Some Results of the SPT Jet Characteristics Comparison

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Abstract

In this report there are the first results on compare outlet characteristics of SPT ion current density distribution. In this work we used the data, got at MAI Department of Spacecraft Electric Propulsion and Powerplants, at the University of Michigan and at NASA LeRC. The ion current, integrating graphically from ion current density distribution by angle or by distance from thruster's axis, was taken as an object of estimation. This parameter was compared with theoretically possible ion current, got in three thrusters configurations: M-50, M-70 and M-100.
It was supposed that the relationship of integrating ion current to theoretically possible ion current must be almost the same for all thrusters.

Nomenclature

α	=angle (circular probe motion) (degrees),
Δ	=ion current error (%),
e	=electron charge (C),
F	=integrating area (m^2),
I	=theoretically possible ion current (A),
Id	=discharge current (A),
Isum	=integrating ion current (A),
j	=ion current density (A/m^2),
$\dot{m}$	= mass flow rate (mg/s),
M_{Xe}	=ion mass (mg),
r	=length (linear probe motion) (mm),
Ud	=discharge voltage (V).

Introduction

In connection with increasing interest to Stationary Plasma Thrusters and its usage as thrusters for correction and orientation on different spacecraft, and, perhaps, its include in powerplants for Mars and asteroids missions, it becomes very important to get a number of characteristics for SPT various modifications and sizes.
These thrusters tests and analyse are usually carried out in different conditions. Thus, the chambers sizes and configurations in laboratories are quite diverse. That's why there is some difference in pressures in these chambers. Test technique in each laboratory is individual too: design and sizes of probes, distances, in which they are positioned according to thruster's outlet, the way of its motion - linear or circular. Even probe's motion half-angle or half-length are also non-unificated and depended, in any case, on chamber's parameters.
As it is impossible to charge all SPT researches with using chambers of one configuration and equal sizes and to carry out measurements by the same equipment and in identical conditions, then it seems very necessary to solve the task about the methods to compare the results of different research groups measurements.

Calculation methodics

Theoretically possible ion current is a function of propellant, mass flow rate, in our case, xenon, ionization probability and secondary processes in discharge volume and is calculated by the following relationship:

$$I = e^* \dot{m} / M_{Xe} = 0.72^* \dot{m}.$$

Propellant usage coefficient was in this case ~0.95.
The graphical integration was carried out by two methodics: in case of linear probe motion - ring integration; in case of circular motion - spherical segments integration.

$$Isum = \int j^* dF.$$

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Substituting integral for sum and going over from step by area to step by angle or length, we finally had:

$$Isum=\sum f_i(r_i)*\Delta r_i \qquad \text{or}$$
$$Isum=\sum f_i(\alpha_i)*\Delta\alpha_i\ .$$

Integration step was chosen ≤5mm for linear probe motion and ≤5° for circular probe motion. Such step guaranteed the calculation error ≤5% as for complete ion current value as for currents on each step. The choice of error allowed limit was depended on measures error, which for Langmuir probe is estimated ~12-15%.

Results of integration

The results of integration for different thrusters:

1) M-50 and its modification.
Data were taken in a medium-sized chamber. This 2.5m long by 0.9m diameter cylindrical chamber with 0.7m appendix was pumped by two 0.9m oil diffusion pumps and piston type roughing pumps. The thruster was mounted in the center of the chamber, firing along the appendix axis. The ambient pressure, measured by an ionization gauge during testing, was $6x10^{-5}$ Torr. Ion current density was measured by tantalum Langmuir probe 2.5mm diameter; discharge voltage was Ud=300V. The probe moved circularly on 500mm distance from thruster outlet. Mass flow rate was $\dot{m}$ =2mg/s. The calculating curves of ion current density distribution of these thrusters are shown in Fig.1.

Ion current errors on half-sphere, calculated by the following relationship:

$$\Delta=\left(1-\frac{Isum}{0.72*\dot{m}}\right)*100\%,$$

were correspondingly -67.8% and -64.1%.
Ion current errors on 60° half-angle were correspondingly -48.8% and -47.5%.

2) M-70 and its modification.
The experimental facilities, probe and the distance were the same; Ud=300V. Mass flow rate $\dot{m}$ values were 3.07mg/s and 3.05mg/s. The calculating curves of ion current density distribution of these thrusters are shown in Fig.2.

Ion current errors on half-sphere: -69.3% and -48.4%.
Ion current errors on 60° half-angle: -36.4% and -31.0%.

3) M-100 on two regimes: Ud=300V; discharge current values were Id=5A and Id=3A; the data were taken in a medium-sized chamber. This 5m long by 1.5m diameter cylindrical chamber was pumped by four 0.82m oil diffusion pumps, a lobe type mechanical blower, and two piston type roughing pumps. The thruster was mounted in the center of the chamber, firing along the major axis. The ambient pressure, measured by an ionization gauge during testing, was $2x10^{-5}$ Torr. Langmuir molybdenum probe effective area was $3cm^2$; the distance was 600 mm. Mass flow rate values were 5.62mg/s for the first regime and 3.45mg/s for the second regime[1, 2]. The calculating curves of ion current density distribution of M-100 on these regimes are shown in Fig.3.

Ion current errors on half-sphere: -44.7% and -62.3%.
Ion current errors on 60° half-angle: -13.9% and -24.1%.

4) M-70 and its modification.
The experimental facilities were similar to those, which are described in (1). Ion current density was measured by tantalum Langmuir probe 2.5mm diameter. Ud=160V, the distance from outlet was 20mm. Mass flow rate in both cases was 2.3mg/s. The probe moved linearly from -80 to 80mm from thruster axis. The calculating curves of ion current density distribution of these thrusters are shown in Fig.4.

Ion current errors on the all length: -39.4% and -49.4%.

5) M-70 on two regimes: discharge voltage values were Ud=160V and Ud=300V, the same facilities and probe, distance from thruster outlet was 4 mm. Mass flow rate in both cases was 2.02mg/s. Probe motion was from -60 to 60mm from thruster axis. The calculating curves of ion current density distribution of M-70 on these regimes are shown in Fig.5.

Ion current errors on the all length: -19.4% and -20.0%.

The half-angle value choice is based on American authors data[1] because just on ~60° half-angle the effects, connected with pressure differences in chambers, and, probably, some background effects are not actual yet. Generally, due to experimental results ~95% of ion current from thruster is going to this angle.

Conclusions

The calculation results just allow making the following conclusions:

1) the data, got in the same conditions (at the same laboratory) are differed insignificantly not only for the thrusters of one configuration, but for various configurations, that proves the basic hypothesis. The distinction, perhaps, is depended on measures error (~12-15%) and differences in design of basic model and its modification.

2) the data, got at NASA LeRC[1, 2], are seemed close to our results, but some difference in ion current on 60° half-angle makes it necessary to compare two laboratories measure errors, especially paying attention to probes comparison.

3) the data, got for Langmuir probes, moved linearly, are also cross-correlated. For the complete comparison it's important to determine the necessary probe motion half-length on either distance from thruster outlet so that measuring would comprise minimum 90% of ion current. This half-length, certainly, increases with moving away from thruster outlet. In the meantime taken 60mm as the working half-length, we got the ion current values in two positions 4mm and 20mm from thruster outlet for M-70 with $\dot{m}$=2mg/s and Ud=160V - 1.74A and 1.99A. This result on the whole is similar to data, got at Michigan University for M-100, Ud=300V and $\dot{m}$=5.22mg/s[3]:

10 mm - 3.97A,
25 mm - 4.92A,
50 mm - 4.95A,
100 mm - 4.51A,
200 mm - 3.86A.

Therefore the next step of our work will be creation of something like mathematical cone, which in each cut would get the equal current share from thruster. Only then we'll be able to compare the experimental data correctly and to analyse results, calculated by two different methodics for two variants of probe motion.

References

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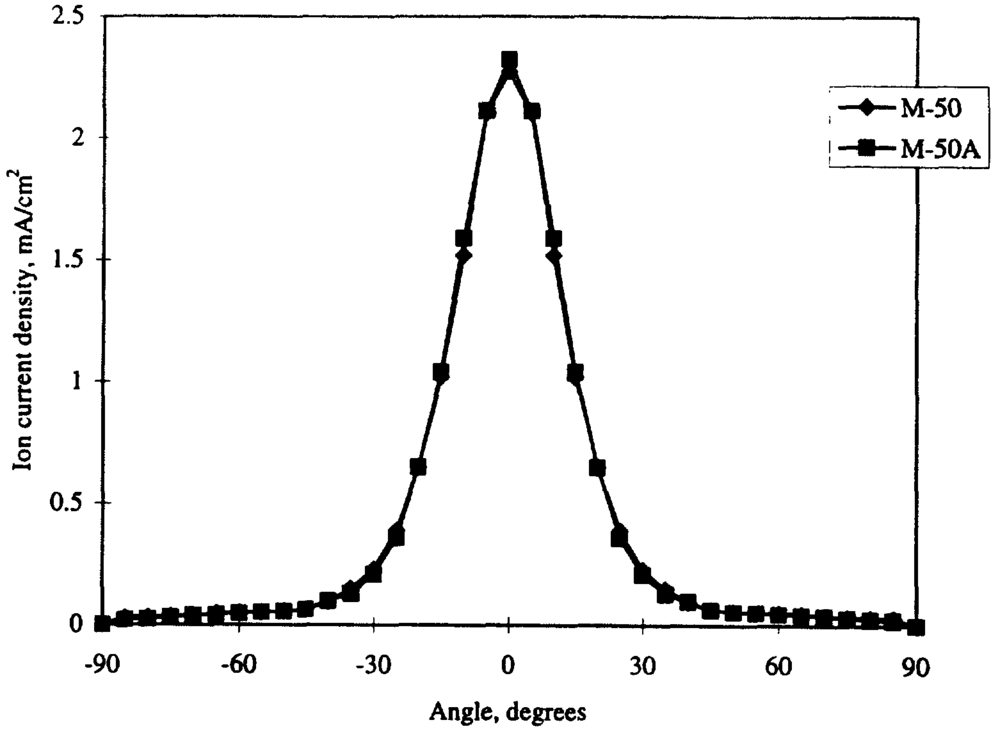

Figure 1. Ion current density distribution of M-50 and its modification (calculating curves).

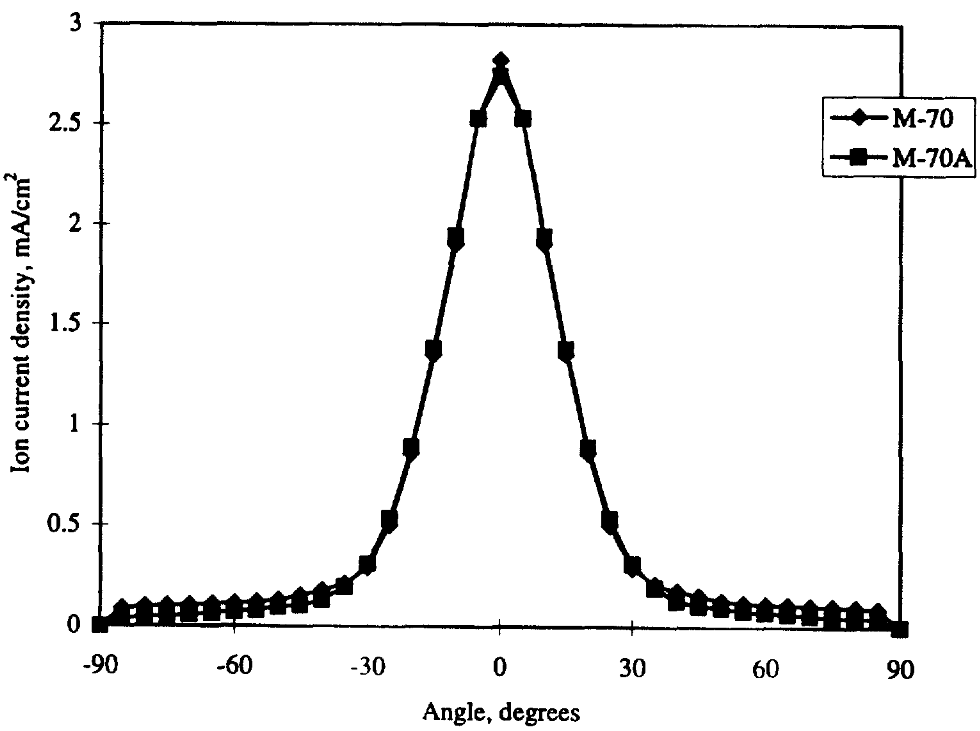

Figure 2. Ion current density distribution of M-70 and its modification (calculating curves).

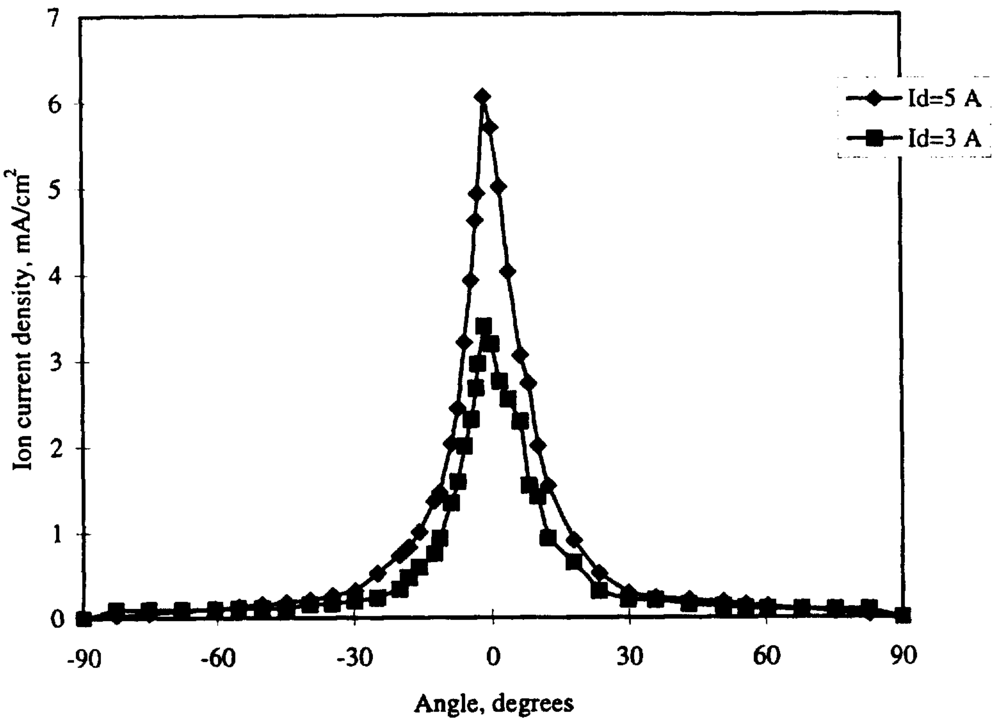

Figure 3. Ion current density distribution of M-100 on two regimes (calculating curves).

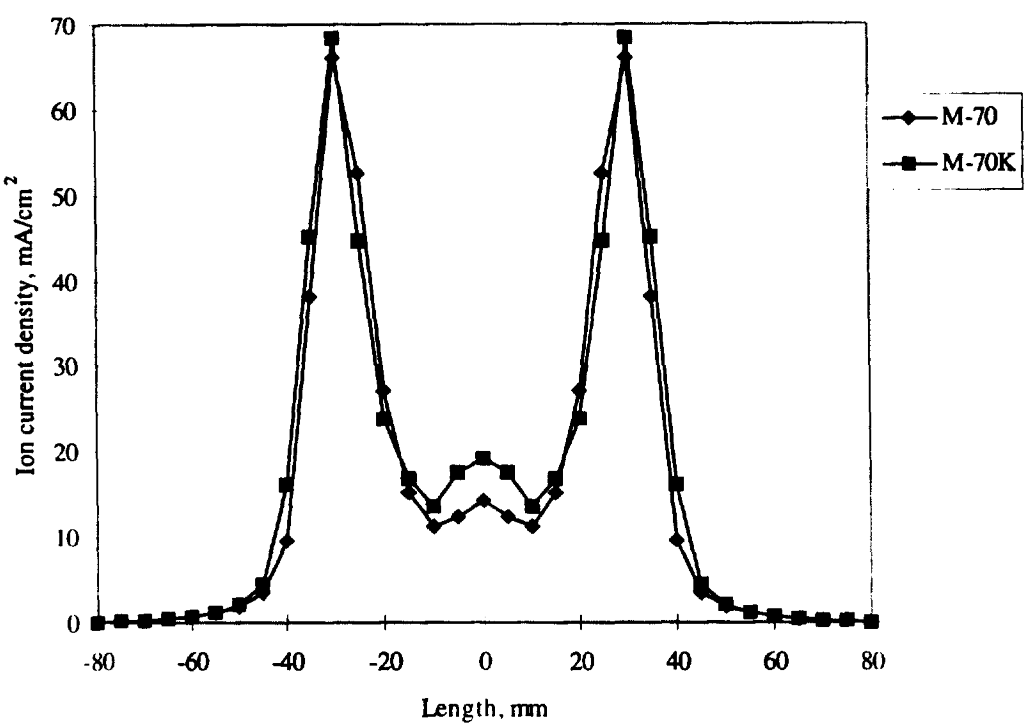

Figure 4. Ion current density distribution of M-70 and its modification (calculating curves).

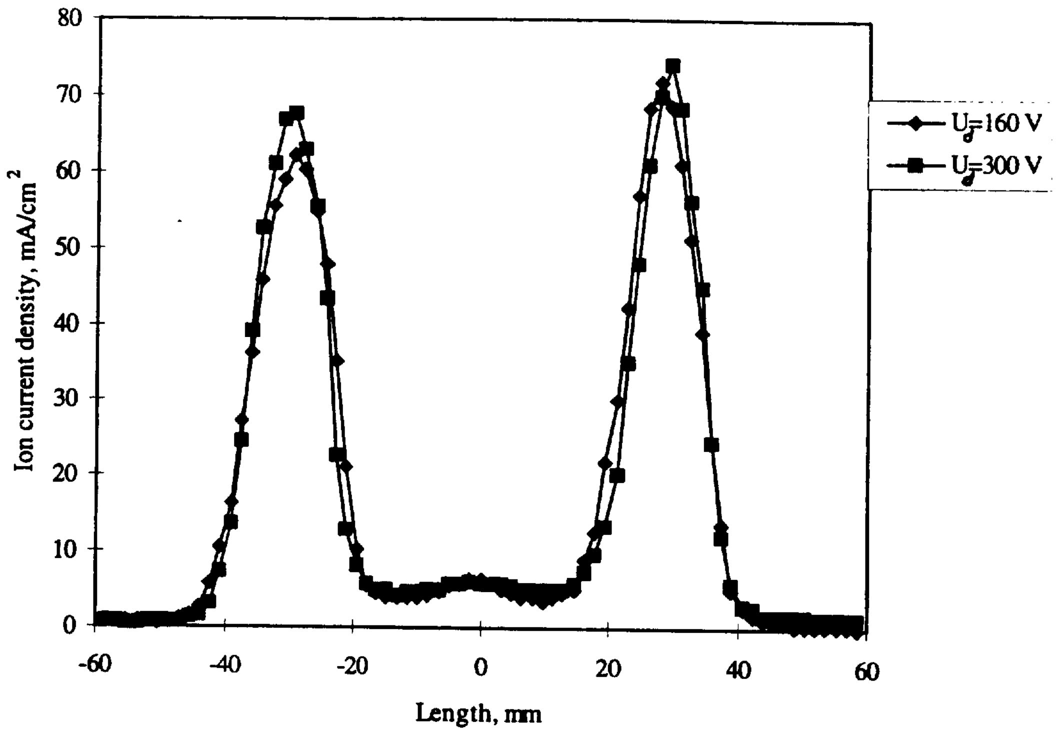

Figure 5. Ion current density distribution of M-70 on two regimes (calculating curves).