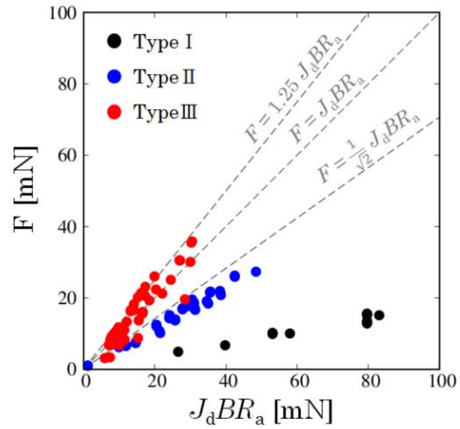

Figure 4. F **vs.** $J_\mathrm{d}\bar{B}R_\mathrm{a}$

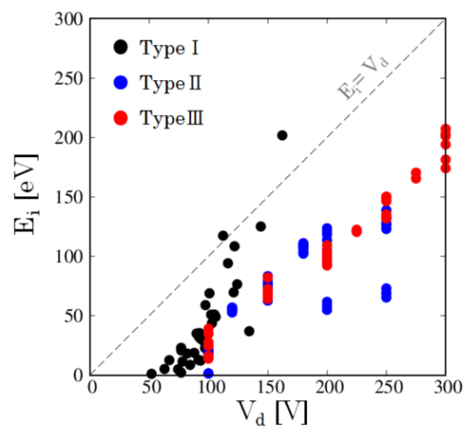

Figure 5. E_i **vs.** V_d

The value of α obtained from data fitting depends on thruster type. The value of α for Type I equals approximately to one third to that of the rigid rotator model; those for Types II and III almost equals to and even exceeds to the value, respectively.

B. V_d Dependence

Figure 5 shows variations of mass-averaged ion kinetic energy, E_i, as a function of a discharge voltage, V_d. In all thrusters, E_i has an offset of the order of 50 V from V_d. This offset can be caused by ionization energy and heat loss. Yet, details warrants further investigation. In Type I, E_i, can exceed V_d. Such thrust characteristics are possible if momentum transfer from the electrons to the ions are done through particle collisions.

IV. Conclusion

In this paper, the thrust performance of three types of electromagnetic/static thrusters are examined by referring to their $J_\mathrm{d}\bar{B}R_\mathrm{a}$ dependences. Each thruster exhibited a linear dependence on the product, yet with a different value of the coefficient. Such thrust performance should be modelled from the viewpoint of plasma acceleration as a continuum; the model should be backed by experimental diagnostics.

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Acknowledgments

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