PLASMA PARAMETER DISTRIBUTION DETERMINATION IN SPT-70 PLUME

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Abstract.

There are represented in a paper results of the SPT-70 plume characterization including results of: determination of:

- the accelerated ion current off-axis distribution measured by the moving RPA probe;
- plasma parameter distributions measured by the moving cylindrical Langmuir probe;
- the ions “back” flows in a thruster exit plane by the flat Langmuir probes;
- dependence of the mentioned above parameters and thruster performance on the pressure inside the vacuum chamber controlled by injection of the additional Xe into the mentioned chamber.

All measurements were made in a vacuum chamber of 2m in diameter and 6m in length under variation of the pressure inside the vacuum chamber within the range $8\cdot10^{-5}$ – $1.8\cdot10^{-4}$ Torr by air ($3\cdot10^{-5}$ - $7\cdot10^{-5}$ Torr by Xe). It is shown that it is possible to measure the accelerated ion flow divergence under pressures till ~$4\cdot10^{-5}$ Torr by Xe.

Introduction.

As it is known[1] the ST-70 was used and still is used on board of spacecrafts for their final positioning and station keeping. Therefore it is interesting to determine the SPT-70 plume plasma parameter distributions allowing determination of plume divergence and other plume characteristics. Some of the SPT-70 plume plasma parameters were determined earlier[2], but there was some difficulties in these measurement results processing because the probe collectors in every probe positions were oriented normally to the thruster axis. Due to this it was difficult to compare results of the mentioned measurements with results of the SPT-100 plume characterization. Taking into account all the mentioned it was decided to realize the SPT-70 plume characterization similar to that one made for the SPT-100[3]. It was interesting also to check impact of the pressure inside the vacuum chamber on plume plasma parameter distributions and in parallel on thruster performance to estimate their correlation. results of such study are represented below.

1. Methodology of study.

Experiments were made with usage of standard SPT-70 model operating under its typical operation mode with the discharge voltage *Ud = 300V* and mass flow rate $m_a \approx 2.35$ *mg/s* through the accelerating channel. The magnetization currents in a coils fed independently were maintained equal to discharge current. This model was tested inside the vacuum chamber of 2m in diameter and 6m in length. It was mounted on thrustmeter by such a way that thruster axis was positioned near the vacuum chamber axis and the thruster axis in the 1st approximation was parallel to chamber axis (Fig.1). There was mounted also the boom carrying probes and rotating them along to semicircle with radius *R* within the horizontal plane parallel to thruster axis and consisting of this axis. On boom there were mounted RPA and cylindrical probes and mechanism allowing adjustment of each probe position to the mentioned horizontal plane. So, measurements by RPA and cylindrical probe were made in turn.

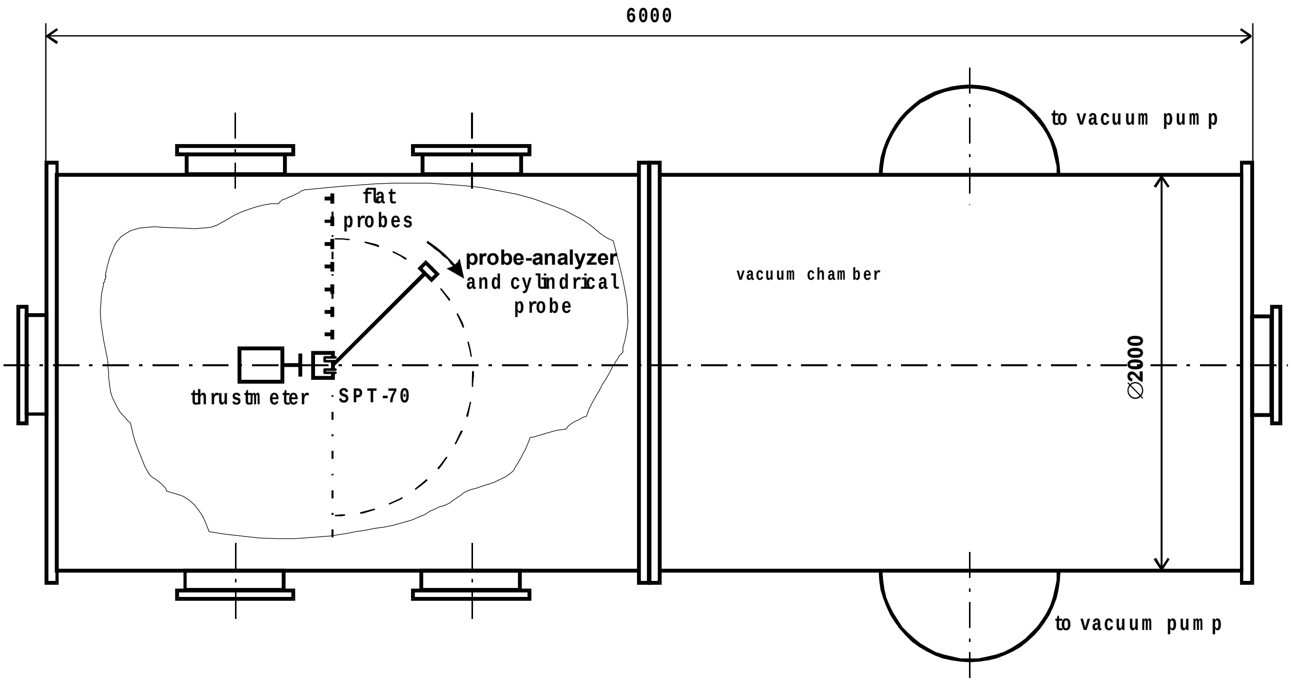

Fig. 1. Schematic of the vacuum chamber.

Besides these probes there were mounted a set of several flat probes positioned approximately in the thruster exit plane with collecting surfaces parallel to this plane. So, using all probes it seemed possible to estimate the “back” ion flows. But there is principal difficulty to divide directed ion current to the probe surface and ion current extracted from plasma by probe with negative relative to plasma potential shift typically used for the probe ion current measurements.

RPA probe was used to determine the accelerated ion flow density angular distribution as it was done for the SPT-100 plume[3] that is there were measured angular distributions of the RPA collector current under retarding potential +50 V relative to cathode. Because the plasma potential in a plume is at level of 25-30V relative to cathode the only ions with energy exceeding 20-25 eV were able to get the collector surface.

It is necessary to note that such ions carry the main part of the ion flow kinetic energy. Therefore data on their flow density angular distribution are useful for estimation of the mechanical, thermal and erosion impacts of thruster plume on structural spacecraft elements intersected by plume.

Concerning the plasma parameters they were determined by processing of the cylindrical probe characteristics. This probe axis was oriented to thruster to reduce impact of the directed ion currents on to probe currents. Nevertheless some directed ion currents got the probe collector surface. Therefore the plasma density number derived from the electronic branch of probe characteristics was by several times less than that one obtained from the ionic part of probe characteristics. Taking this into account as the plasma density number there were chosen that one derived from the electron current under probe potential equal to plasma potential. To determine this potential there was used the standard procedure of the probe characteristics processing. To check the plasma potential level there was used emissive probe. Results of the plasma potential determination by emissive and cylindrical probes were in agreement within ~1V. So, main part of measurements were made with usage of cylindrical probe.

The SPT-70 plume parameter measurements by were made under distance *R=0,5m* between moving probes and thruster. So, it was possible to compare obtained data with the SPT-100 plume measurement results obtained at *R=0,7m* available at RIAME MAI because under the mentioned distances the ratio of these distances to thruster sizes were approximately the same as well as the accelerated ions flow densities at the mentioned distances were to be close.

To control pressure inside the vacuum chamber there was used injection of the additional Xe flow through the hole near the chamber wall positioned upstream relative to thruster position. It was possible to vary pressure within the range $3{\cdot}10^{-5}$ - $7{\cdot}10^{-5}$ Torr(by Xe).

2. Results of measurements.

SPT-70 operation under described conditions could be imagined, if some one consider its integral parameter dependence on pressure inside vacuum chamber. The discharge current is increased almost linearly under increase of pressure (Fig.2). Thrust behavior is a little bit more complicated (see Fig.2). The specific impulse behavior corresponds to thrust behavior (Fig.3) because thrust efficiency η_{to}calculated taking into account only mass flow rate through the accelerating channel is almost constant (see Fig.3). If some one takes into account the additional Xe flow rate through the accelerating layer it is possible to get another conclusion. Indeed, taking into account that studied variation of all integral parameters does not exceed 5% it is possible to assume that increase of discharge current is proportional to the additional Xe flow rate into thruster and to calculate effective mass flow rate as sum of mass flow rate through thruster going from feeding system and the mentioned additional mass flow rate. As one can see the thrust efficiency $\eta_t$calculated with usage of this effective mass flow rate is going down with increase of pressure inside the vacuum chamber (see Fig.3). This could be explained by the fact that atoms entering the accelerating layer from the vacuum chamber are ionized in its exit part. So, the ions appeared here get less energy than that ones created in a high voltage part of the accelerating layer.

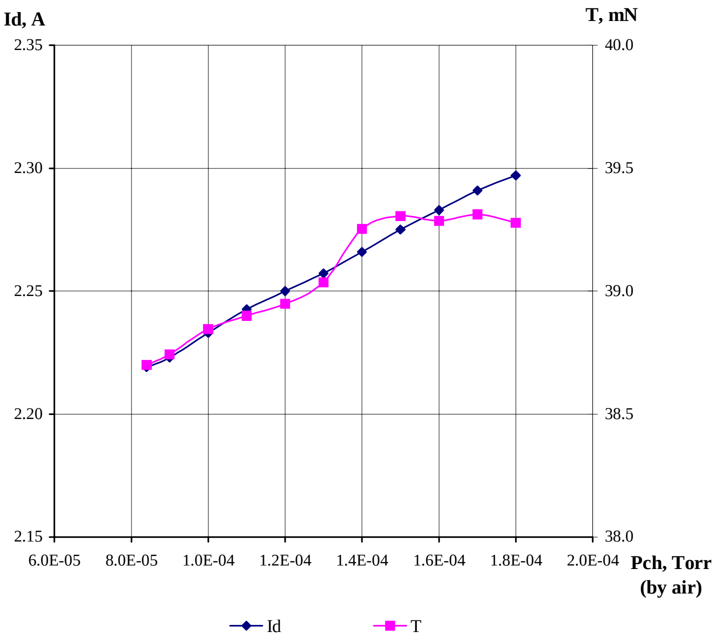

Fig. 2. Discharge current and thrust versus the pressure inside the vacuum chamber.

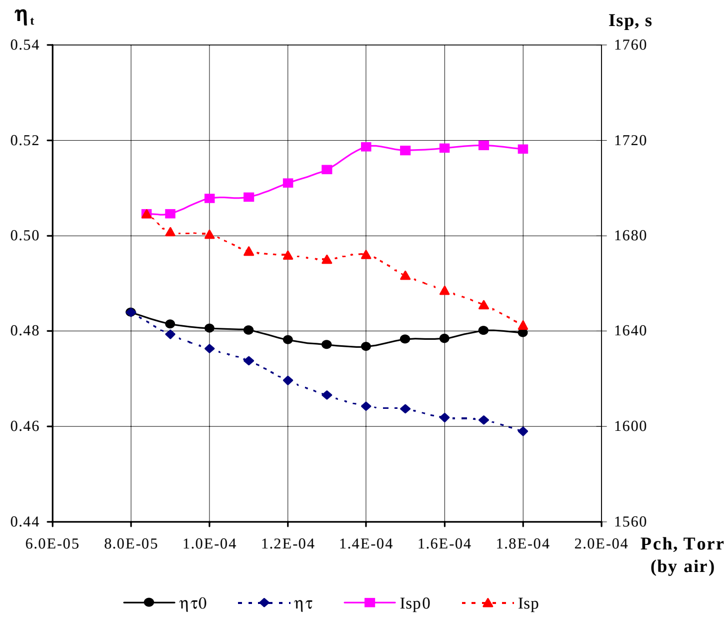

Fig. 3. Thrust efficiency and specific impulse versus the pressures inside the vacuum chamber.

The accelerated ions flow off-axis distribution is typical for the modern SPT's (Fig.4) and there is trend of the distribution sharpness increase with increase of pressure. The last conclusion is confirmed by results of the mentioned distributions processing to determine the half-angle $\beta_{0.95}$ of plume consisting of 95% of ions crossing the reference surface. The corresponding data (Fig.5) shows that under pressures higher than ~$1.1\cdot10^{-4}$ Torr by air (~ $4\cdot10^{-5}$ Torr by Xe) the $\beta_{0.95}$ values are reduced significantly with increase of pressure (such dependence was fixed several times and it is repeatable).

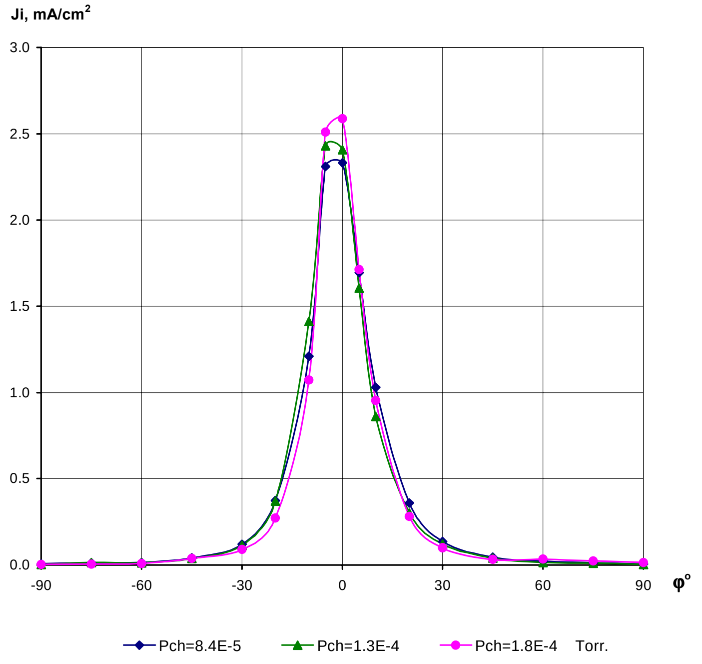

Fig. 4. The accelerated ion current density off-axis distributions under different pressures inside the vacuum chamber.

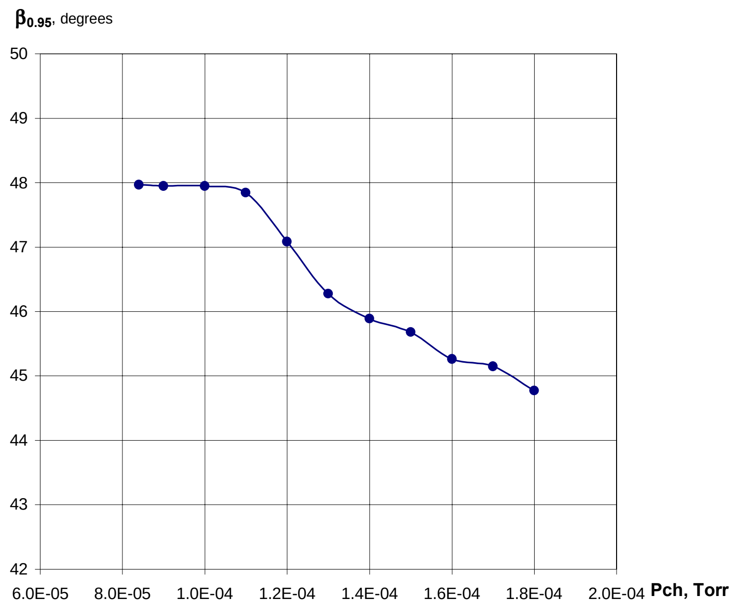

Fig. 5. The accelerated ion flow divergence versus the pressure inside the vacuum chamber.

The represented behavior of the accelerated ions flow divergence could be explained by the following. First, mean energy of ions is reduced with increase of the off-axis angle (Fig.6). Because the charge exchange cross-section area is increased with decrease of ion velocity (energy) the probability of ions recharging is higher in peripheral part of plume, that is charge exchange process reduces the accelerated ions current density more significantly in a peripheral parts. An another possible reason is impact of the neutral atoms density increase on the accelerating layer structure, namely: increase of neutral atoms density and respectively the transverse plasma conductivity in exit part of the accelerating layer can deform the potential distribution within this layer shifting it into anode direction and reducing the accelerated ions flow divergence. Increase of the ion current density near thruster axis (see Fig.4) and decrease of the mean ion energy in the peripheral parts of plume with increase of pressure show that the second factor plays more significant role.

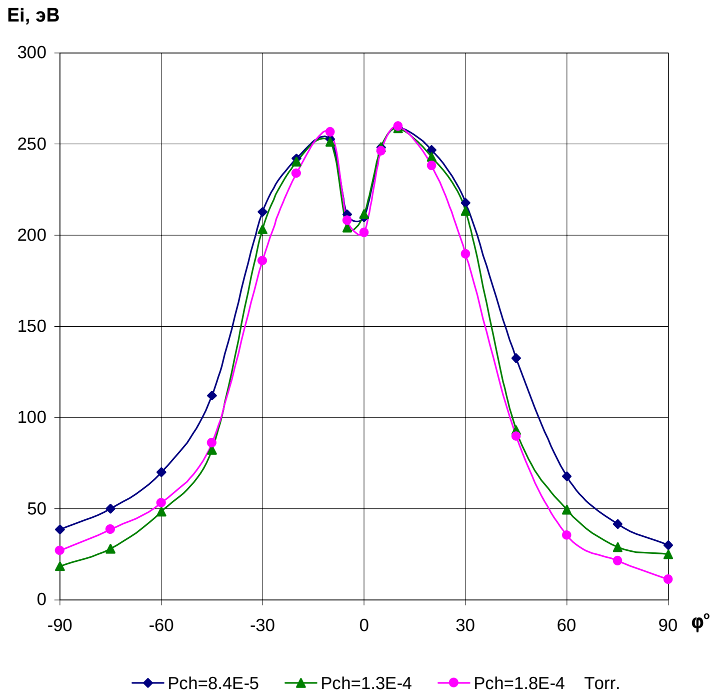

Fig. 6. The accelerated ions mean energy off-axis distributions.

Plasma potential off-axis distribution has maximum near axis and level of this potential is 25-30V (Fig.7). The electron temperature distribution has also maximum near the axis and level of temperatures was 1.1-1.7eV (Fig 8). Plasma density number in a plume was at level of $1{\cdot}10^{10}$ 1/cm^3 (Fig.9) near plume axis and approximately by two times exceeds the density number of the accelerated ions calculated with usage of their measured current density and velocity (energy). Under off-axis angle ~30 degrees the plasma density number is by an order of magnitude higher than that one calculated with usage of the measured accelerated ion current density and velocity. This is explained by the fact that plasma density in a plume is formed mainly by the charge exchange process creating slow ions. These recharged slow ions are moved by the electric field appeared in a plume and create the so-called ion “back “flow. As it was mentioned to estimate this “back” flow there were used flat probes mounted in thruster exit plane. Results of measurements by these probes (Fig.10) show that the ion current densities at radiuses R=0.3-0.5m were at level ~0.01mA/cm^2 while plasma density was at level of $(1 – 2){\cdot}10^8$ 1/cm^3 and electron temperature was at level of ~2eV. Estimation of the ion current extracted from plasma by probe under the mentioned conditions shows that this current is by several times less than the measured one. This means that for theses probes the main part of measured current is that one caused by the directed ion flows. So, one can estimate the “back” flow ion current under the test conditions. Such estimation gives the current values 0.13-0.24A for the part of the exit plane with radiuses R=0.1-0.5m depending on pressure inside the vacuum chamber.

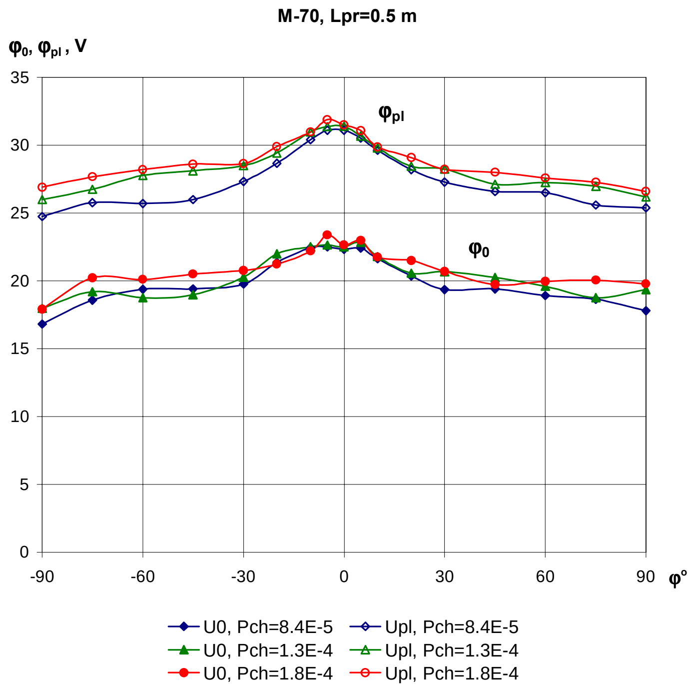

Fig. 7. Plasma (φ_{pl}) and probe floating (φ_0) potentials off-axis distributions.

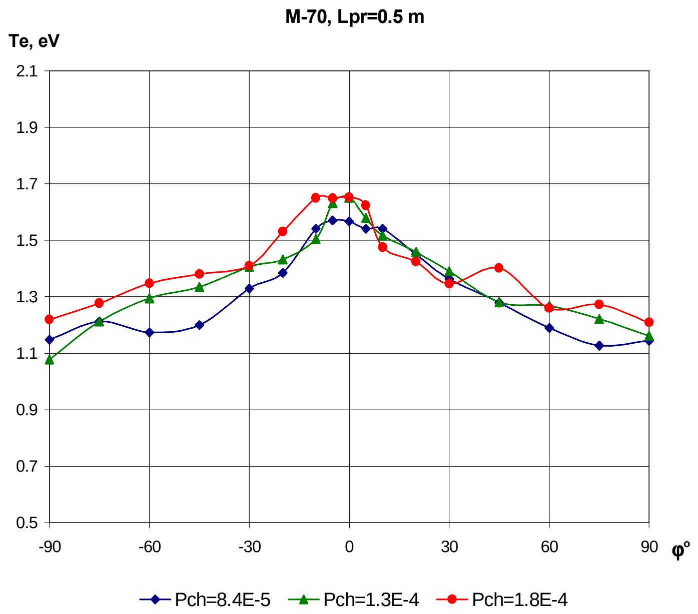

Fig. 8. The electron temperature off-axis distributions.

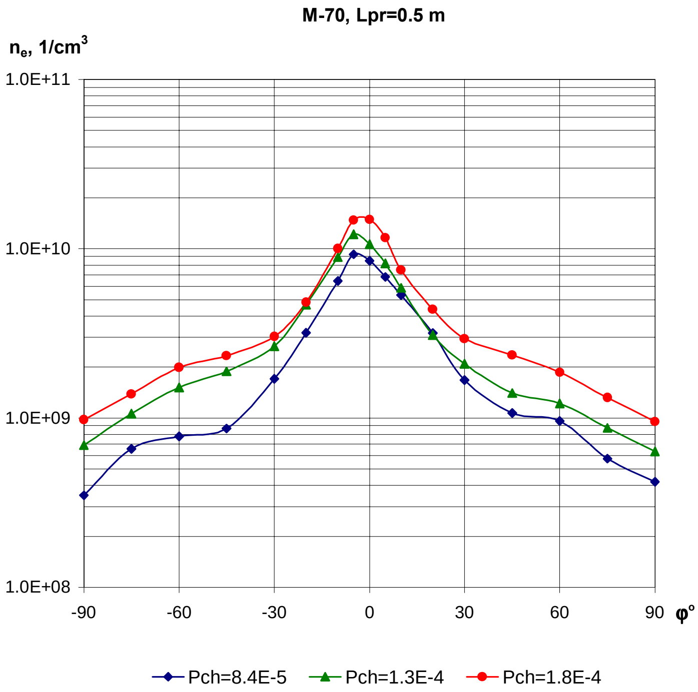

Fig. 9. Plasma density n_e off-axis distributions.

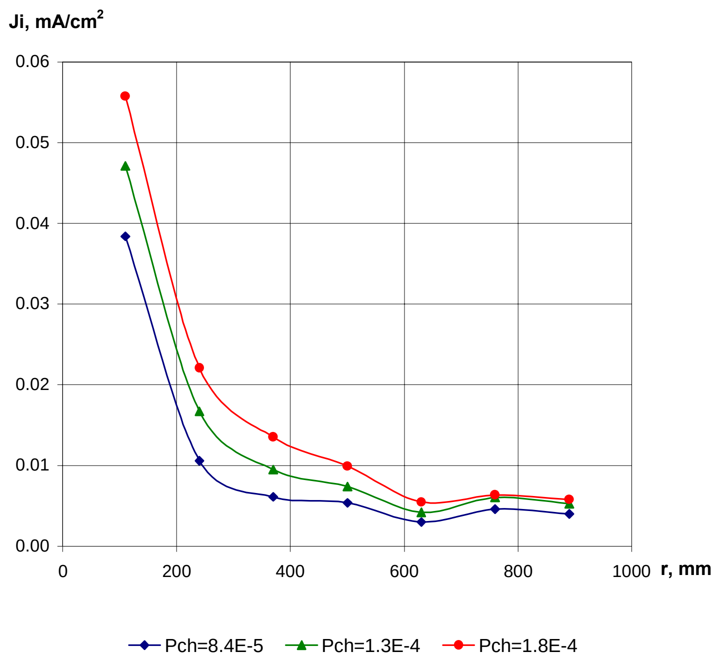

Fig. 10. The probe ion current versus the radices.

Obtained data allows estimation of the minimum value of the total ion current leaving thruster to discharge current ratio. Indeed, the total current of the accelerated ions under pressure ~ $3{\cdot}10^{-5}$ Torr was ~66% of the discharge current (Fig.11). If one adds the mentioned “back” ion flow and assume that directed current of slow ions (not fixed by RPA) on to the hemisphere is the same as the “back” flow current then the total ion current I_{sum} is to be at level of ~70% of the discharge current. In reality it should be even higher because as one can see with increase of pressure the calculated total ion current I_{sum} is reduced with increase of pressure while it should be almost constant or should be slightly increased. One can see also that the accelerated ion current is reduced significantly with increase of pressure due to these ions recharging. But from the applied point of view it seems important that the accelerated ions flow divergence can be determined under pressures lower than ~ $4{\cdot}10^{-5}$ Torr (see Fig.5).

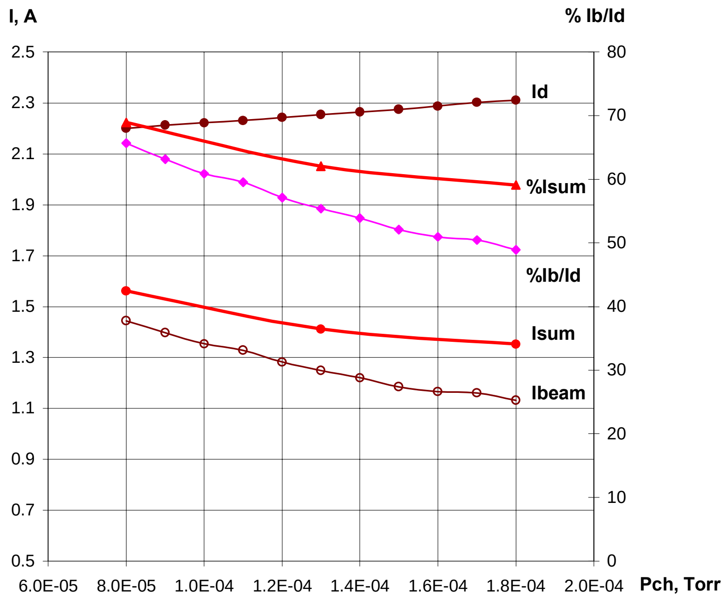

Fig. 11. The accelerated ions current Ib and its ratio to discharge current Id.

Comparison of the SPT-70 plume parameters with that one for the SPT-100 determined at a distance ~0.7m one can conclude that they are very close on the accelerated ion flow divergence (for the SPT-100 type model basic option the $\beta_{0.95} \approx 48$ degrees[4], that is practically the same as for the SPT-70 model - see Fig.5).

Conclusions

The represented data show that the SPT-70 plume has similar plume characteristics as the SPT-100. It is important also that the accelerated ion flow divergence could be determined under pressures inside the vacuum chamber ~ $4{\cdot}10^{-5}$ Torr and lower during thruster performance characterization.

References

1. 1.V.Kim, G.Popov, V.Tikhonov et al. Modern trends of Electric Propulsion Activity in Russia- Proceedings of the 26th International Electric Propulsion Conference, October 17-21, 1999, Kitakyu-shu(Japan), p.p. 27-32.

2. S. Askhabov, M. Burgasov, V. Fishgoit et al. Investigation of plume of the stationary plasma thruster with closed drift of electrons- Physika Plazmi, v.7, 31, 1981, p.p. 225-230.

3. V.K. Absalyamov et al Measurement of plasma parameters in the stationary plasma thruster (SPT-100) plume and its effect on spacecraft components-paper
AIAA-92-3156, 28th Joint Propulsion Confrence, July 6-8, 1992, Nashville, USA.

4. V.Kim, V.Kozlov, A.Skrylnikov et al. Investigation of the possibility to reduce SPT plume divergence by optimization of the magnetic field topology in the accelerating channel-paper IEPC 97-154, 25th International electric Propulsion Conference, August 24-28, 1997, Cleveland, Ohio, USA.