Plasma parameters investigation in the near cathode zone of the SPT discharge

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Abstract: Up to now it is not known completely how electrons move from a cathode – compensator into the SPT channel. There is no single meaning about electron parameters behavior in near cathode area of the discharge, its function of distribution over energies (EEDF). But it is clear that the processes taking place in the area between cathode and exit of the accelerating channel influence significantly onto SPT operation. The results of the previous experiments show that EEDF is closed to Druyvesteyn distribution with ill-defined additional group of electrons with mean energy ~ 4 eV, which is closed to a group of intermediate electrons in the SPT channel. But it is necessary to carry out an additional experimental investigation concerning electron dynamic in the area between cathode – compensator and SPT exit cross section in order to confirm a hypothesis about EEDF formation in the SPT channel. The experiments were done using SPT-70 thruster model with a laboratory cathode with LaB_6 emitter. Special processing procedure permitting to obtain proper performances was developed. The new experimental results are presented in the paper.

Nomenclature

EEDF = electron energy distribution function
Te = electron temperature
ne = electron density
PP = plasma potential

I. Introduction

There is no single meaning about electron parameters behavior in near cathode area of the discharge, its function of distribution over energies (EEDF). The results of the previous experiments show that EEDF is closed to Druyvesteyn distribution with ill-defined additional group of electrons with mean energy ~ 4 eV, which is closed to a group of intermediate electrons in the SPT channel. The statement of problem was represented in details in the paper presented at the previous IEPC conference[1]. In this paper the new experimental results

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obtained with the help of modified procedure of results procession are represented. The experiments were done using SPT-70 thruster model.

II. Experimental procedure description

The detailed experimental procedure was presented at our previous work[1]. The current experiments were done using SPT-70 thruster model under discharge potentials 200…600V and propellant flow rate through anode - 2.26 mg/s and through cathode – 0.26 mg/s. In the experiments we used the two cathodes – one with flat LaB_6 emitter and second one with tubular LaB_6 capillary emitter. Both cathodes were the laboratory ones and due to this fact its operation in “auto-heating mode” was difficult. Basing on that it was decided to carry out the experiments with grounded cathode and additional heating of emitter (~20…40 W). Heating process was controlled by keeping of igniting electrode potential relatively ground in the range 1…6V.

For plasma parameters measurements it is assumed to use the cylindrical Lengmuir probe made of tungsten wire 0.8 mm, probe length considering ceramic ~100 mm. The approvement of such probe usage was given in the work[1].

In fig.1 one can see the probe size and positioning.

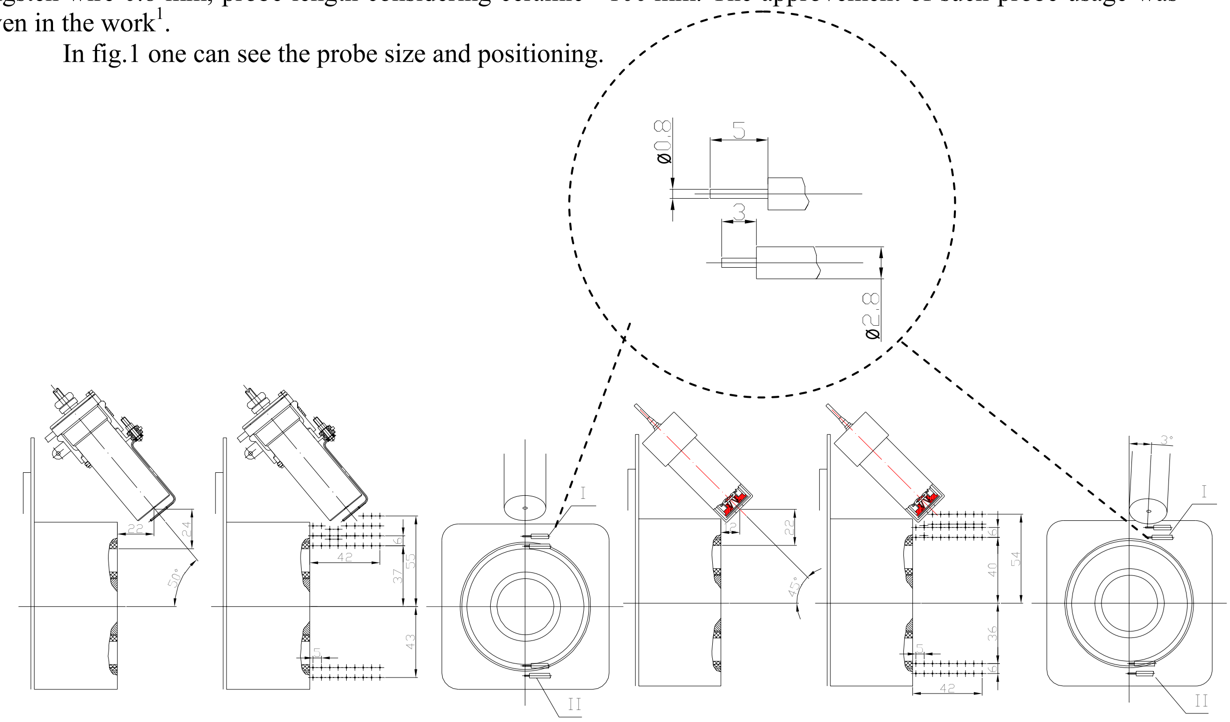


Figure 1.

III. Experimental Data Analyze and Discussion

During measurements in the near-cathode zone it was found out that in this zone the probe performances (probe curve) are “noised” greatly that is especially visible relatively similar measurements in the jet.

Probe curve processing was carried out over derivatives (Druyvesteyn method[2]) and according to Langmuir method[3]. But due to high “noisiness” of the signal it is very difficult to interpret plasma potential profiles, which were determined by both methods (see fig. 2…5 in the appendix). The situation with profiles of integral parameters *Te* and *ne* is the same. The most probable cause of this phenomenon is a distinction in cathode-compensator operational mode during measurements in different points of the jet. The clearness evidence – is potential “profile” of igniting electrode at the moment of probe curve recording in the respective experimental points.

Electron energy distribution function (EEDF) (see fig. 6…11 in the appendix; red – Maxwellian distribution, blue – experimental one, green is the difference between them) view obtained under probe curve procession depends greatly on a procedure of plasma potential determination. But in general it is possible to say that in the area between cathode plane and exit plane of the thruster the experimental electron function of distribution is closer to Druyvestenian function than to Maxwell one and in some cases coincides with it. In the area located beyond the plane, in which cathode-compensator is placed, the experimental view of electron function of distribution begin to approach to Maxwell one and in some cases coincides directly with it. Comparing the view of EEDF in the near-cathode area and in opposite part of the channel one can see that EEDF in theses areas is the same in boundaries of measurement accuracy.

Besides the main group of electrons in the EEDF drawing one can see additional maximums, but it is difficult to interpret them as far as we can't find univalent correlation between maximums' size and position and any discharge parameter or probe position. It is only possible to see that the EEDF mostly has a "strange" view (with hypertrophied humps) under high potential of the discharge or in the case of igniting electrode potential great deviation from normal value (4…6 V), that is right for all tested cathodes.

The most probable reason of this phenomenon is a potential oscillation or particle density stimulation in any part of the system (mostly in cathode). One cannot see these oscillations in plasma potential (PP), but they influence on to PP second derivative. At that the oscillation frequency is greater than the frequency of probe saw signal generator 5 Hz and less than operational frequency of oscilloscope discretization 5 kHz. The estimation of oscillation frequency according to the interval between local maximums of the same humps in the second derivative of the PP over time gives 25 ms that corresponds to the frequency close to 50 Hz, i.e. to the frequency of power supplying system.

The other possible reason of hump appearing in the EEDF is small capacity of analog to digital converter (8 bit) that can cause pseudo-oscillations in the derivatives in the area of probe's small currents. It is especially actually in the case of digital filters usage, which bases on quick inverse Fourier transform.

Unfortunately we do not investigate how discharge parameters in the near-cathode area depend on cathode operational mode. More over, choosing cathode operational mode we assume that such dependence is insufficient and reasoning from this fact the mode of operation with grounded cathode was chosen (this mode permits to test cathodes of different types under maximum similar conditions).

Basing on carried out investigations it is possible to give some recommendations, which necessary to take into account under further investigations:

If one likes to clarify the nature of high-energy maximum in the EEDF, it is necessary to measure PP under higher and smaller frequencies of probe signal generator. In the first case it is possible to exclude the influence of mentioned oscillation, in the second – to average it.

In order to decrease the probability of pseudo- noise appearing caused by quantification of measured potentials in analog to digital converter block, it is necessary to assume the measures permitting to increase measurement accuracy at least in the area of small currents.

Due to high level of noise in the near-cathode area in further investigations it is necessary to use filament probe for more accurate determination of plasma potential.

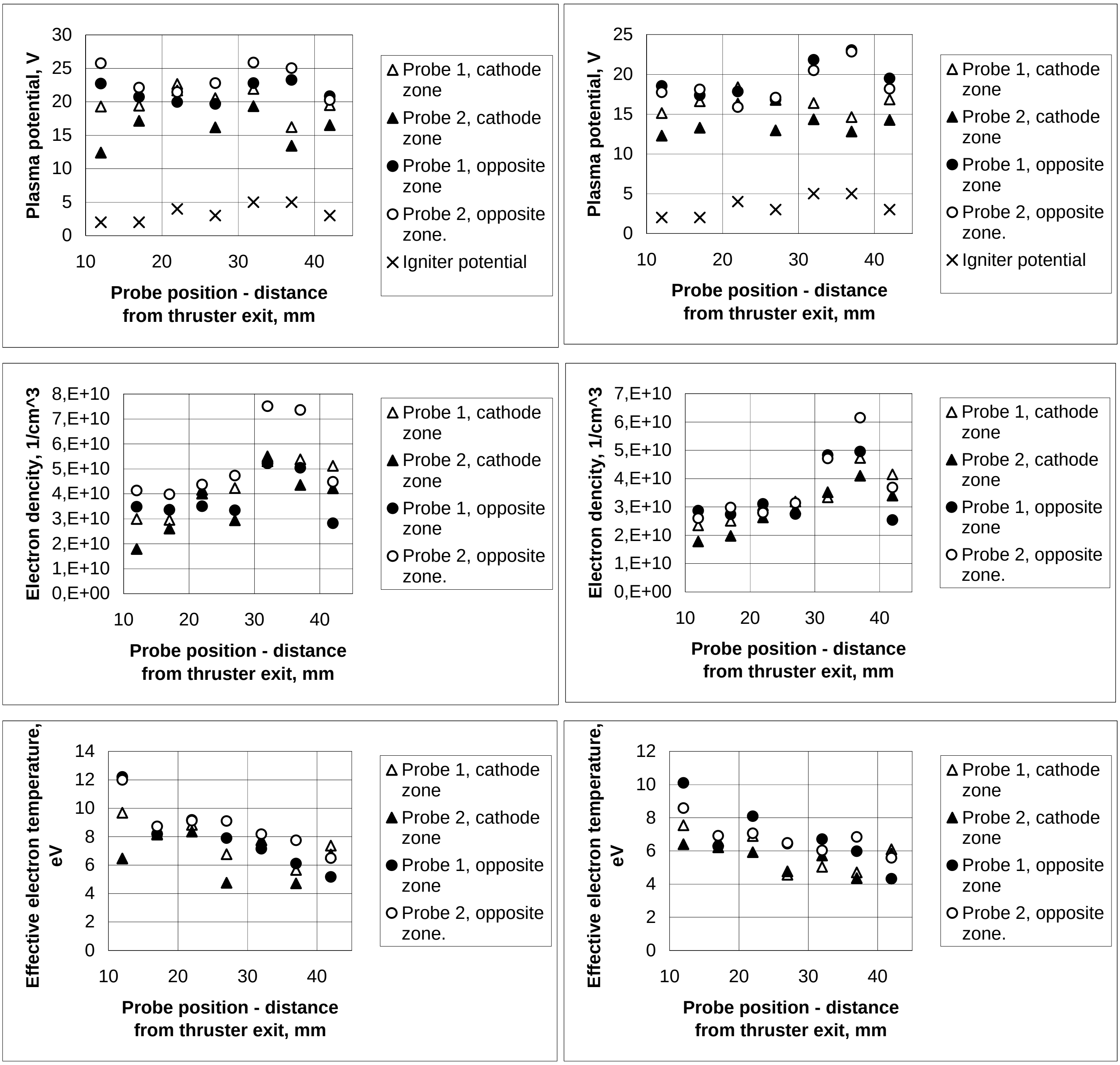
The works in this field will be continued.

IV. Conclusions

- it is examined plasma parameters in the near – cathode area of SPT-70 with different cathode modifications and their different position in the discharge voltage range 200…600 V;
- it is obtained that in the near-cathode area the EEDF is closer to Druyvestenian function than to Maxwell one;
- in the area located beyond the plane, in which cathode is placed, the EEDF begins to approach to Maxwell one and in some cases coincides directly with it;
- comparing the view of EEDF in the near-cathode area and in opposite part of the channel we obtain that EEDF in theses areas is the same form in boundaries of measurement accuracy;
- it is obtained that besides the main group of electrons in the EEDF drawing there are additional maximums, but it is difficult to interpret them as far as we can't find univalent correlation between maximums' size and position and any discharge parameter or probe position. It is only possible to see that the EEDF mostly has a "strange" view (with hypertrophied humps) under high potential of the discharge or in the case of igniting electrode potential great deviation from normal value (4…6 V), that is right for all tested cathodes. The most probable reason of this phenomenon is a potential oscillation or particle density increasing in any part of the discharge (mostly in cathode).

Appendix

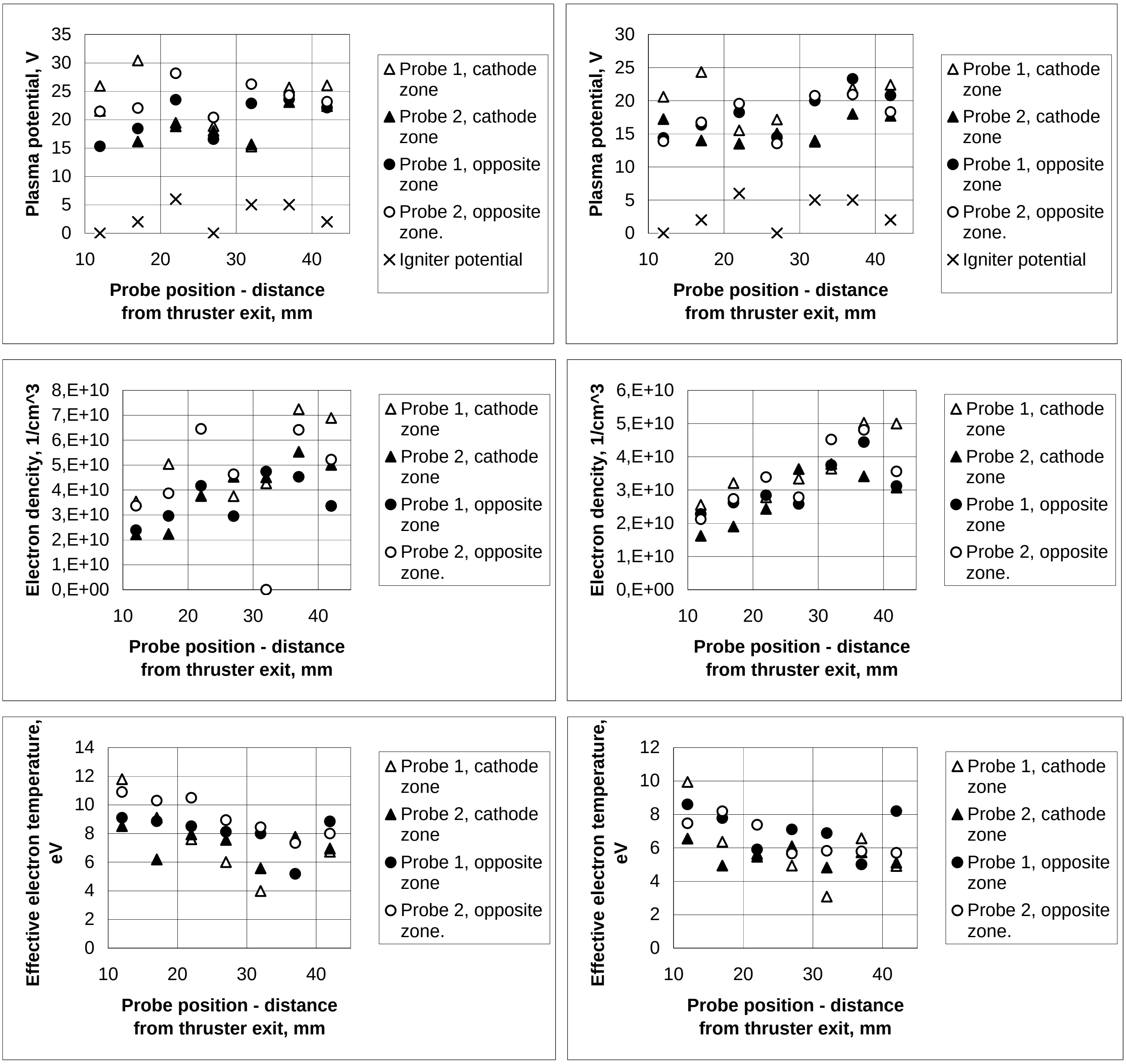
Ud=300V



Flat emitter capillary emitter

Figure 2

Ud=400V

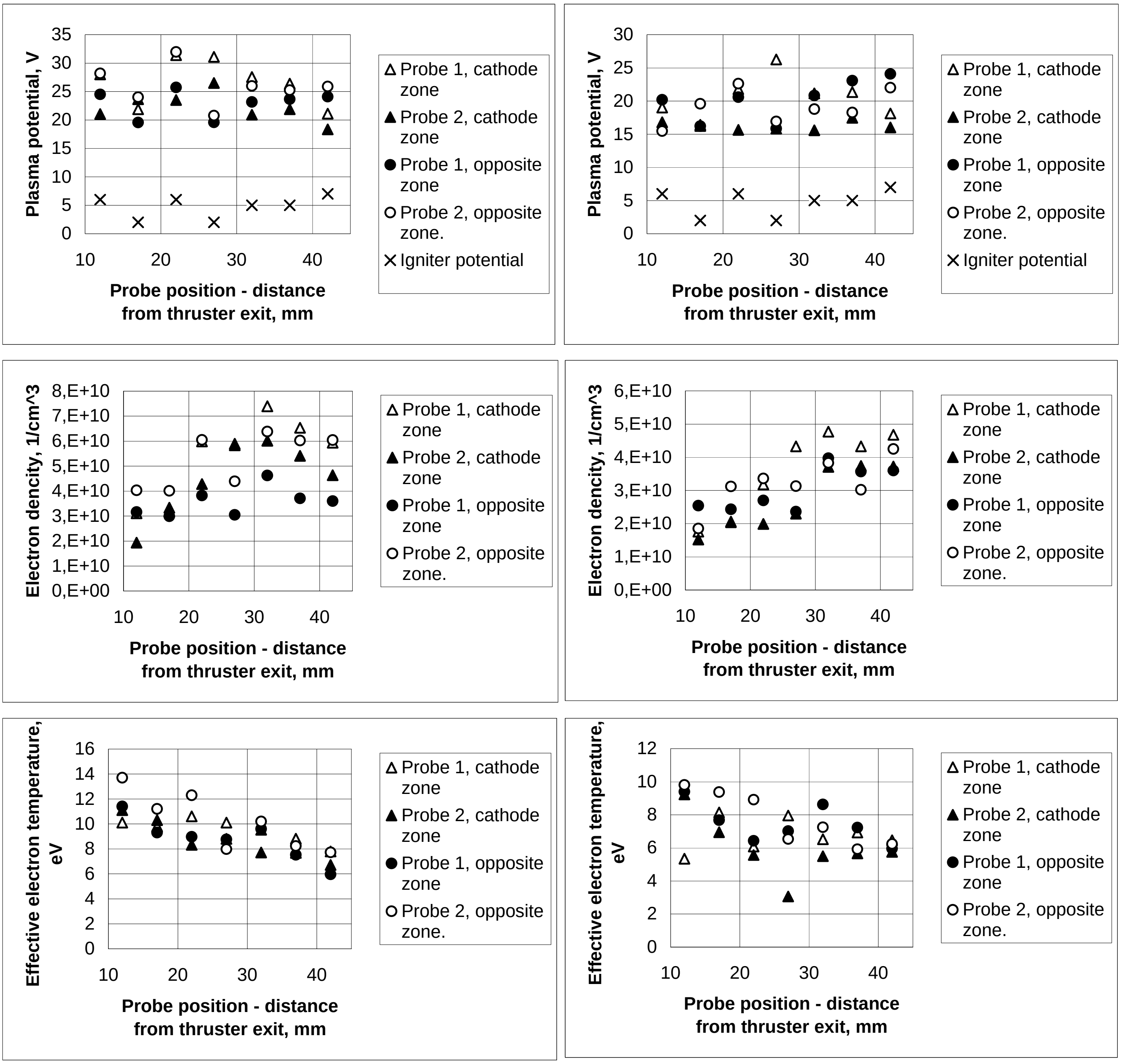


Flat emitter

capillary emitter

Figure 3

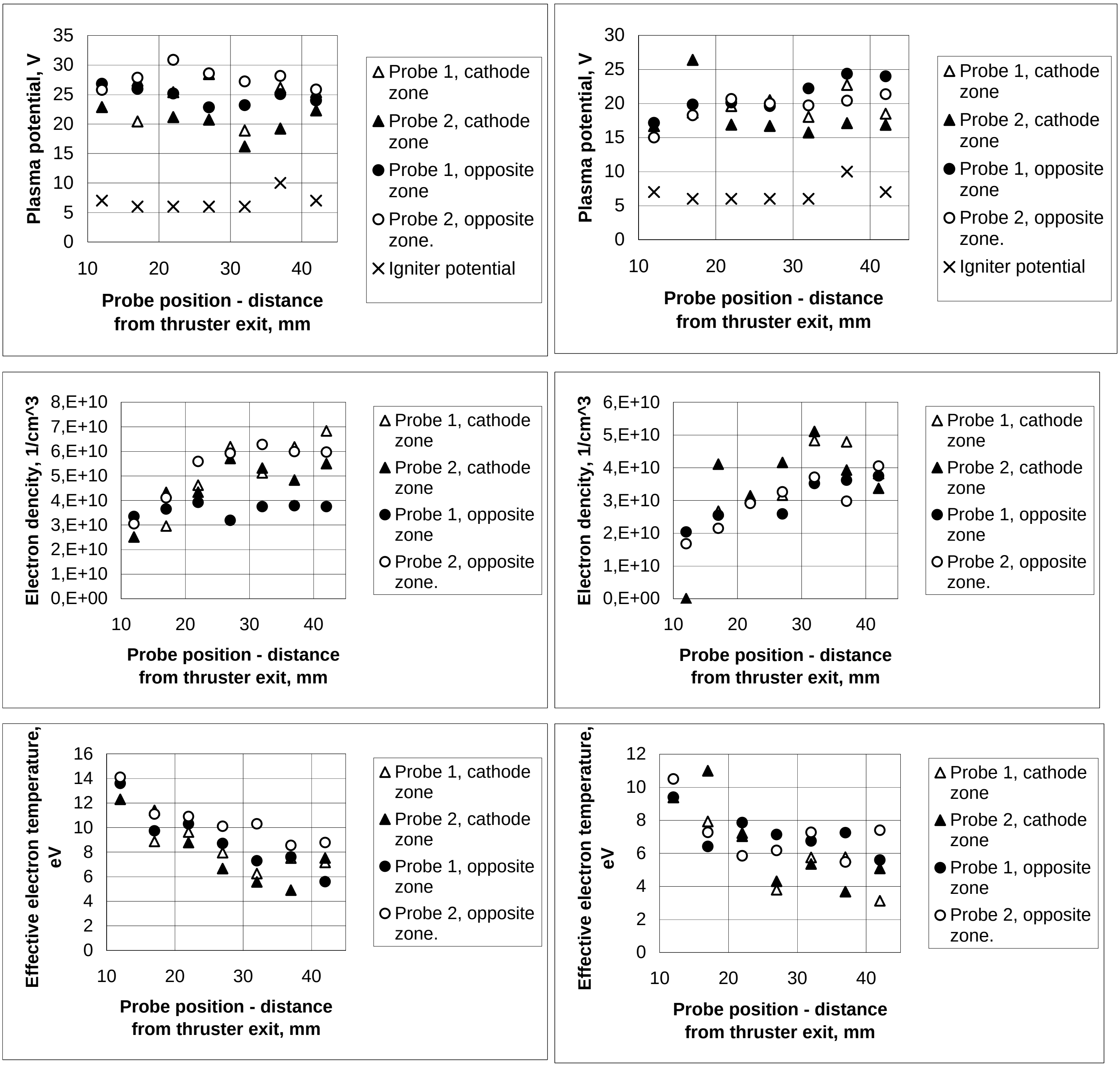
Ud=500V



Flat emitter capillary emitter

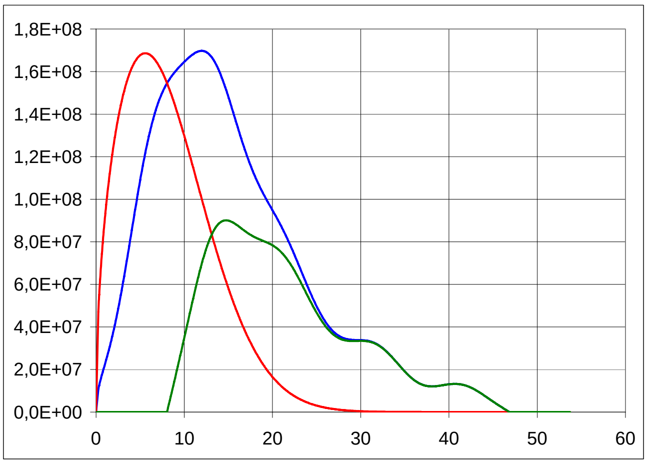
Figure 4

Ud=600V

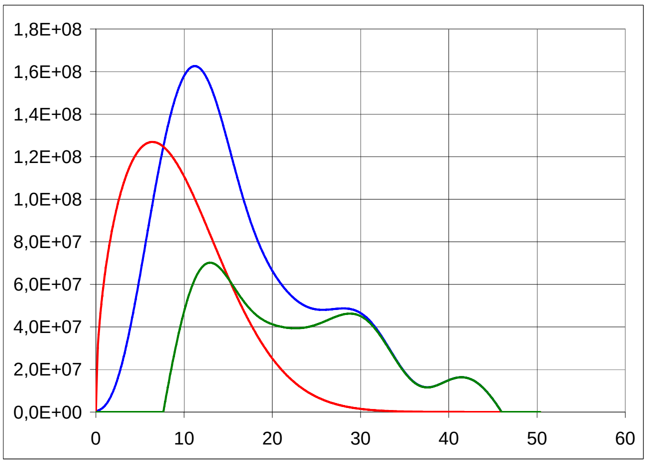


Flat emitter capillary emitter

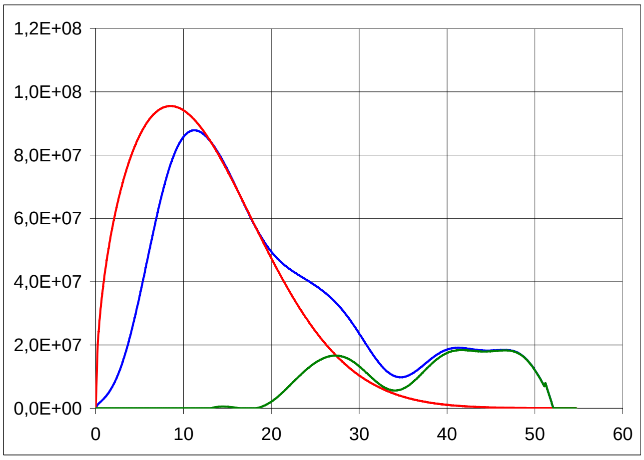
Figure 5



300V



400V



500V

The probe curve is too noisy
600V

Figure 6. EEDF (flat emitter, probe 1, position 3mm from thruster cut and 40mm - from axe)

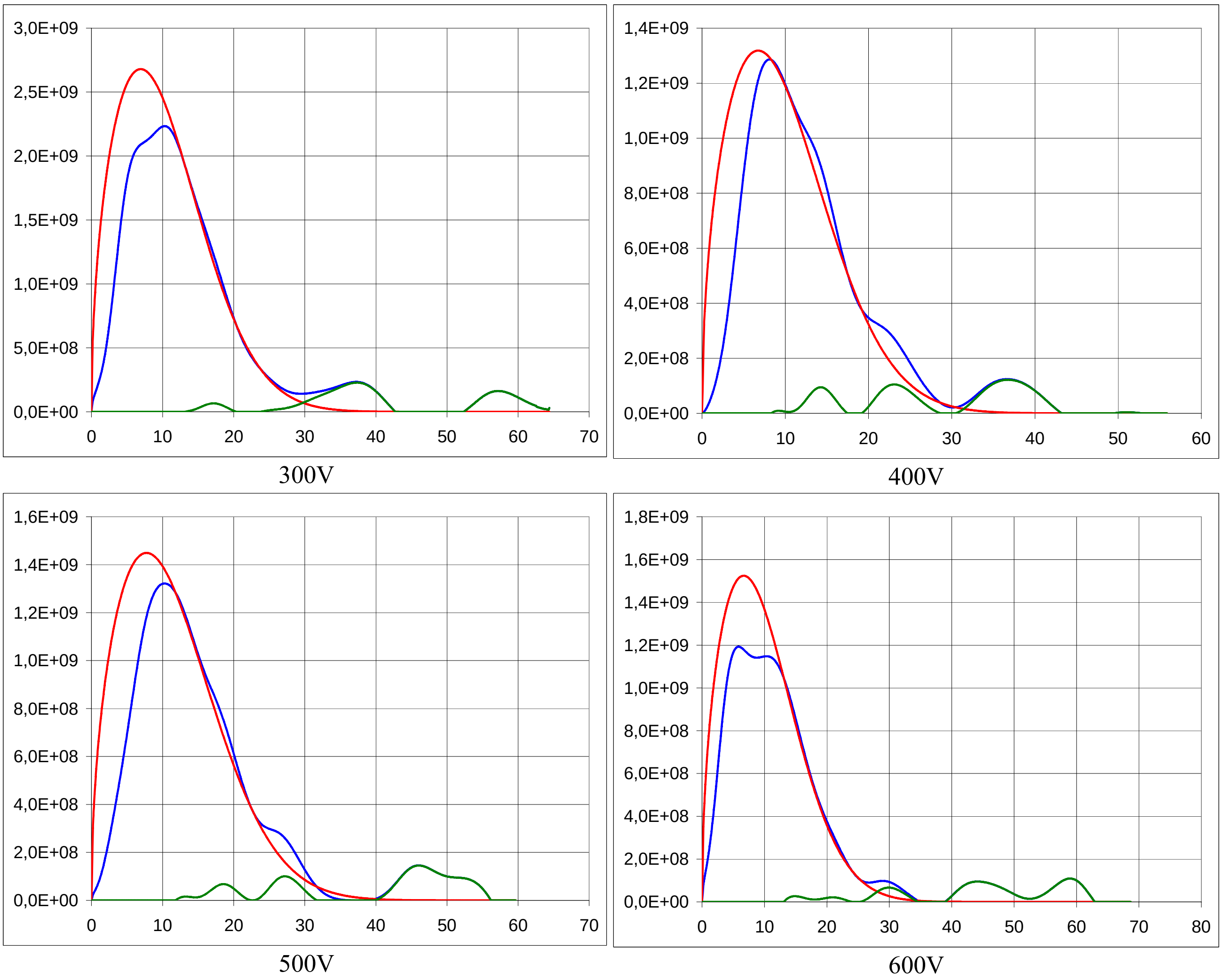


Figure 7. EEDF (flat emitter, probe 1, position 23mm from thruster cut and 40mm - from axe)

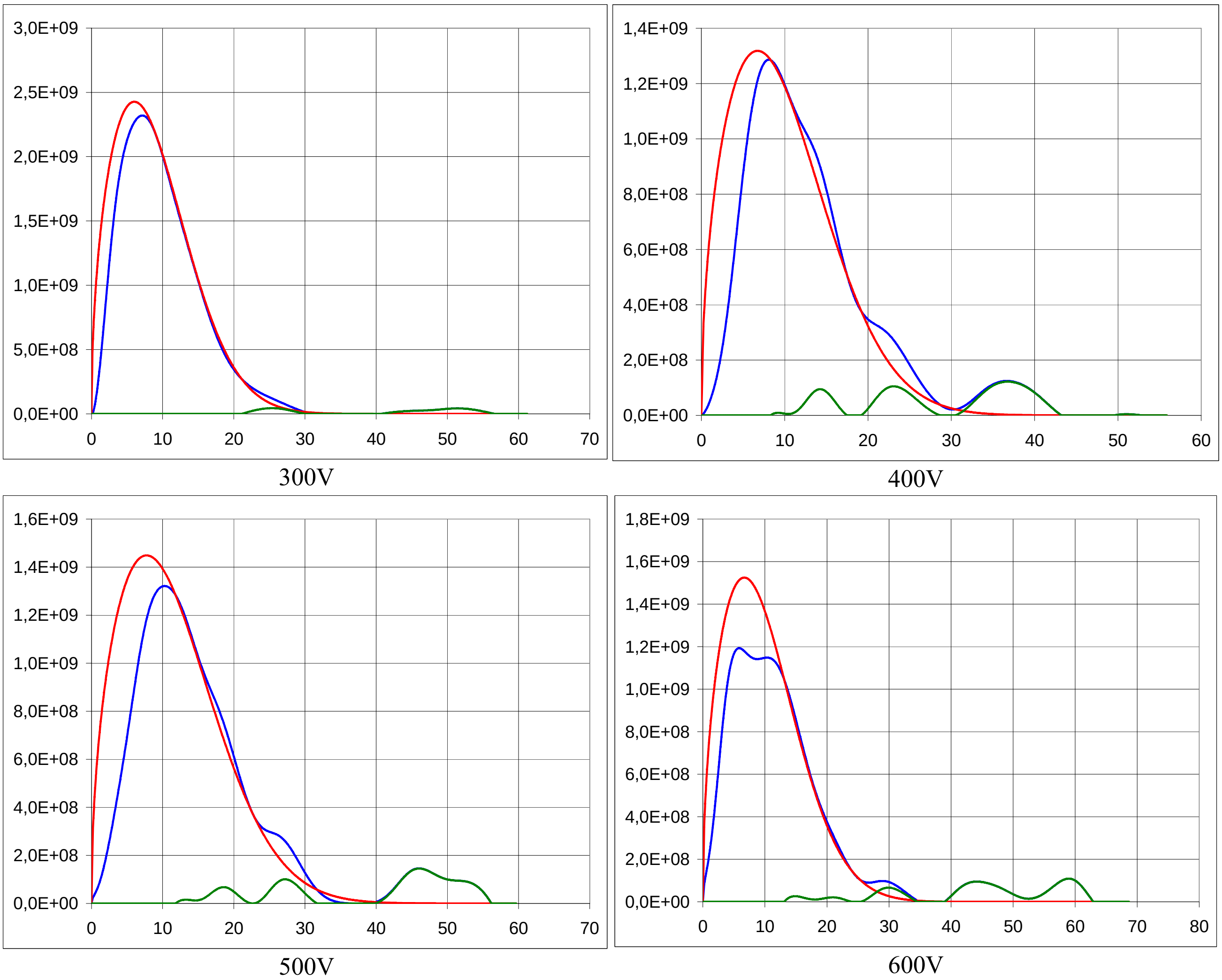


Figure 8. EEDF (flat emitter, probe 1, position 42mm from thruster cut and 40mm - from axe)

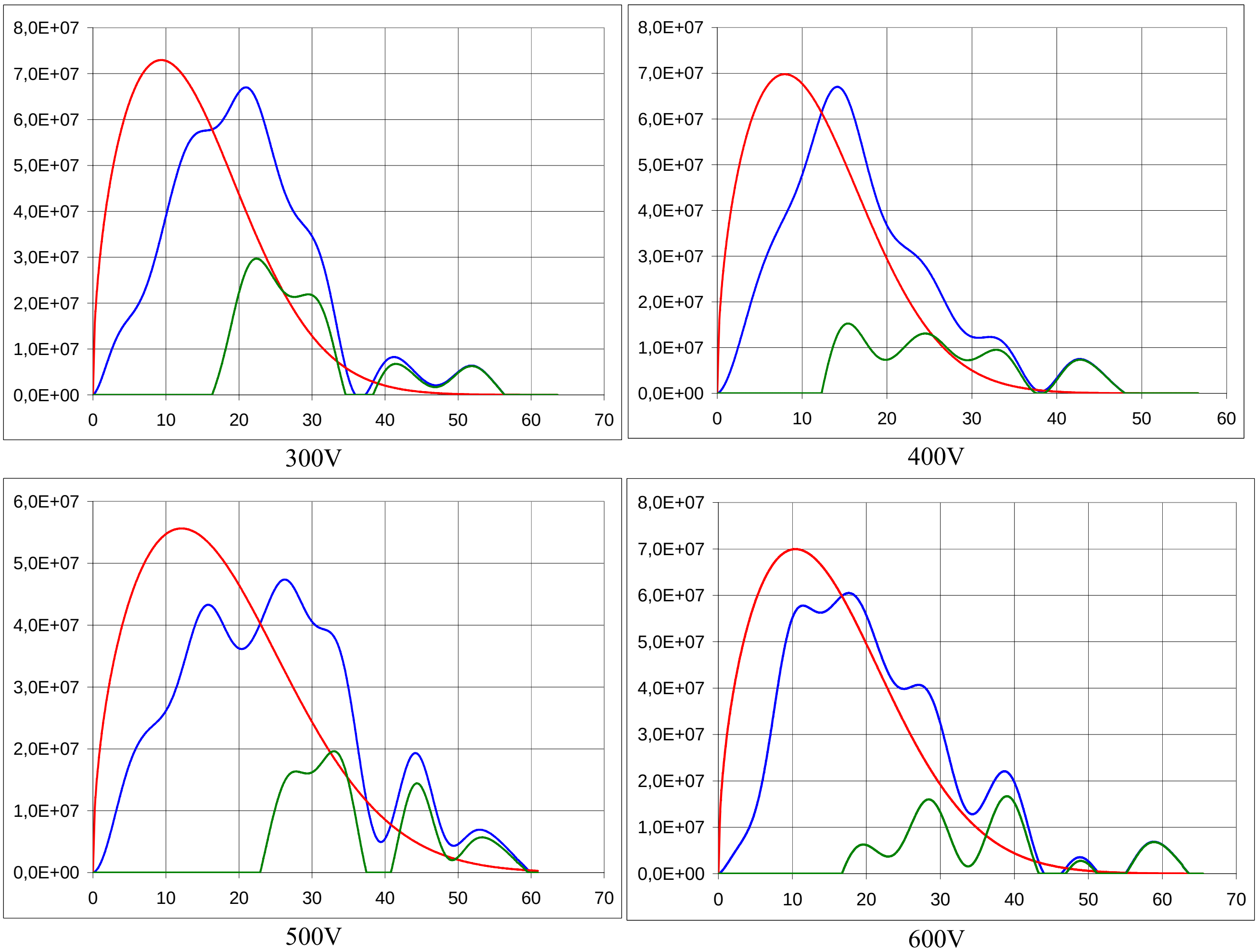


Figure 9. EEDF (capillary emitter, probe 1, position 3mm from thruster cut and 40mm - from axe)

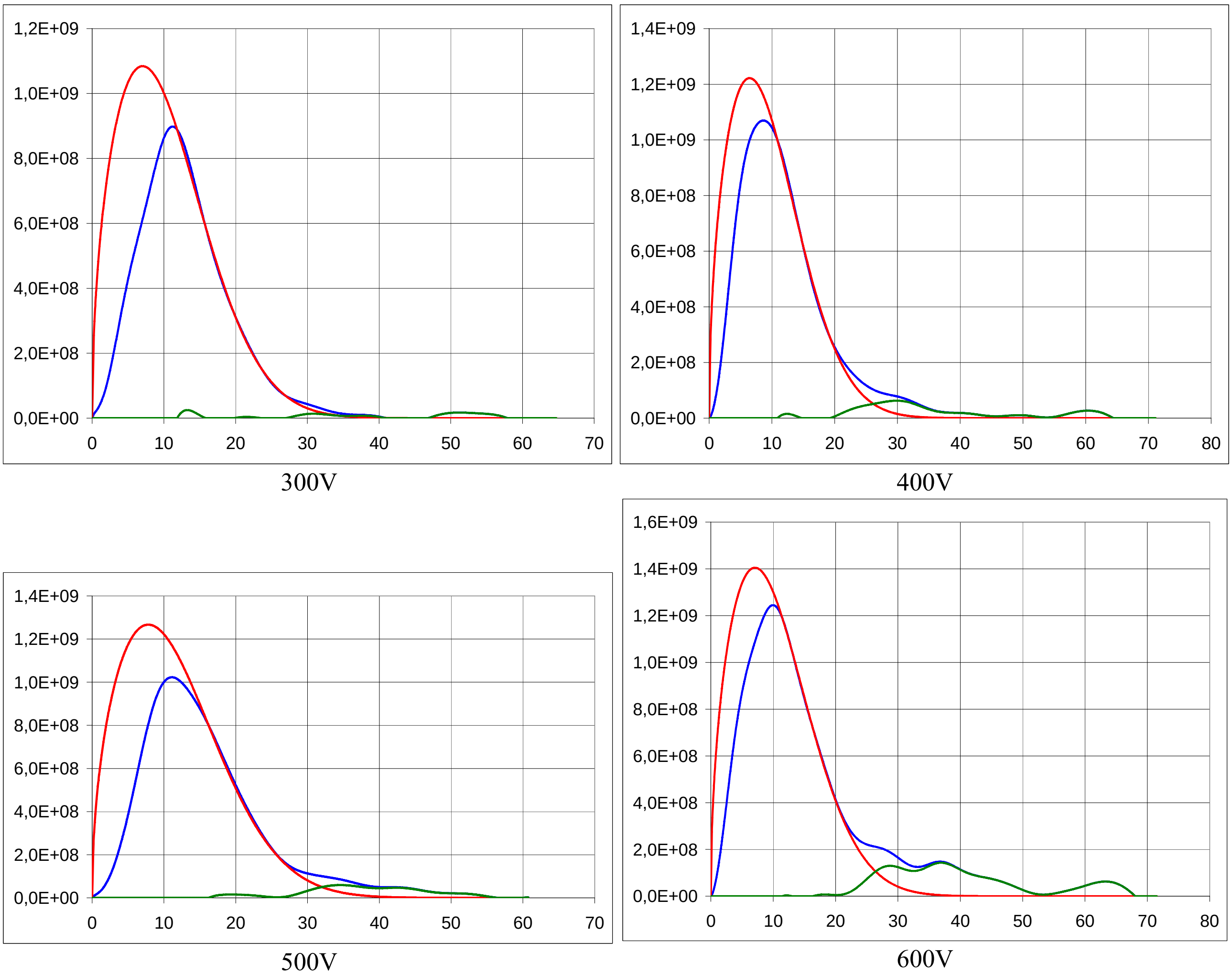


Figure 10. EEDF (capillary emitter, probe 1, position 23mm from thruster cut and 40mm - from axe)

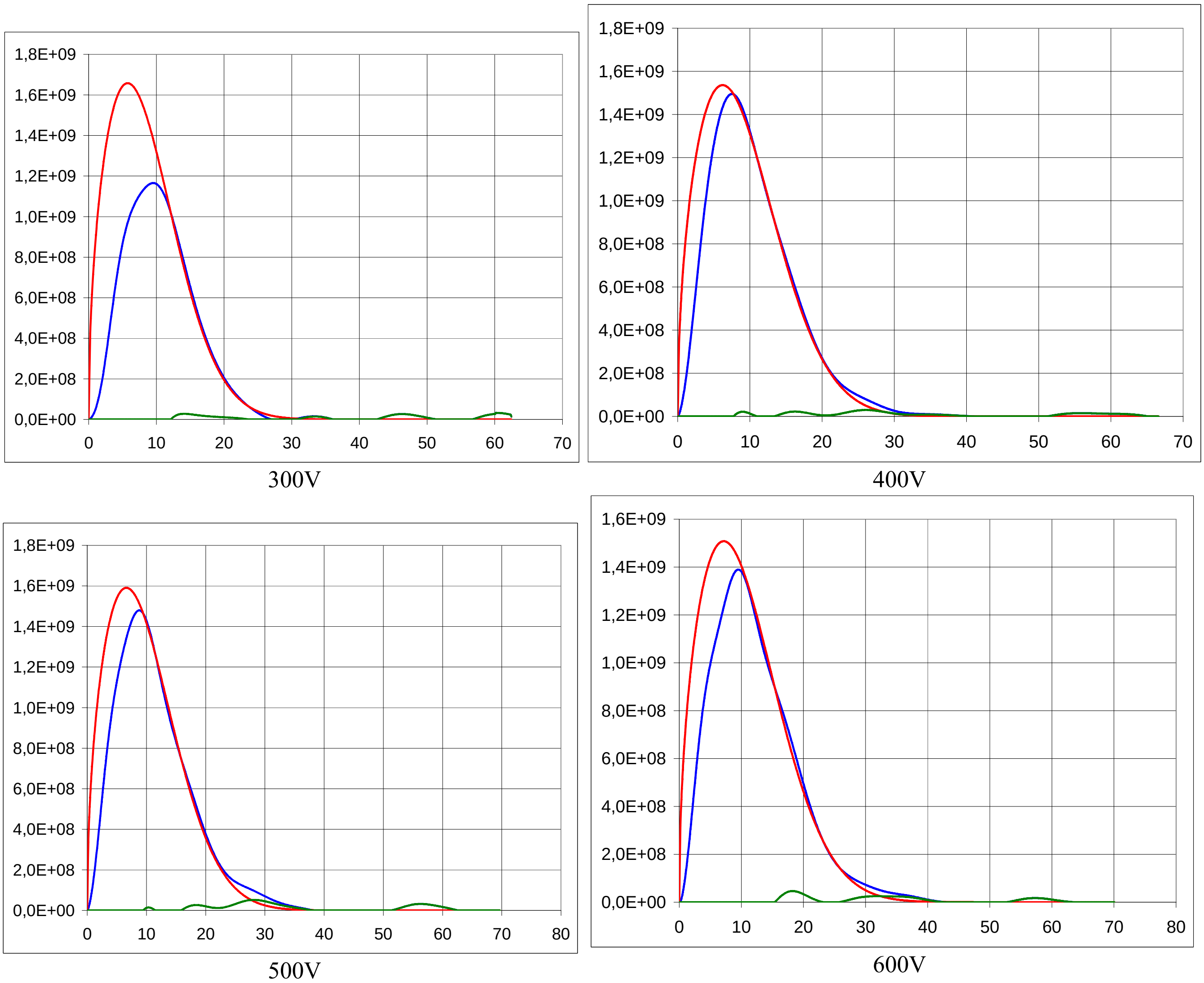


Figure 11. EEDF (capillary emitter, probe 1, position 42mm from thruster cut and 40mm - from axe)

Acknowledgments

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[3] Koslov O.V. Electrical probe in plasma, M.: Atomuzdat, 1969, (in Russian).