

Measurement Features and Results of TAL D-55 Plume

IEPC-2005-184

*Presented at the 29th International Electric Propulsion Conference, Princeton University,
October 31 – November 4, 2005*

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Abstract: Parameters of accelerated plume of electric thrusters are of great importance for proper consideration of its interaction with a spacecraft. Most of analytical models and computer codes describing this interaction are based on experimental data in regard to initial distribution of the plasma plume parameters. So that accuracy of this data determines accuracy of further computation and analysis. But available plume data measured in different facilities and by different measurement equipment differ significantly, and there is no clear criteria for applicability of the equipment and test conditions for proper measurements. In the presented paper requirements for Hall thruster plasma plume diagnostic and possible diagnostic set are analyzed. The measurement of ion current density, plasma potential and electron temperature by means of different types of electric probes are considered. The results of verification of different probes and comparison of experimental data obtained at the distance of 300, 500 and 1000mm from thruster exit plane are represented. Significant influence of the probe design and size on measured value of ion flow density has been identified. Applicability of Ø2mm small flat probes for electron temperature and plasma potential measurements is experimentally demonstrated and proven. The results of plasma plume parameters mapping using flat oriented probes are presented. Electron temperature, plasma potential, ion energy and flow density values data base for D-55 thruster plume has been collected for number of regimes with different discharge voltage (200–400 V) and variable test conditions. The influence of test condition and operation mode of thruster on plasma plume parameters is studied and significant influence of the test conditions on measured plasma parameters identified. Experimental data showing dramatic influence of residual pressure in the vacuum chamber on measured electron temperatures and plasma potential are presented.

Nomenclature

j_i	= Ion current density
T_e	= Electron temperature
λ_D	= Debye radius
V_p	= Probe potential
I_i	= Saturation ion current
I_e	= Electron current
d_p	= Characteristic size of a probe

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I. Introduction.

Generally, to describe an exhaust plume of a plasma thruster at every point of a cross section of this plume, it is necessary to determine the following parameters:

- structure of plume: the quantity/concentration of neutral particles, singly and repeatedly charged ions;
- directional velocity: the value and direction for every group of heavy particles;
- temperature (chaotic velocity) of each component of heavy particles;
- temperature of electrons;
- velocity (value and direction) of the directional motion of electrons;
- potential of space (domain of plasma spread) .

It is important to measure *local* parameters, and this requirement predetermines the choice of electrical probes mounted on coordinate devices as the basic diagnostic method. The method of probes is the most informative and also enables determination of most of the parameters listed above as well as their spatial distributions. The missing information can be filled up with other methods: energy and mass analysis, LIF measurements, spectrometry etc. Although application of probes for investigations of plasma has a long history, a lot of particularities of measurements in electric thruster plumes are studied insufficiently. The measurements procedure and design of probes demands improvement and verification with regard to specified test conditions.

II. Hardware description

A. Description of the used thruster

D-55 hall thrusters with anode layer has been chosen as studied one. External view of the thruster is shown in Fig. 1. D-55 thruster is analog of flight version TAL-WSF successfully tested onboard STEX spacecraft in the ranges of EPDM program during October 1998 – March 1999¹. D-55 thruster was developed to operate at power level up to 1500 W. At the present moment D-55 is the most studied thruster available at TSNIMASH. TSNIMASH's laboratory cathode with LaB₆ emissive element providing electron current up to 10 A was used in the tests.

Thruster and cathode-neutralizer axes were parallel and located at the distance 90mm from each other. Thruster and cathode exit plans were at one and the same plan.

In the bulk of experiments the following operating regime of the thruster was chosen:

- thruster discharge voltage 300V;
- thruster discharge current 3A;
- anode mass flow rate 3,5mg/s.



Figure 1. External view of the D-55 thruster.

B. Description of the developed/used diagnostic tools

The area of plume to be diagnosed can be divided into two zones: “near field” and “far field”. Higher concentration and density of the current are typical to the first zone while the second has lower energy level and a low gradient of parameter variations. In the first zone due to high intensity of particle fluxes from out of plasma, an essential heating and destruction of probes as well as gears designed for their movement can occur. It entails necessity of taking measurements during a time interval shorter than the time of heating of a probe, and moving the probes rather fast in this zone. In the second zone these are not important. In view of the differences in the measurement conditions, there is a necessity of creation of two different diagnostic systems, individually, for the “near field” and “far field” zones. On the basis of earlier activities, with regard to thruster D-55 the “near” field zone is defined as the interval from 0 up to 500 mm from the exit of the source of ions, and the “far field” zone - as beyond 500 mm from the source exit. For each zone a dedicated coordinate device was designed.

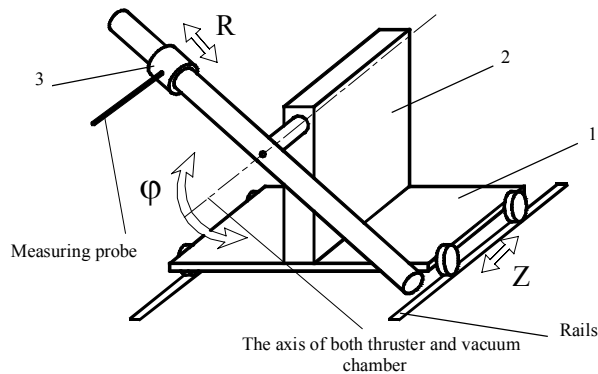
2D near field zone positioning system. To study the plasma flows generated by an electrical thruster in the zone close to its exit, a dedicated device for moving probes in the planes perpendicular to the direction of flow was developed. Schematic diagram of the probe moving system is shown in Fig. 2.

Driver 2 is a gear providing an angular movement (coordinate φ). The output shaft of the driver is connected with a boom on which probes are mounted. Angular movement driver 2 is fixed on carriage 1 which is capable to move on rails along the axis of chamber. The basic performances of the system are shown in **Table 1**.

Table 1

Coordinate	Parameter Range	Velocity	Accuracy of Positioning
Z	0...2000 mm	2 mm/s	± 1 mm
φ	$\pm 100^\circ$	90 degree/s	$\pm 0.1^\circ$

3D far field zone positioning system. To obtain the data about spatial parameter distributions of plasma flows, movement of probes (or other primary sensors) to any specified point of tested area should be ensured. Therefore, development of a 3D positioning system has been carried out. The system is dedicated to place the probes, analyzers etc. into any point of investigated plasma - by means of PC (under a special software) or manually, by means of an electronic control block. Schematic diagram and the overall view of the 3D moving system is shown in Fig. 3.



1 - the carriage (Z), 2 – the probe driver for angular movement (φ), 3 - the probe (sensor) driver for movement along the radius of the carriage (R).

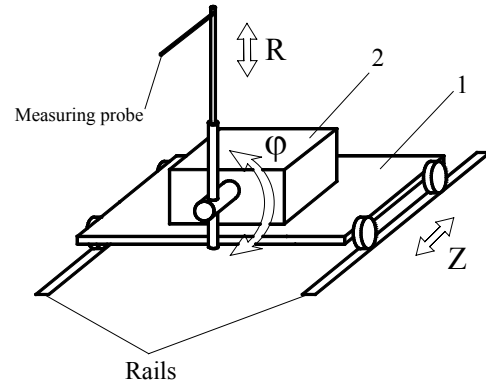


Figure 2. Schematic diagram of the "near"-zone probe driving device.

1 - the carriage (Z), 2 - the probe driver for angular movement (φ).

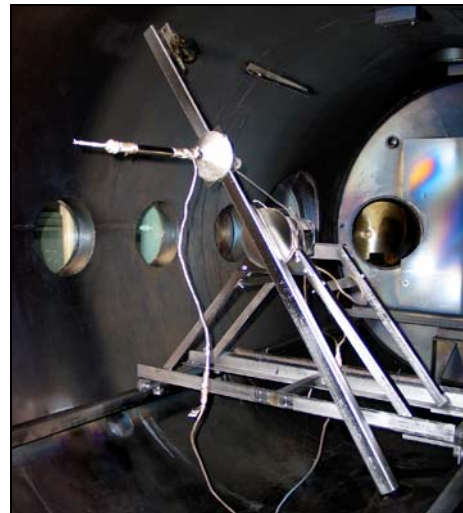


Figure 3. Schematic diagram and external view of the "far filed" zone probes driving system.

The system consists of three interconnected units. Along the chamber, there are rails for movement of carriage 1 (coordinate Z). Carriage 1 with installed probe drivers for angular (coordinate φ) and radius (coordinate R) movements are driven by an electric motor with the reduction gearbox.

Accuracy of positioning of primary sensors (probes) at a specified point depends on the actuating devices as well as the electronic circuit of positioning. Main performances of the system are represented in Table 2.

Table 2

Coordinate	Parameter Range	Velocity	Accuracy of Positioning
Z	0...2000 mm	2 mm/s	± 1 mm
φ	$\pm 100^\circ$	3 degree/s	$\pm 0.5^\circ$
R	± 600 mm	40 mm/s	± 0.5 mm

Systems for control and measurement. To control the coordinate systems for positioning and automated registration of probe characteristics, a dedicated instrumentation, which ensures placement of probes in predetermined points of space with a capability of dynamical taking of measurements (manually or with a PC under a specialized software) was used.

The schematic diagram of the control and measurement system is shown in Fig. 4.

The system enables registration of probing characteristics in an automatic mode, under a predetermined computer program which ensures preset of the algorithms for drivers simultaneously with the performances registration (on a computer). There are three independent channels available for probe (or an analyzer) performances measurement, that ensures simultaneous registration of signals from three probes. Each channel has its individual set-up that enables use of probes of diverse types at a time, and analyzers too. The system has three measuring ranges of the current coming on the probe of a channel: 15 mA, 50 mA and 150 mA. This enables selection of optimum parameters for measurement at diverse points in plasma. Generator of saw-toothed voltage provides a probe with the bias voltage in the range from -25 V up to +50 V that enables obtaining of a complete probe characteristics.

This instrumentation supports registration of probing characteristics in two ways. The first one consists of a direct measurement of volt-ampere characteristic of a probe or an analyzer. The second way differs by that probing characteristics are obtained via averaging of several measurements. This reduces the probability of random failure and noise during the measurement.

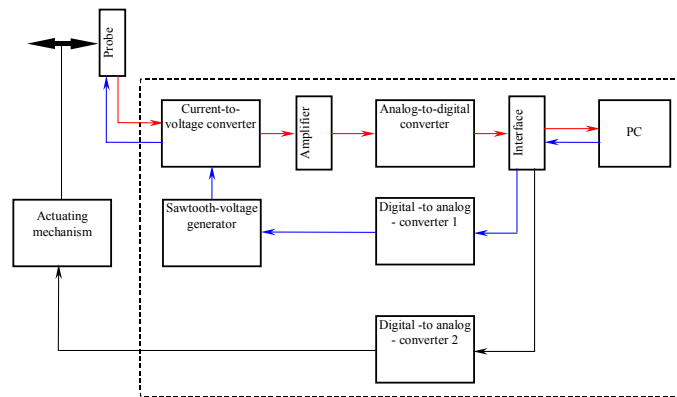


Figure 4. The schematic diagram of the control and measurement system.

III. Selection, improvement and verification of probe designs and sizes. Improvement of the measurement procedure

With purpose of obtaining complete information about plume characteristics in every point requires determination of three components of a flow in three mutually perpendicular directions. It is a complex engineering problem, which has not been solved earlier, demanding a dedicated research. Nevertheless, for the first estimate, a system consisting of three probes pointed in three mutually perpendicular directions can be used.

For hardware realization of such a diagnostic instrument a probe designs improvement program was carried out. It included the following phases:

- improvement of the design (with a guard ring and without it) and sizes of flat probes;
- verification of measurement results via comparison of the data obtained from different probe types and independent measurements.

The basic criteria for selection of the probe designs were:

- minimal size - to obtain as higher resolution as possible and the lowest disturbance of the tested flow;
- simplicity of manufacturing and reproducibility of the design;
- agreement of the measurement results with the data obtained by other independent methods.

To verify the measurement results cylindrical probe was used, because these are the most investigated and extensively described in literature².

The probes are shown in Fig. 5.

Current-voltage probe characteristics were measured according to a standard scheme when biasing the probe in the range of -25 V... +50 V. Volt-amps curves (VAC) were recorded on a computer controlled by a routine software. To eliminate accidental errors and electromagnetic noise effect in a registered signal, recording of a VAC curve was made in two ways:

- at a single change of the bias;
- via averaging of 10...25 measurements at each point.

All the results represented below were obtained under coincidence of measurements in both ways of registration.



Figure 5. Flat probe 5 mm, flat probe 5 mm with guard ring, cylindrical probe (from left to right).

Plasma parameters were estimated with the following relations.

Ion current density:

$$j_i = \frac{I_i}{S_p},$$

where I_i – saturation ion current, S_p – geometrical area of a collecting probe surface.

Electron temperature:

$$T_e = \frac{e}{k \cdot \left(\frac{d \ln(I_e - I_i)}{dV_p} \right)},$$

where I_i - saturation ion current, I_e – electron current, V_p – probe potential.

A. Selection of the probe size and geometry

Among the problems solved on the phase of improvement of probe designs was a well-grounded selection of the size of a flat probe. As a rule, the size of Langmuir probe is determined from the following relation:

$$d_p \gg \lambda_D, \quad (1)$$

where d_p - the characteristic size of a probe; λ_D - Debye radius.

$$\lambda_D = \sqrt{\frac{\epsilon_0 \cdot k \cdot T_e}{2 \cdot N_e \cdot e^2}} = 17,6 \cdot \sqrt{\frac{T_e}{N_e}}, \quad (2)$$

where T_e and N_e - electron temperature and concentration.

The bigger is the probe size, the less is the measurements error caused by the change of the effective collecting surface of a probe (due to formation of boundary layer of the order of λ_D). On the other hand, the bigger is the probe, the greater are disturbances in the tested plasma and deformations of plasma initial parameters. So, selection of the probe size assumes a compromise to be found between the mutually opposite requirements.

Typical parameters of the accelerated flow of D-55 thruster at the distance of about 0.5 m are: $T_e = 2 \text{ eV}$; $n_e = 3 \cdot 10^9 \text{ cm}^{-3}$. So, the Debye radius is: $\lambda_D \sim 0,5 \text{ mm}$.

On the basis of condition (1), the size of a flat probe was initially chosen equal to 5 mm. This size coincides with the sizes of similar probes used in earlier and passed through the cross tests in several laboratories³.

Probes of two types were manufactured:

- a Ø5-mm flat probe;
- a Ø5-mm flat probe with a guard ring.

Although the second design is more complicated, it ensures more reliable measurements².

The material for probes is molybdenum.

Also, to get an extended database for comparison of the plasma flow parameters obtained with probes of a different design, cylindrical probes of Ø0.5x10 mm were made and tested. These probes also satisfy condition (1).

In Fig. 6 is an example of the plasma potential obtained with three types of probes at the distances of 300 mm and 500 mm from the D-55 thruster exit along the plume flow direction. In Fig. 7 the density of ion current obtained with a flat probe and a probe with a guard ring at the same distances from the thruster exit are depicted. The curves are plotted depending on the radial distance from the geometrical axis of thruster. Electron temperature distributions obtained with the same types of probes at 300-mm and 500-mm distances from the thruster exit are shown in Fig. 8. Thruster D-55 operating in the base mode of 300 V, 3 A was used in all these cases.

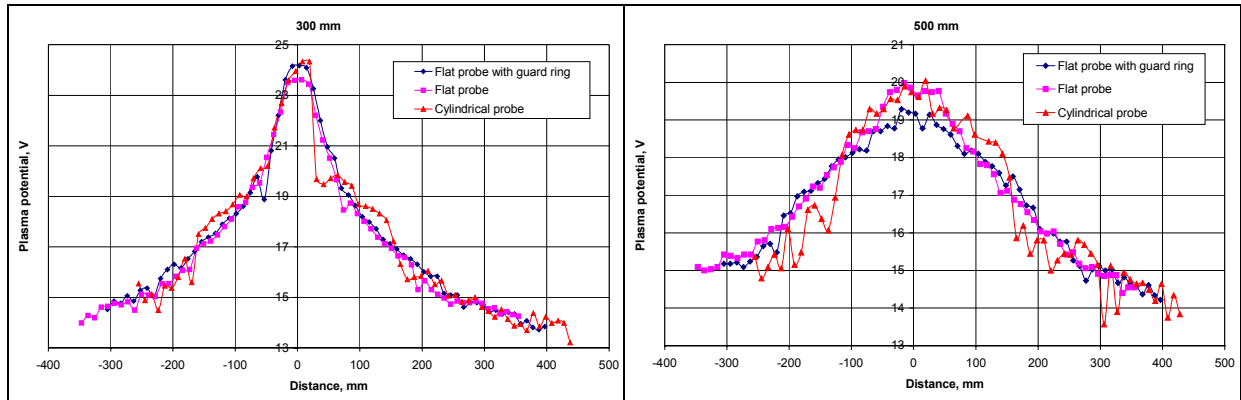


Figure 6. Plasma potential measured with probes of diverse types (300 and 500 mm).

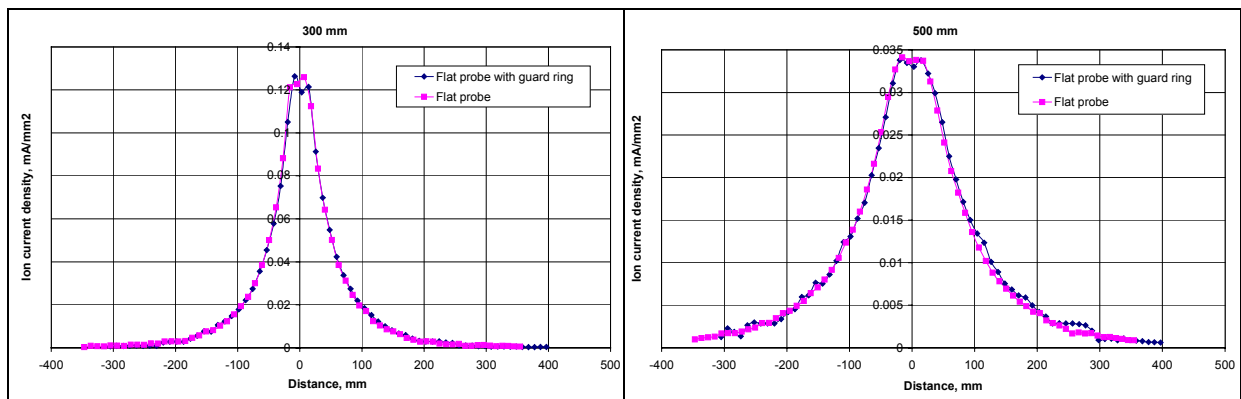


Figure 7. Density of ion current measured with a flat probe and flat probe with a guard ring (300 and 500 mm).

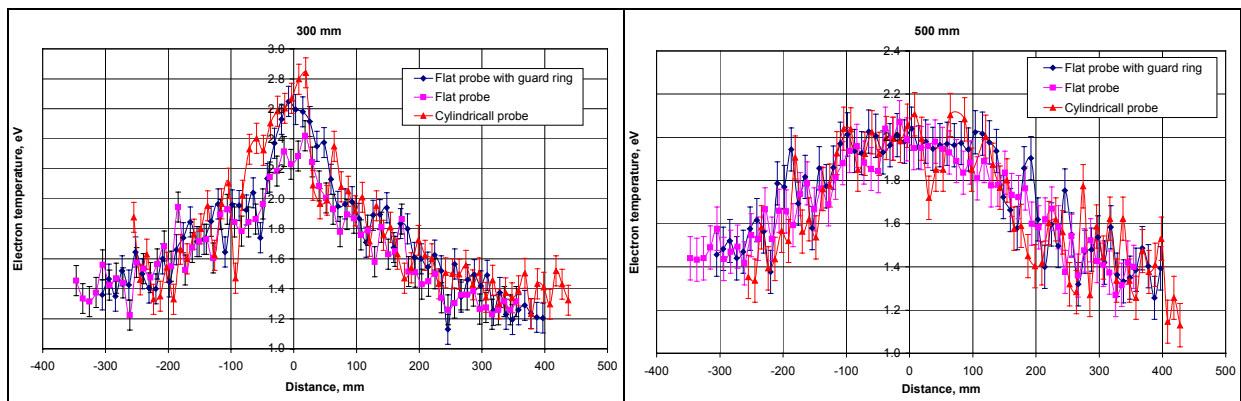


Figure 8. Temperature of electrons, measured with probes of diverse types (300 and 500 mm).

As one can see from Fig. 6 and Fig. 8, there are no essential differences between the plasma potentials or between electron temperatures, measured with cylindrical and flat probes. Also, as follows from Fig. 7, densities of the ion current obtained with the flat probe and the flat probe with a guard ring have a good-accuracy coincidence (the density of ion current of the cylindrical probe is not submitted here in view of the uncertainty of the collecting surface size for such a probe under conditions of accelerated plasma flow). These results were true in all the investigated volume of a plume at the distances of 300-1000 mm from the thruster exit.

The obtained quantities are in a good agreement with the data obtained earlier⁴, that proves the executed measurements.

As one can see from the data above, results of measurements with single flat probe of 5-mm diameter and with a similar probe having a guard ring are completely coincident. No differences between the VAC of probes and the results of plasma parameters estimations are revealed. It is an evidence of that actually the size of the 5-mm probe is essentially greater than Debye radius and there is a capability of reduction of the probe size. There are two reasons for desirability of such reduction:

- probes of the smaller size enables a higher spatial resolution;
- reduction of the probe size decreases the disturbance contributed by it into tested plasma.

However, the minimal size of a probe has a limitation described by expression (1). The values of Debye radius calculated after handling of characteristics of a Ø5-mm flat probe at D-55 plume measurements are depicted in Fig. 9. The values of Debye radius are plotted depending on the distance between the thruster center and position of the probe in a direction perpendicular to the axis of the flow. The values are shown for three distances from the engine exit along the axis of a flow: 300, 500 and 1000 mm. The D-55 operation mode was 300 V, 3 A.

From the presented data one can see that, if the size of probe is less than 5 mm, relation (1) is not true for a significant part of a plume and an experimental check of the possibility for its use is required.

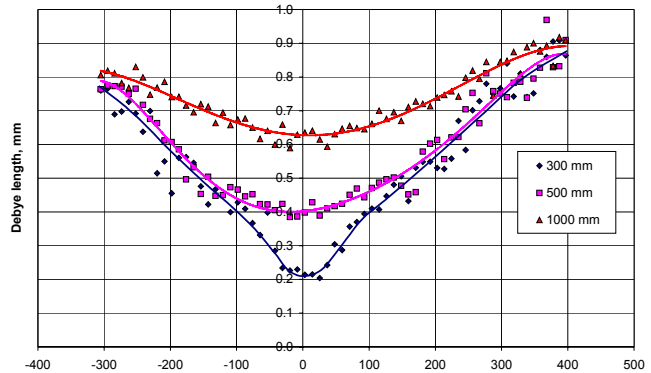


Figure 9. Debye radius.

B. Comparison of flat probes of different sizes.

Since application of smaller probes is important for creation of an assembly of several directed probes, special efforts were aimed at investigation of possibility of using of the probes for which condition (1) is not true. Operation of flat probes of a 2-mm diameter was studied.

The 2-mm size was chosen, on the one hand, to reduce essentially the probe size comparatively to the design described above, and on the other hand, to avoid technological difficulty while manufacturing details from molybdenum. At the 2-mm diameter of the probe the technological tolerance on this size is (± 0.1 mm) that is quite acceptable for measurement of the ion flow density.

For a functional check of small probes, plasma parameters measured with the 2-mm diameter probes and with a 5-mm probe (which was used as a reference one) were compared. The measurements were taken at a base operational mode of the D-55: 300 V, 3 A.

The distribution of plasma potential, measured with a flat probe of 2 and 5 mm, which can be considered as a standard is shown in Fig.10. The values of plasma potential obtained with both probes (as can be seen from Fig. 10) differ from each other in a value exceeding not more than 1 V. It is close to the threshold of sensitivity in our measurements, which is about 0.5 V.

Taking the classical probe theories as a basis, it is possible to expect the greatest difference between the parameters, measured with the probe, sized close to Debye radius, and the results of measurements with a rather large probe for which the condition (1) is true, at a great distance from the ion engine (where the plasma particle number density drops and Debye radius increases). However, direct comparison of the results for the density of ion flow measurement with probes of 2-mm and 5-mm diameters at the distance of 1 m actually demonstrates their coincidence. The difference between the indications of probes increases with approaching to the exit of thruster (Fig. 11) that contradicts the results, which could be expected basing on a classical probe theory.

Fig. 12 illustrates a characteristic change in the density of ion flowing the center of a plume measured with 2-mm and 5-mm probes depending on the distance from the thruster exit.

A future investigation is demanded to understand the noticed divergence.

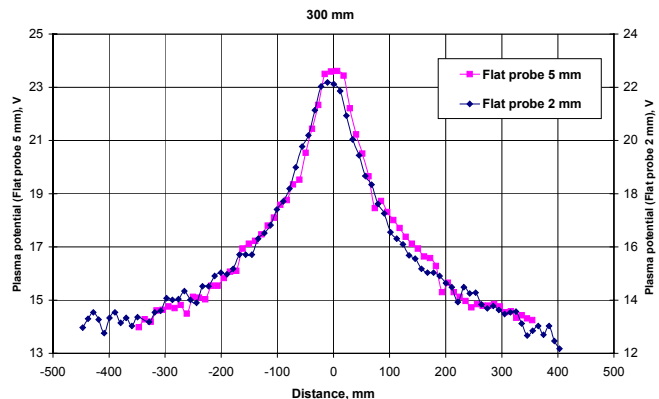


Figure 10. Plasma potential measured with a flat probes of 2 and 5 mm.

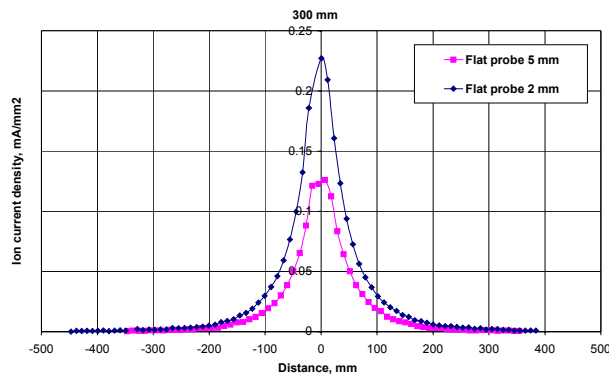


Figure 11. Densities of ion current, measured with flat probes of 2 mm and 5 mm.

It should be mentioned that owing to the design features and different heat sink from the collecting surface, a small probe was essentially heated up at a distance closer than 500 mm to a thruster. At the distance of 300 mm it was visible to the naked eye that the probe was heated up to the temperature of red heat (Fig. 13). A possibility of an abnormally high electronic emission from a hot metal surface located in dense plasma is denoted in paper⁵. However, it is only one of possible hypotheses explaining the difference between the results of measurements of ion current. The problem demands its further study, including a more detail investigation of the capability of measurements with a “shooting probe”, having the residence time in a flow much less than the time of its surface heating.

With regard to the task of a future Hall thruster plume investigation, it can be noted that the system for ion currents measurement enables registration of ion current density relative changes. However, an additional calibration of the system is necessary for more precise quantitative measurements. The discrepancy of the density of ion current measured with different probes performs a comparison of the ion current magnitudes impossible. Nevertheless, it is of the essence that the results of measurement of plasma potential as well as of electronic temperature completely coincided. It allows to talk about, at least of a possible limited application of small probes (the linear sizes are comparable with Debye radius) to measurement of local parameters of plasma.

As an illustration for the said, a distribution of electron temperature across a plume, obtained with 2-mm and 5-mm flat probes, is depicted in Fig. 14. As one can see from Fig. 14 the electron temperatures are rather close to each other.

So, the represented data denote the applicability of 2-mm probes in our conditions in spite of the fact that the size of the probe is comparable to the Debye radius for some part of a plume.

Thus, for further investigation of plumes, flat directed probes enabling more definite registration of the direction of flow in comparison with cylindrical probes and also having smaller sizes and design simplicity in comparison with flat probes with a guard ring were chosen. In Fig. 15 the scheme of directed flat probes of 2-mm diameter chosen for future studies is shown.

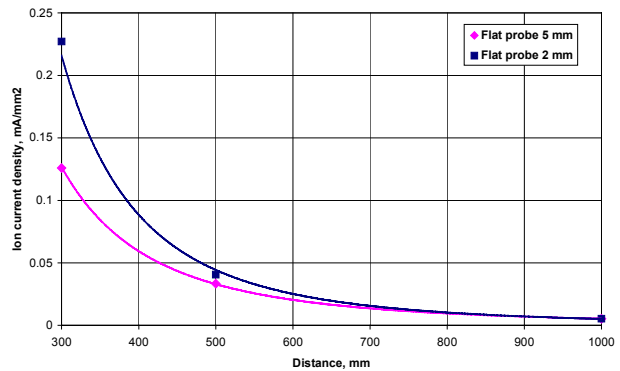


Figure 12. Density of ion current of 2-mm and 5-mm flat probes .



Figure 13. Heating of probes.

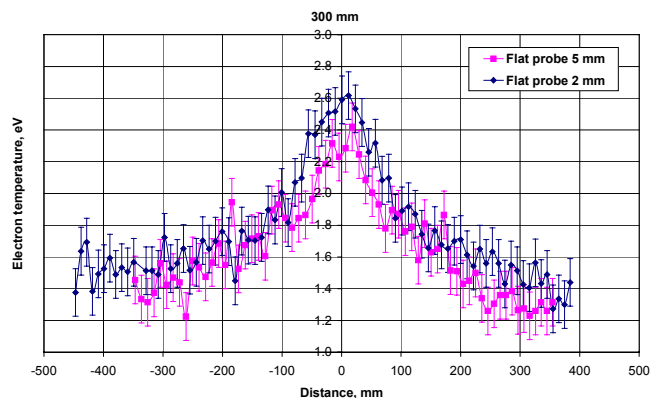


Figure 14. Electron temperatures, measured with flat probes of 2 and 5 mm.

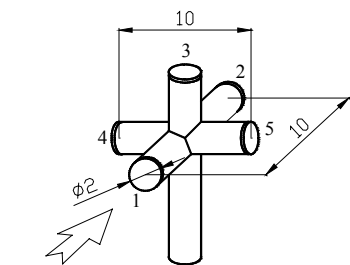


Figure 15. Oriented flat probes.

IV. Experimental results of investigation of a single thruster plume

With directed probes installed on a coordinate device, spatial distributions of electron temperature, potential of plasma and ion flow the D-55 plume were investigated.

Distributions of plasma potential, measured across the D-55 plume at the distances of 300 mm and 500 mm from the thruster exit with directed probes *1*, *2* and *3* (Fig. 15) are shown in Fig. 16. Probe *1* was placed across the incident plume, probe *2* - at the rear, in the “shadow” of the incident flow, and the face of probe *3* was directed in parallel to the engine axis.

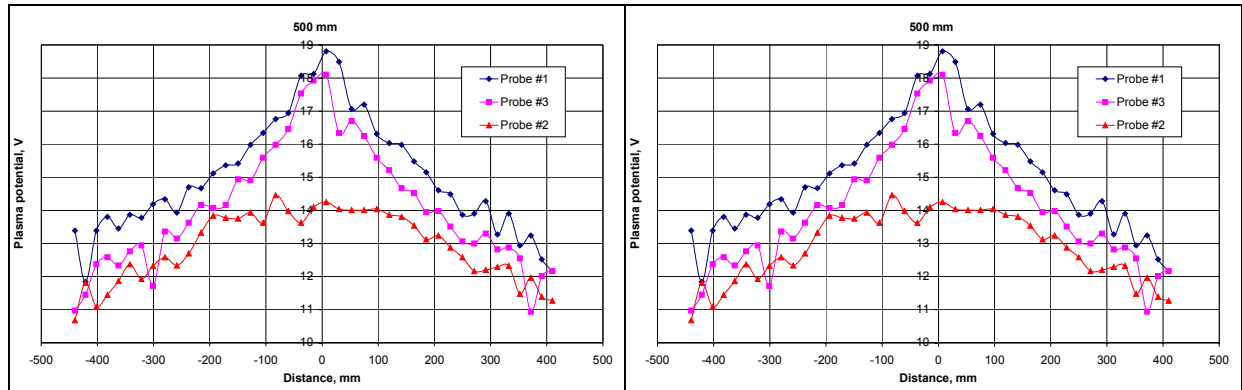


Figure 16. Plasma potential ($Z = 300$ and 500 mm).

Distributions of ion current density and electron temperature (measured with probes *1*, *2* and *3* across the plume at the same distances from the thruster exit) are depicted in Fig. 17 and Fig. 18.

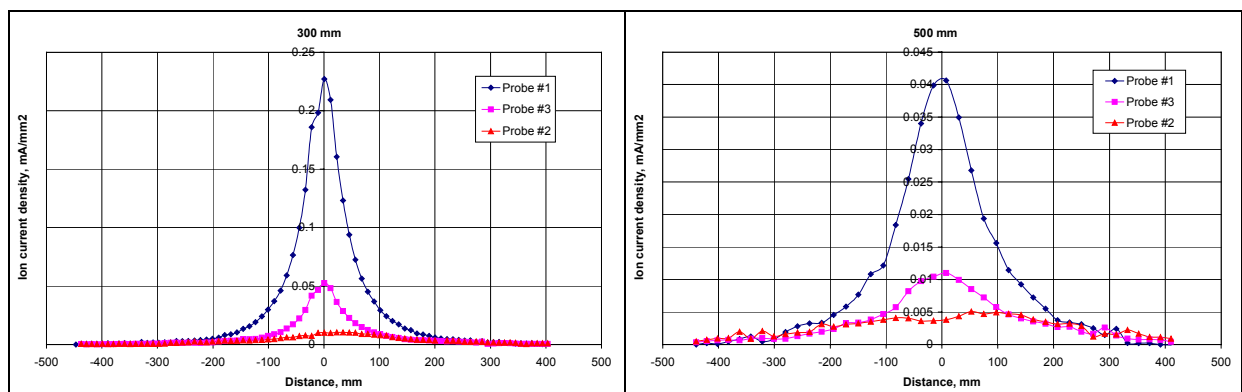


Figure 17. Density of ion current ($Z = 300$ and 500 mm).

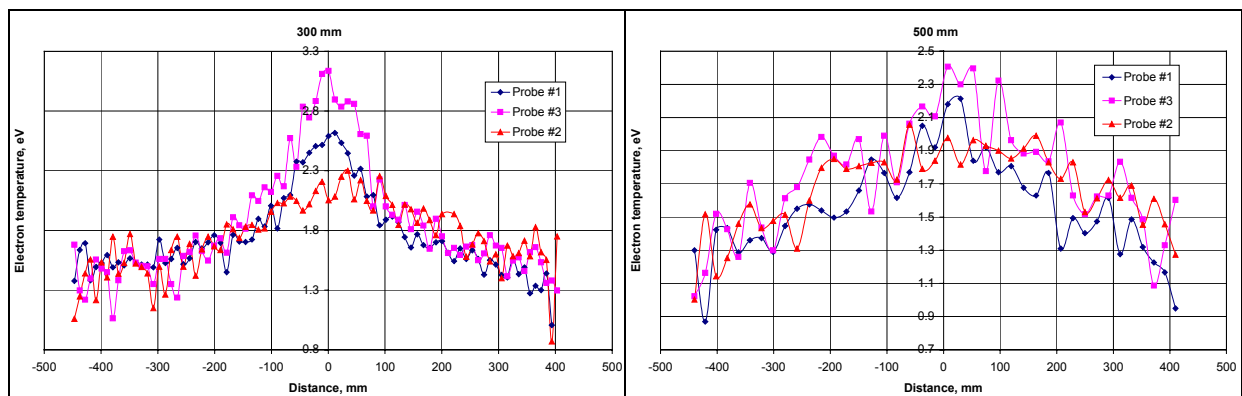


Figure 18. Electron temperature ($Z = 300$ and 300 mm).

The difference of the ion current collected on probe *1* and that on probe *3* is approximately proportional to the ratio of directional and chaotic velocity of the ion component⁶. With moving away from the center of a plume, the directional speed drops, and at some distance it is compared to the chaotic speed of secondary plasma. The later may be considered as a criterion to determine boundary of accelerated plume. In cross-section $X = 300$ mm: the directional flow practically disappears in the radius of 200 mm; for $X = 500$ mm - in the radius

of not more than 300 mm. It corresponds to the divergence of an accelerated plume within the angle of approx. ± 30 degrees.

The electron temperature measurements of three directed probes are practically coincident in periphery of a flow and at great distances from the thruster exit where concentration of the secondary plasma is comparable to concentration of an accelerated flow. In the near zone $X=300$ mm, in the central part of a plume there is a difference in the values of temperature measured with probes of diverse orientation. It can be assumed that such difference is connected to the directional motion of tested plasma, but this question demands the further study.

When approaching the thruster discharge (thruster exit) the temperature of electrons grows and (see Ref. 7) reaches 10...15 eV at the distance of 10...15 mm from the thruster exit. The obtained change of temperature along the radius of a plume is similar to data of work ⁴.

As one can see from Fig. 16, the plasma potentials measured with probes *1* and *3* are close to each other. However, the potential of plasma obtained with probe *2* differs essentially from the first two. Presence of this probe in the “shadow” created by the very assembly of directed probes can be a reason of such difference. A similar phenomenon is well-known in plasma and space engineering. Nevertheless, in the periphery of the plume where both velocity and density of a flow are not so high, the values of plasma potential for all the three probes are rather close to each other.

In general, it can be stated that the tested measuring instrumentation under an appropriate technique enables measurement of electron temperature with the resolution of 0.1...0.2 eV, and the plasma potential - not worse than 0.2 V. It can support investigation of a rather fine structure of a flow and potential effects, which may arise in both single plume and complex one, generated by several operating thrusters.

V. Influence of thruster operating mode on characteristics of flow

To study the influence of an operating mode of a thruster on characteristics of its plume, probe testing of the plume of D-55 engine was executed at the modes of 200, 300 and 400 V, 3 A. The distributions of plasma potential and electron temperature across the plume are depicted in Fig. 19, Fig. 20 respectively. Flat probe *1* of 2-mm diameter (Fig. 15) was used at the distance of 300 mm from the thruster exit and discharge voltages 200 and 300 V.

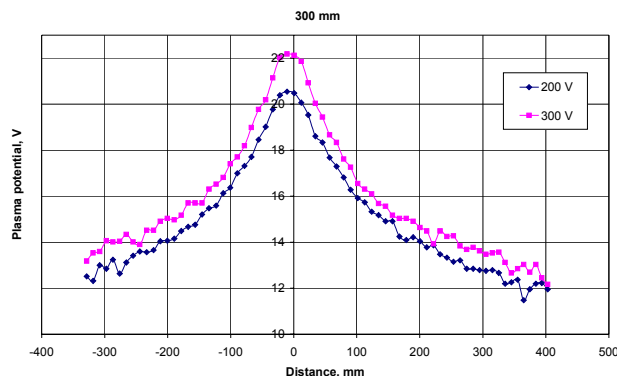


Figure 19. Plasma potential at discharge voltage of 200 V and 300 V.

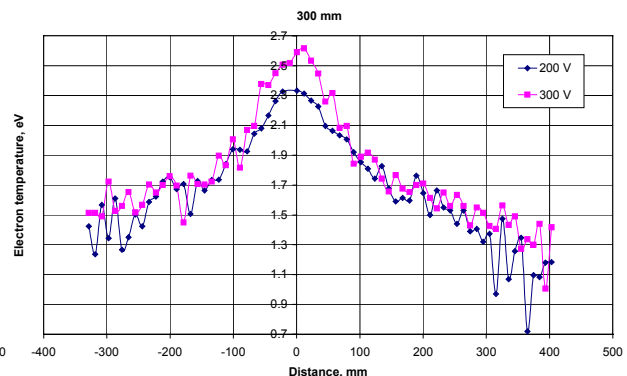


Figure 20. Electron temperature at discharge voltage of the thruster 200 V and 300 V.

The density distributions of the ion current, obtained with the same probe at discharge voltages of 200 V and 300 V are shown in Fig. 21. As one can see from Fig. 21, an increase of discharge voltage results in growth of the density of ion current and better focusing of the plume that was already shown earlier ^{6,8}.

An example of variation of the ion current distribution at the distance of 500 mm and voltage 300–400 V is represented in Fig. 22 (obtained by the flat probe of 5-mm diameter).

As one can see from the presented data, variation of discharge voltage results in an essential difference of the distribution of ion flow. At the same time, the differences between the values of plasma potential as well as electron temperatures are not so essential. The variations of both electron temperature and potential are much weaker in comparison with the change of discharge voltage causing it. Therefore, it can be stated that a relatively little variations in the operational mode of a thruster will not cause a noticeable asymmetry in plume parameters – electron temperature and plasma potential of this thruster.

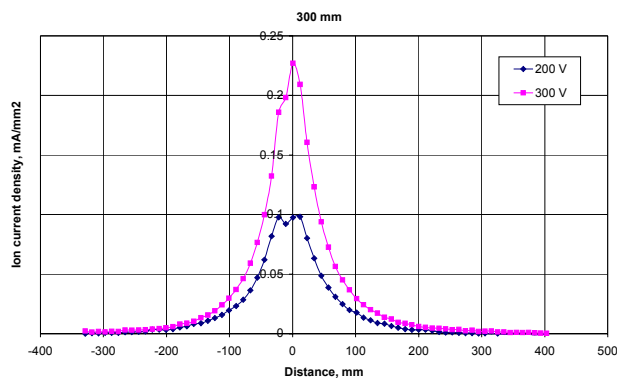


Figure 21. Density of ion current, discharge voltage of the thruster: 200 V and 300 V.

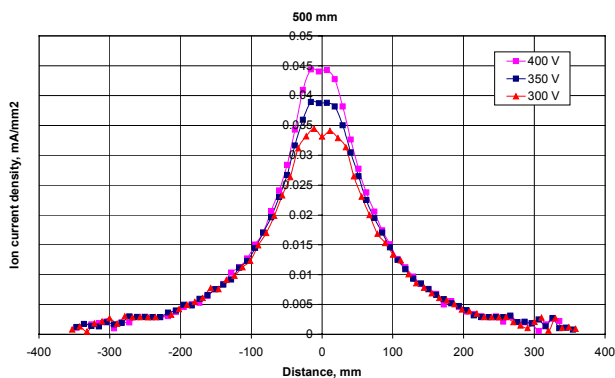


Figure 22. Density of ion current, discharge voltage of the thruster: 300 V, 350 V, 400 V.

VI. Influence of test conditions on the plume characteristics

During thruster ground testing at different test facilities the residual pressure in vacuum chamber may be various. Therefore, determination of degree of residual pressure influence upon plume characteristics is required.

The influence of pressure on characteristics of a D-55 thruster plume was investigated. The bottom tested residual pressure corresponds to operation of the D-55 thruster with the xenon flow rate of 3.5 mg/sec. The upper tested value of residual pressure corresponds to the conditions with the triple xenon flow rate (3.5 mg/sec through operating D-55 and 7.0 mg/sec through additional input in vacuum chamber). In both case the thruster worked in the reference mode of 300 V, 3 A.

Variation of residual pressure in the vacuum chamber causes significant changes in the value and distribution of electronic temperature and plasma potential (Fig. 23, Fig. 24). With increase of the pressure the electron temperature drops abruptly (Fig. 24). It could be possibly accounted for cooling of electrons during interaction with atoms of residual gas. This fact is important, since the quantity of electron temperature is crucial for computer simulation of propagation of a plasma flow and its interaction with surfaces of a space vehicle. As it follows from the obtained data, the measured value of electron temperature is a function of two “quantities”: both the operational mode of thruster and test conditions. Therefore, in future it is important to define the test conditions, which would enable obtaining of electron temperature values appropriate to the conditions of EP flight operation, or to develop methods of data recalculation of ground tests to the conditions of flight operation.

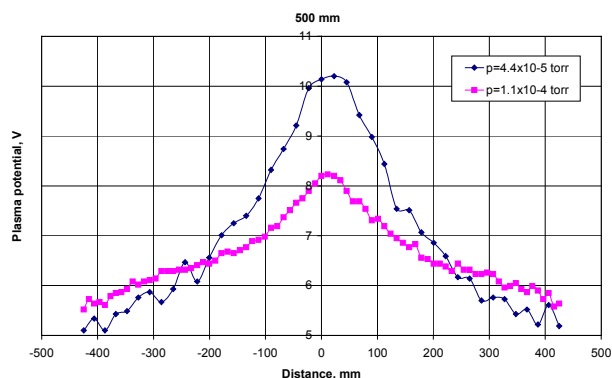


Figure 23. Plasma potential at various pressure.

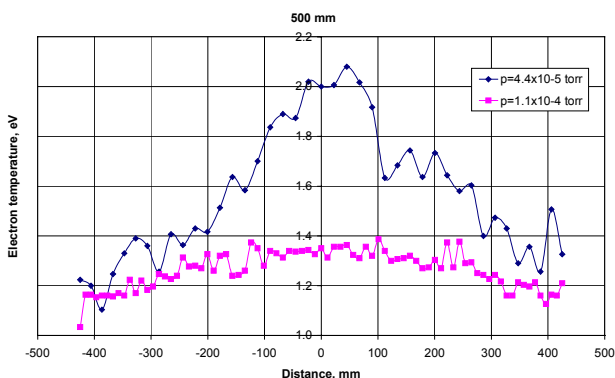


Figure 24. Electron temperature at various pressure.

VI. Conclusion

Measurement equipment utilizing different types of probes for plasma diagnostics have been designed, assembled and tested. Design of the oriented flat small probes has been selected as most simple one and allowed to perform fine measurements with good space resolution. In general, it can be stated that the tested measuring instrumentation under an appropriate technique enables measurement of electron temperature with the resolution of 0.1–0.2 eV, and the plasma potential - not worse than 0.2 V.

The measured plasma parameters are in a good compliance with data obtained earlier. Conditions of applicability of small flat probes for electron temperature and plasma potential measurements have been identified. Significant influence of the probe design and size on measured value of ion flow density has been determined.

Electron temperature, plasma potential and flow density data base of single thruster plume has been collected for different operation modes of the thruster and variable test conditions.

Variation of residual pressure in the vacuum chamber causes significant changes in the value and distribution of electronic temperature and plasma potential. With increase of the pressure the electron temperature drops abruptly. This fact is important, since the quantity of electron temperature is crucial for computer simulation of propagation of a plasma flow and its interaction with surfaces of a space vehicle. The measured value of electron temperature is a function of two “quantities”: both the operational mode of thruster and test conditions. Therefore, in future it is important to define the test conditions, which would enable obtaining of electron temperature values appropriate to the conditions of EP flight operation, or to develop methods of data recalculation of ground tests to the conditions of flight operation.

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