A 3D model of electron dynamics near the outlet section of SPT thruster.

343X-H2B4H0B3J5

Presented at the 30th International Electric Propulsion Conference, Florence, Italy
September 17 –20, 2007

Grigory Toropov[*]
Moscow Aviation Institute (State Technical University) MAI
Engineering Plasma Computational Laboratory (EPCLab)
24b-120, Zalineynaya str., Vologda, 160010, Russia. Web: http://www.epclab.com/

Sergey Khartov[†]
Moscow Aviation Institute (State Technical University) MAI
Electric Propulsion and Space Power Plants Department
4, Volokolamskoe sh., Moscow, 125971, Russia

Abstract: This paper is a report of our simulations of different processes occurred in the outlet section domain of Hall thruster (SPT-70).

Up to now it is not known completely how electrons move from a cathode – compensator into 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 outlet of the accelerating channel influence significantly onto SPT operation. The trajectory electron analysis was carried out numerically with considering magnetic field, change of electron energy during movement and interaction loss with neutrals, primary and CEX ions but without considering electric field influence.

I. Introduction

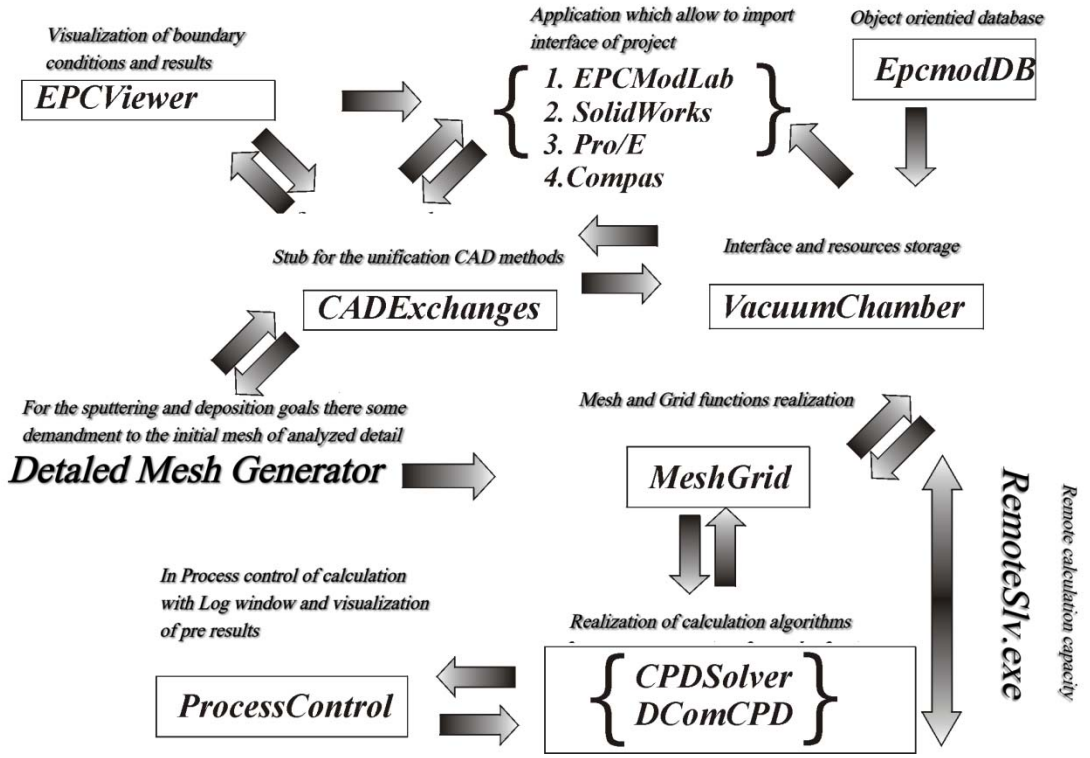
The main problem in the trajectory simulation of electron is the demand for grid size. It should be three orders less than radius of Larmour. Because of this the calculation trajectory time also increases. For the normal distribution it should be calculated thousands of electron trajectories. Because of this demands and the limited possibilities of one computer we tried to use all possible means to increase speed time of one calculation. There are our main improvements:

- Detailed cell in the big gradient places
- Network calculation
- 64 bit processor calculation also gives us some advantages: 1) one tact processor calculate 64 bits instead of 32 2) OS Vista 64 support processes larger than 2Gb.

The developed project main features are shown below:

---

*PGD Student, toropov@epclab.com
[†]Professor, k208@mai.ru



The project structure libraries

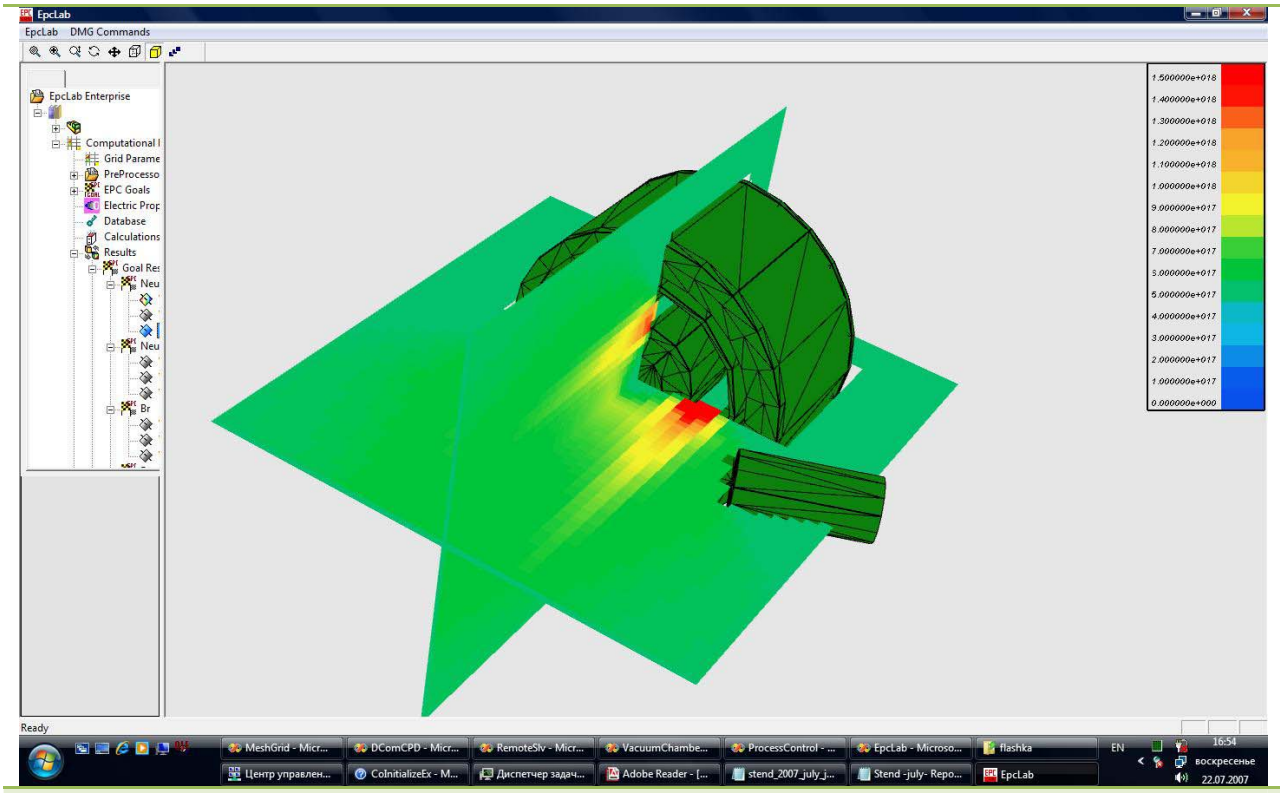
All our calculations were carried out on the two machines in the network. One had AMD64 3000 processor (with OS Windows XP 64) and the other had AMD 64x2 1800 processors (with OS Vista 64). The second one was main computer and it control network calculation. First core of this machine had been used for calculation and the other had been used for control of network calculation and data processing between computers and processes.

The EPCModLab application was developed for the user control of project uses .step format initial shape definition and transform it in triangles with OpenCascade[3] free modules (according to LGPL license). The other CADs shown on the image is just alternative for EPCModLab and there wasn't any use of them during calculations. CAD system was used only for the STEP file creation.

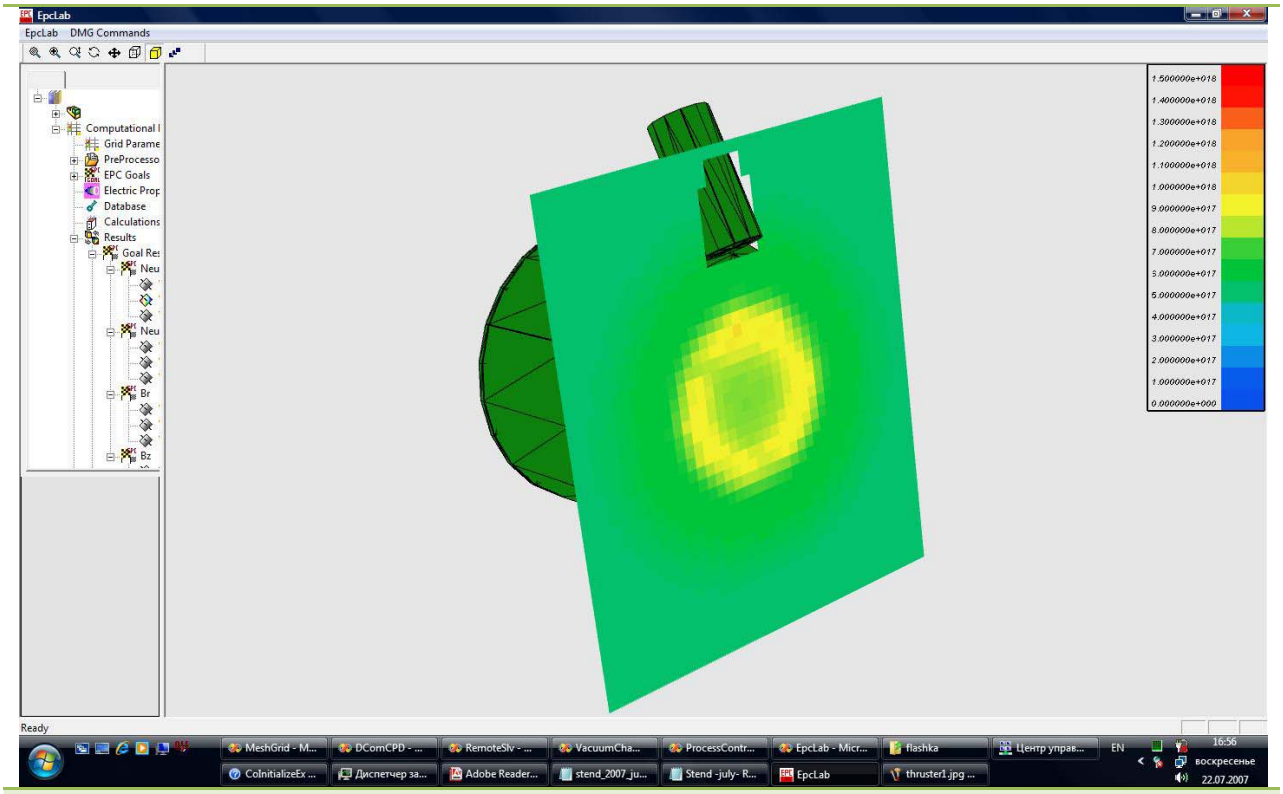
Neutrals pressure calculation

The dynamic neutral concentration I've taken from vacuum chamber calculation 5e17 [1/m^3] (1.66e-5 Tor). It's for all domain. Also we've emitted not ionized part of neutrals from thruster with average temperature of 1000K from the virtual cathode (the thruster exit section (the displacement from face of anode is 25 mm). Mass consumption I've took 0.15 mg/s, e.g. 5% from total consumption.

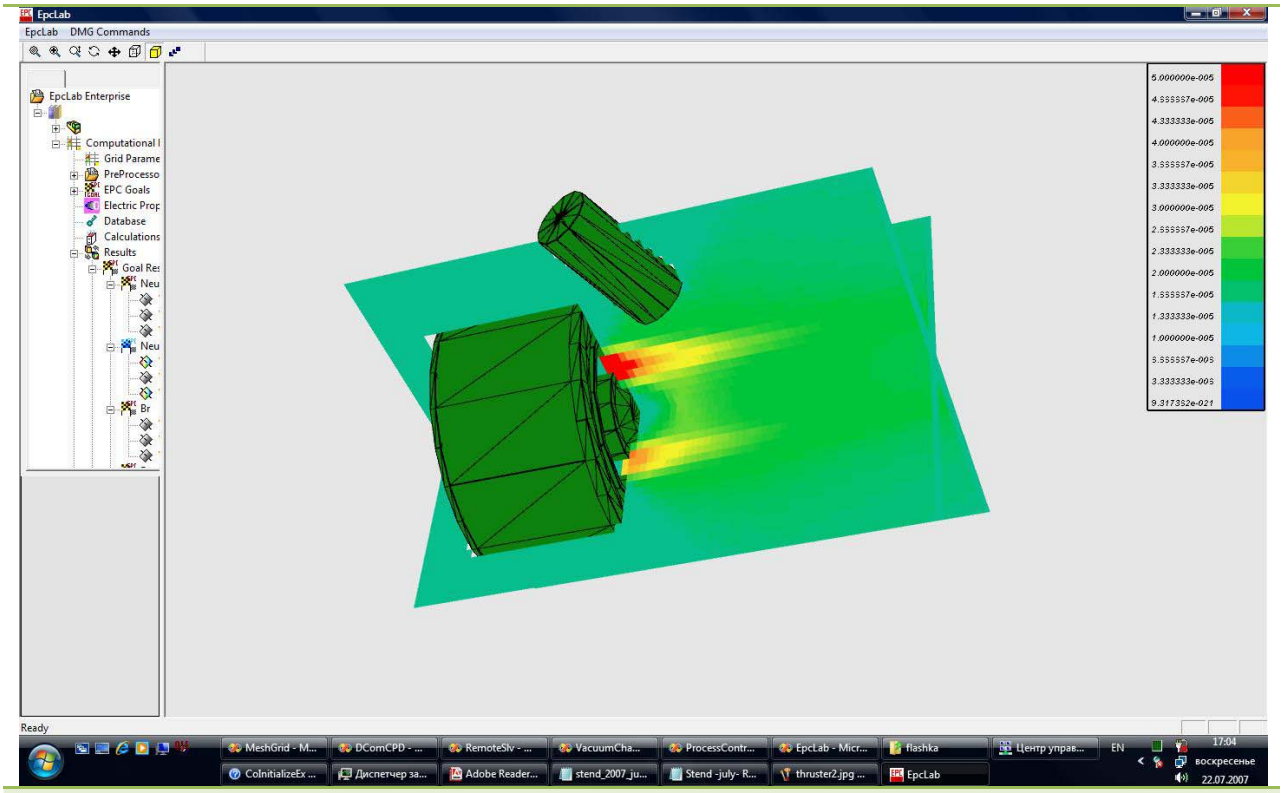
Shown is the calculated distribution:



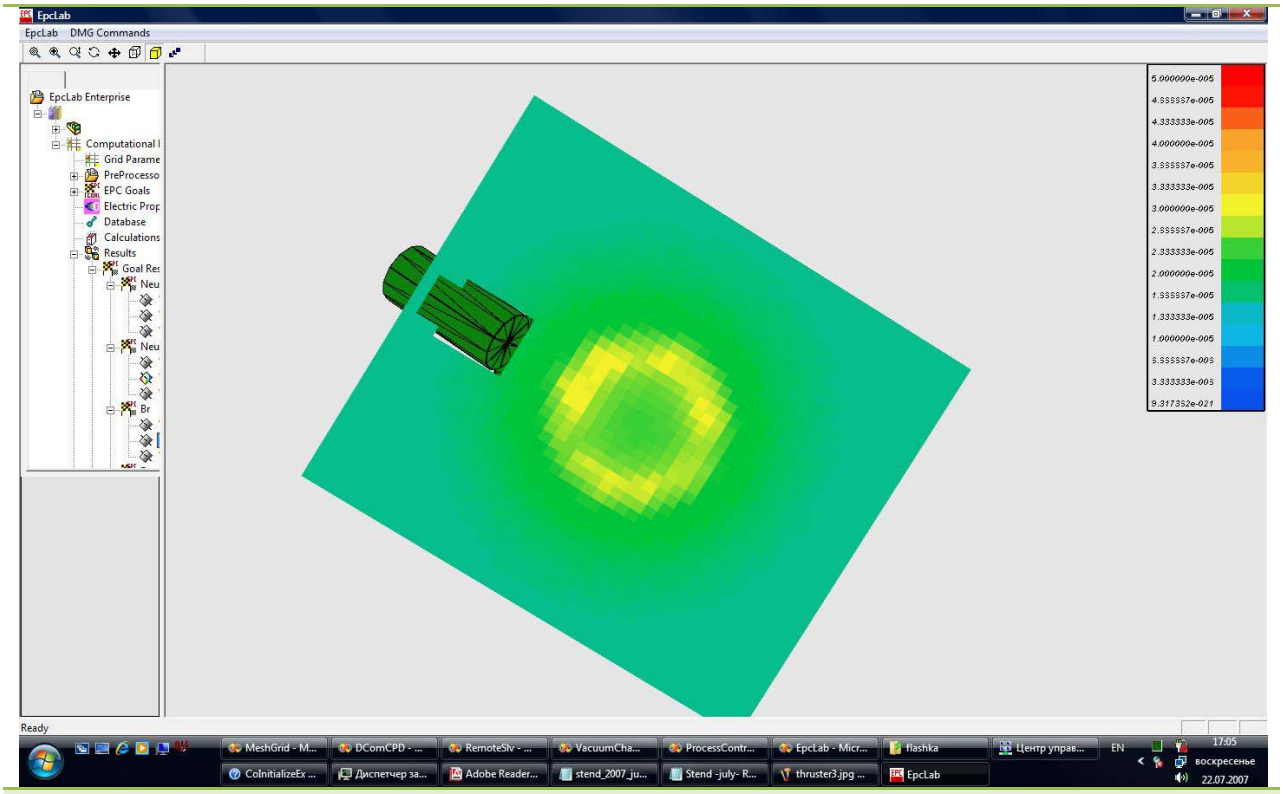
Neutral particles concentration 1/m^3



Neutral particles concentration 1/m^3



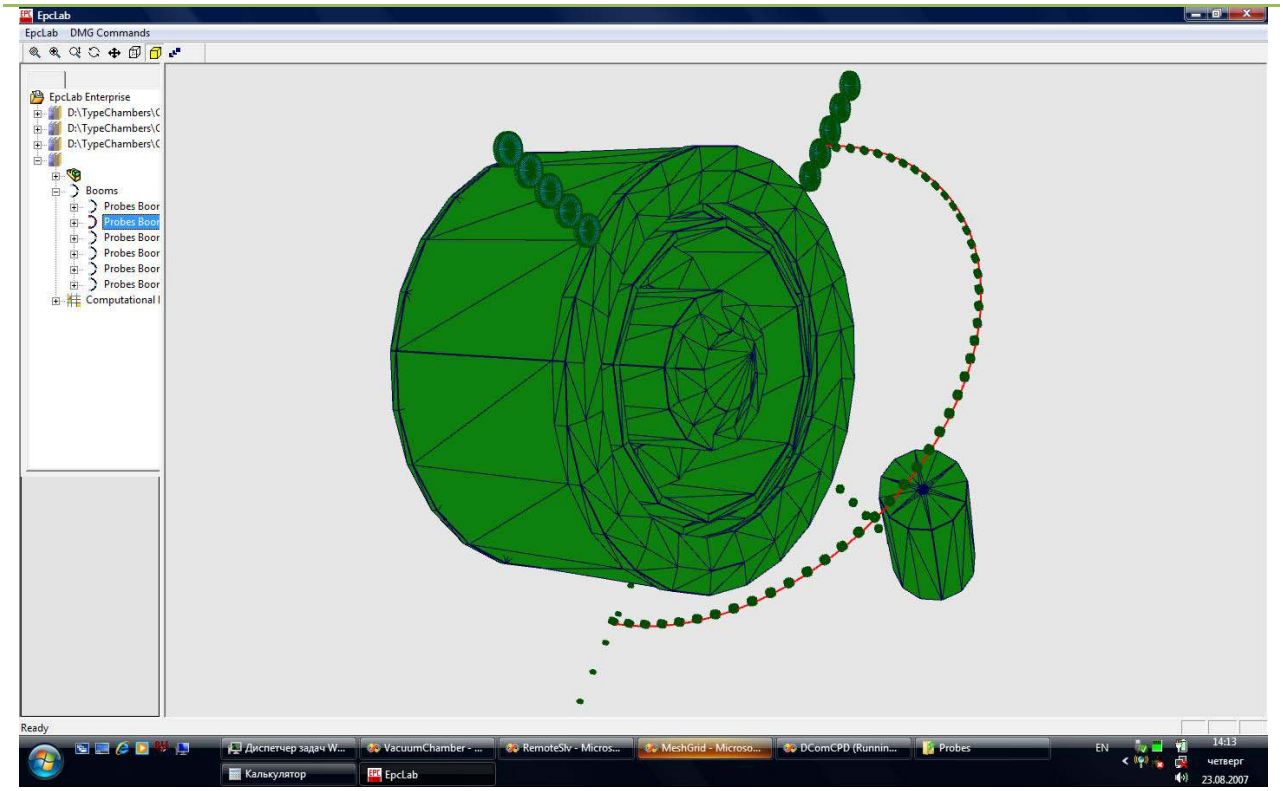
Pressure (Tor)



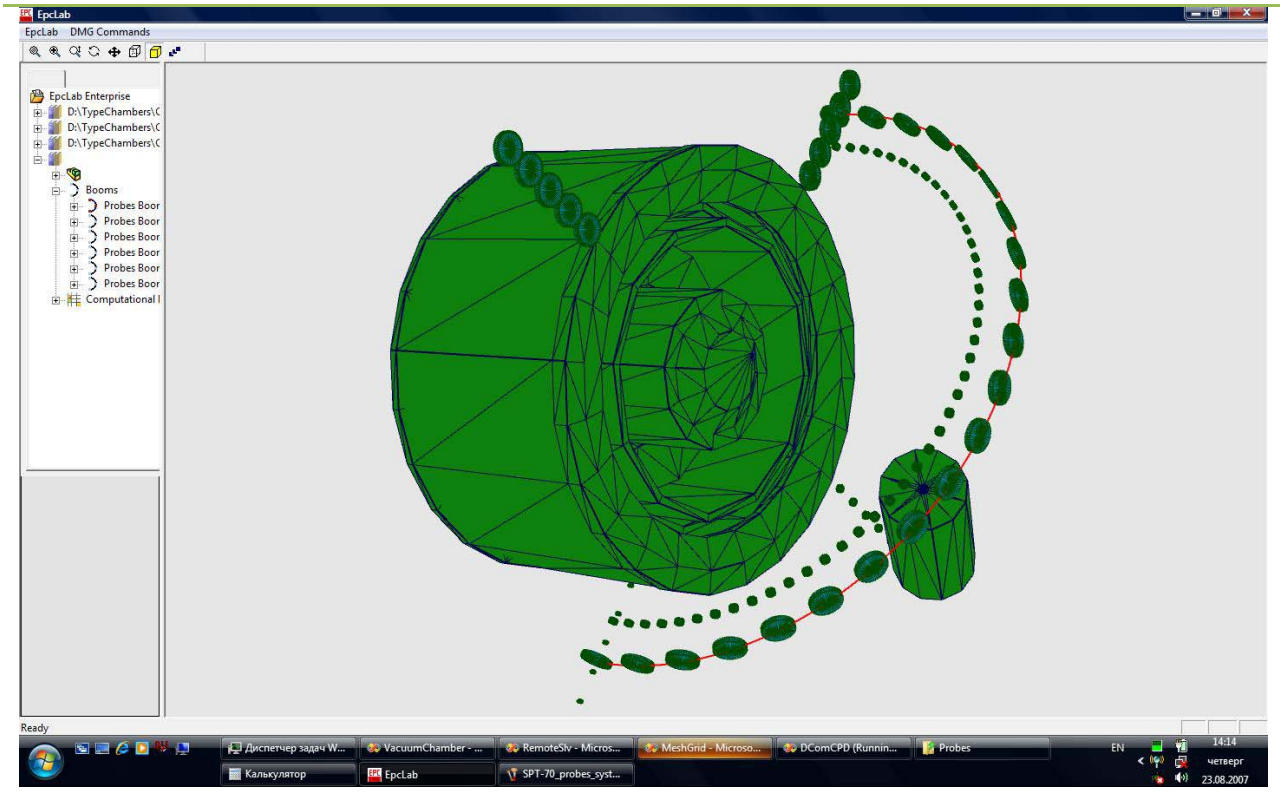
Pressure (Tor)

The primary ions calculation:

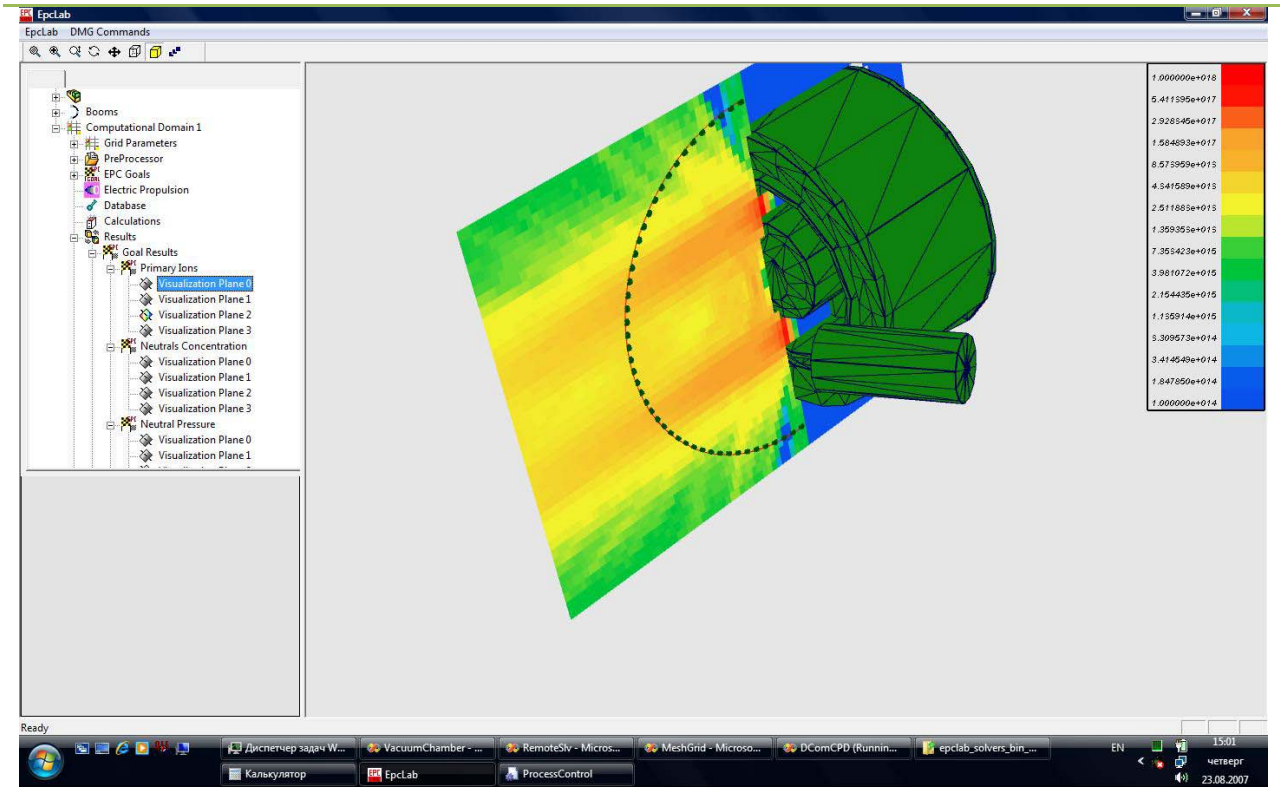
We didn't investigate processes occurred in the SPT channel itself. Our boundary condition was the outlet face of thruster which has 25mm displacement from anode. From this face our particles were emitted. So the concentration of ions in the channel we did not consider. This is the same calculation which had been carried out in [1] the only difference is computation domain size. So details I wouldn't publish, they can be found in the reference.



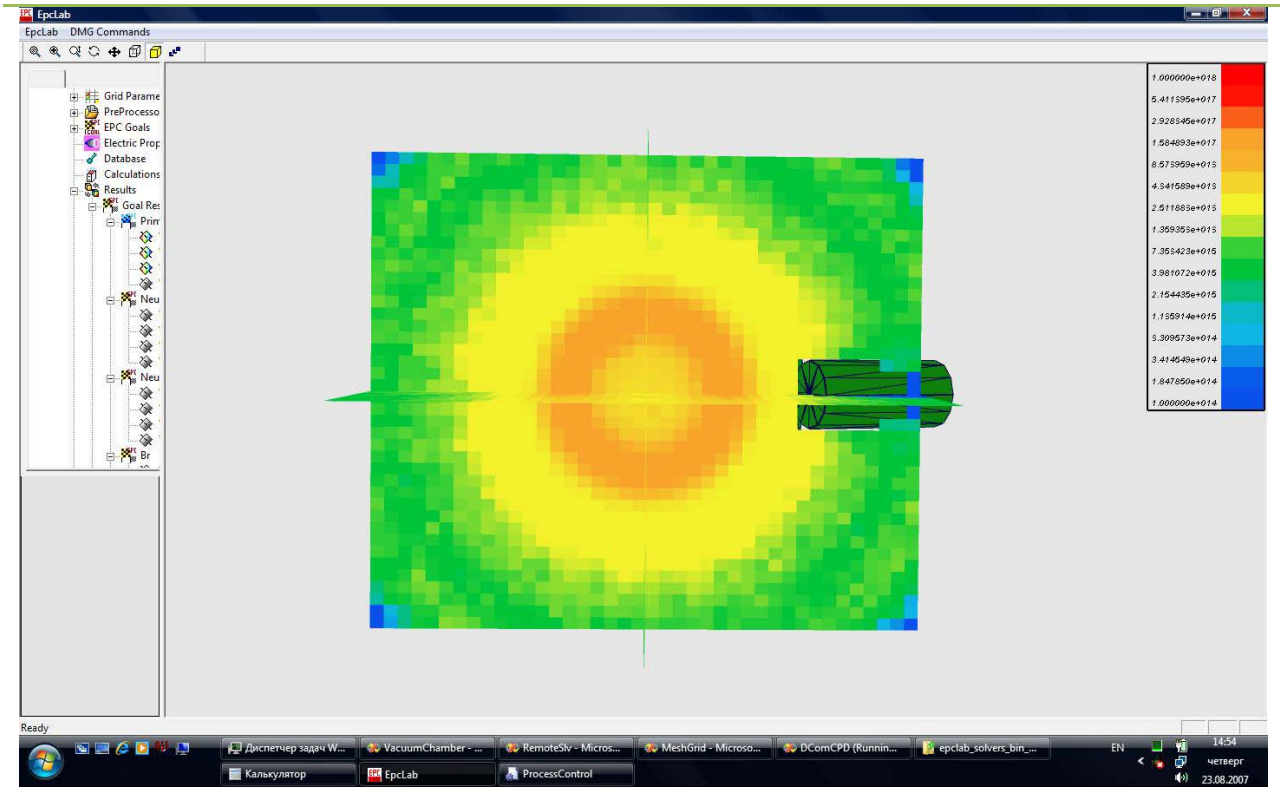
The probes system



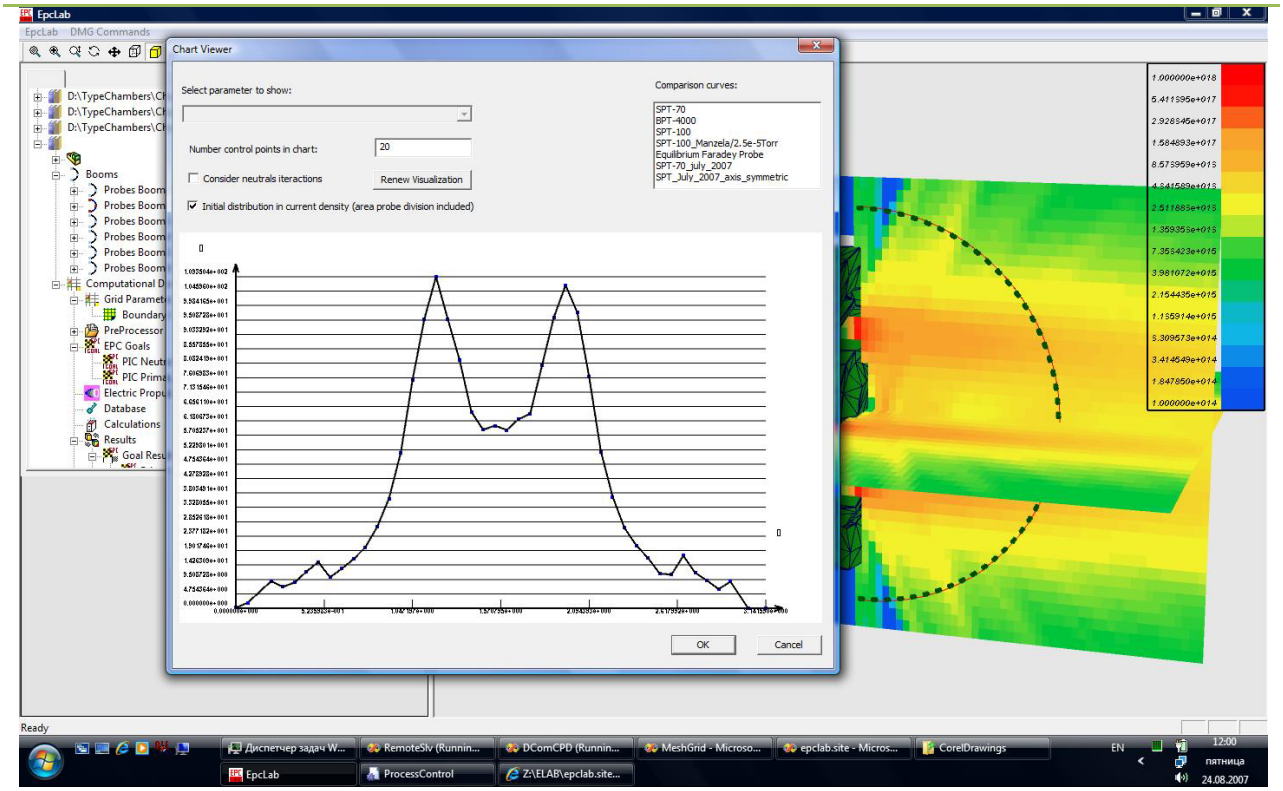
The probes system with energy distribution measurement probes



The primary ions distribution (general view)

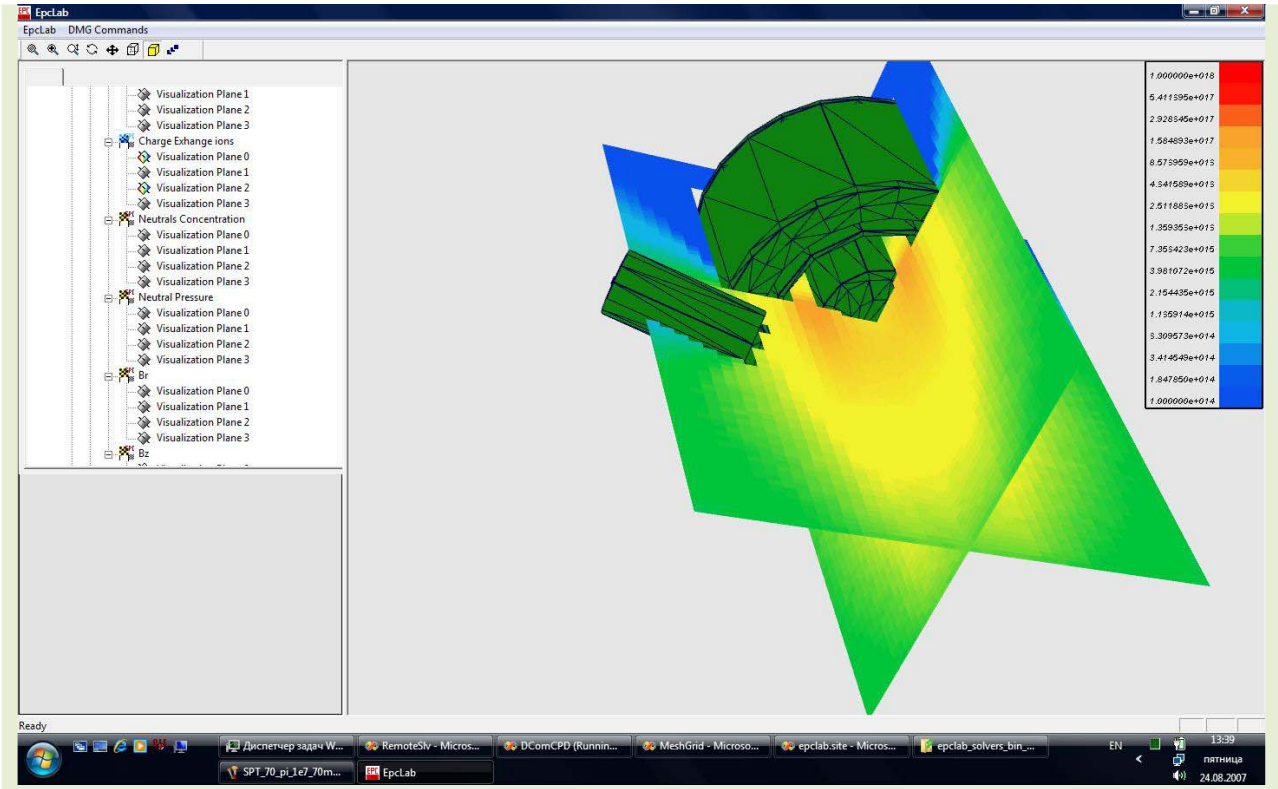


The primary ions distribution (parallel toward thruster exit face surface visualization)



The calculated ion current on the boom with probes

The CEX ions calculations



The distribution of calculated CEX ion distribution with average velocity for 300K

Two comments I should make to the CEX simulations. Actually the CEX ions concentration about 2 orders smaller. It is because on the first iteration we do not take into account an electric field. Our CEX ions move with average velocity for 300K.

The second one is that the CEX ions simulated in procedure includes only those which were ionized in the domain and doesn't include other CEX ions which were generated in the rest volume of chamber.

II. Electron Trajectory Analysis

Now having arrays of heavy particles, we can start research of light particles trajectories simulation. And then we will try to make concentration arrays.

Because of the weight of electrons, they move strictly by the field. So before any kind of electrons trajectory simulations it must be calculated magnetic and electric field. In some cases whether magnetic field is preeminent or electric it can be decided to use only one.

We have used 3d party program ELCUT[2] for the external magnetic field simulation.

Though ELCUT works only with 2D, our problem is axis symmetrical so we easily made 3D arrays of Bx, By, Bz.

The equation of electron movement is:

$$m_e a_x = q(E_x + B_z v_y - B_y v_z)$$

$$m_e a_y = q(E_y + B_z v_x - B_x v_z)$$

$m_e a_z = q(E_z + B_y v_x - B_x v_y)$

To this equations we should add that tensity of electric field can be calculated with fluid electron model whether with solution of Poisson equation or with the direct probe measurement. Now our fluid model is not tested yet, so we wouldn't take into account electric field in calculation.

The boundary conditions:

1) Cathode. Interface of our program allow selecting cathode outlet face. Then as initial condition we determine electron average energy measured with Langmuir probe. As an initial direction of electron movement we use normal of the cathode outlet surface.

Algorithm testing

For the testing I've used one electron motion simulation in the magnetic field with induction Bz and the direction of velocity was perpendicular toward the lines of magnetic induction.

Centripetal acceleration is:

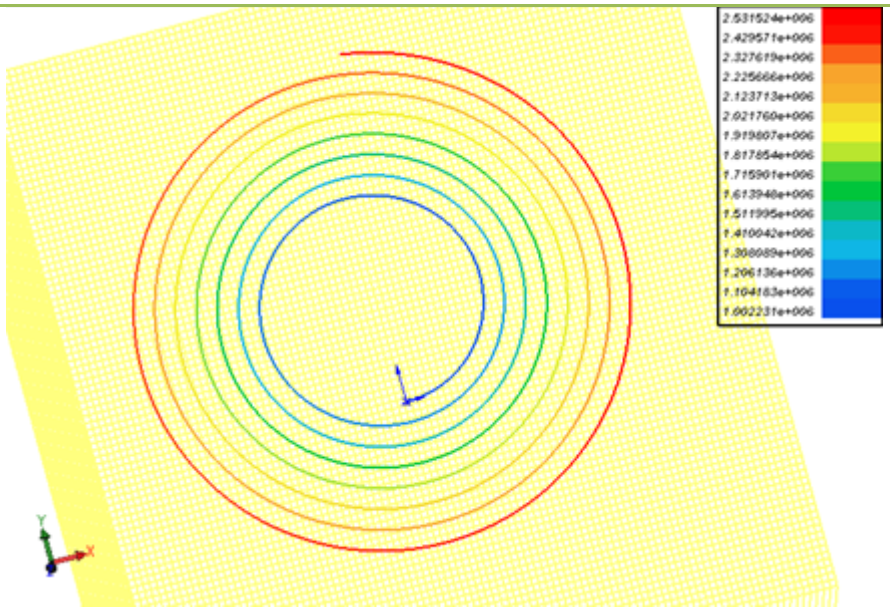
$$a_n = \frac{v^2}{r} = \frac{qvB}{n}$$, orbit radius $$r_n = \frac{mv}{qB}$$

By this radius we test our algorithm.

In our case the electron velocity was 1e6 m/s. Induction of magnetic field was B=0.001, and theoretical radius was 5.68 mm.

Simulation results. The main parameter for the building of the grid we took coefficient k_cell = $R_{larmour}$/H_cell, where H_cell – is the smallest dimension of cell.

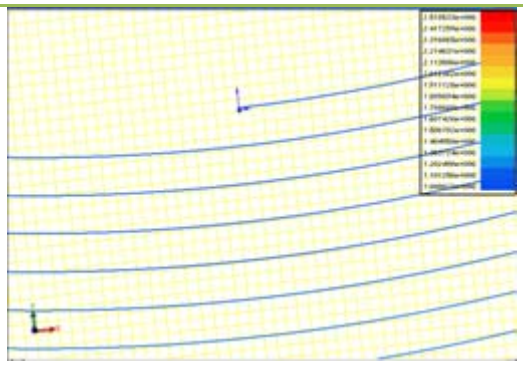
The result of simulation for k_Cell = 14:



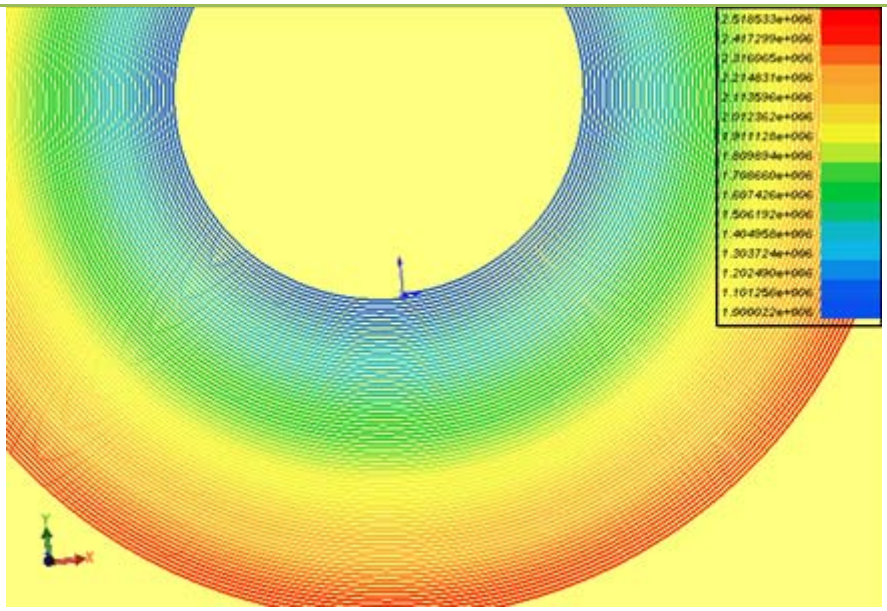
Electron trajectory k_Cell = 14

By the radius of electron motion we see that miscalculation was about 15%.

For k_Cell = 140:



Electron trajectory k_Cell = 140

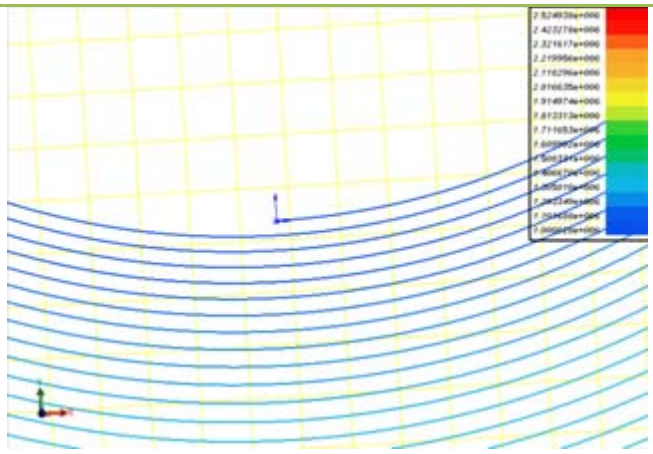


Electron trajectory k_Cell = 140

The miscalculation was 1.5%.

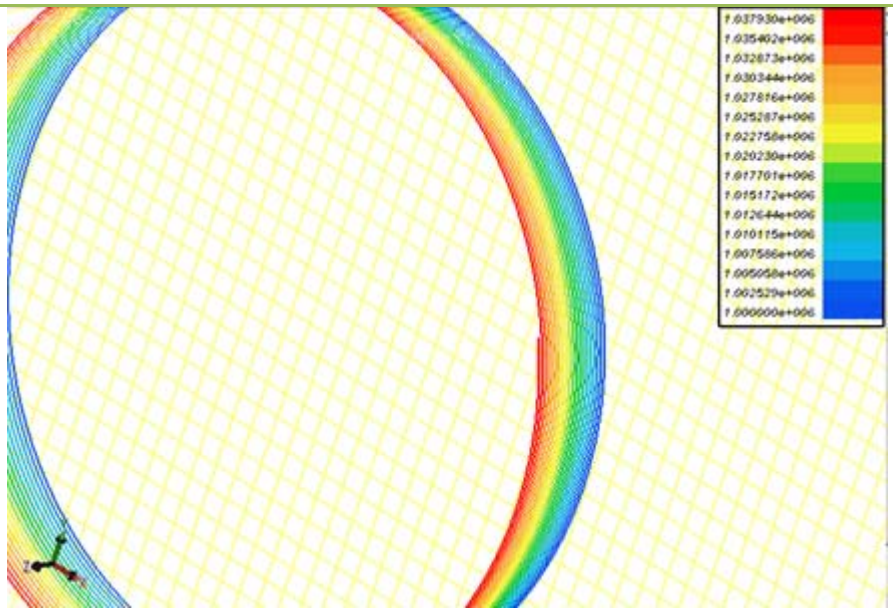
Resources of the system don't allow increasing the grid so we created algorithm of detailed cell for one grid. This allows us without allocating memory create smaller grids.

Shown are the results of simulations for the grid with k_Cell = 14 and detalization k_Cell = 140:



Electron trajectory k_Cell = 14 detalization 140

Shown are results for grid with k_Cell = 14 and detalization k_Cell = 1400:

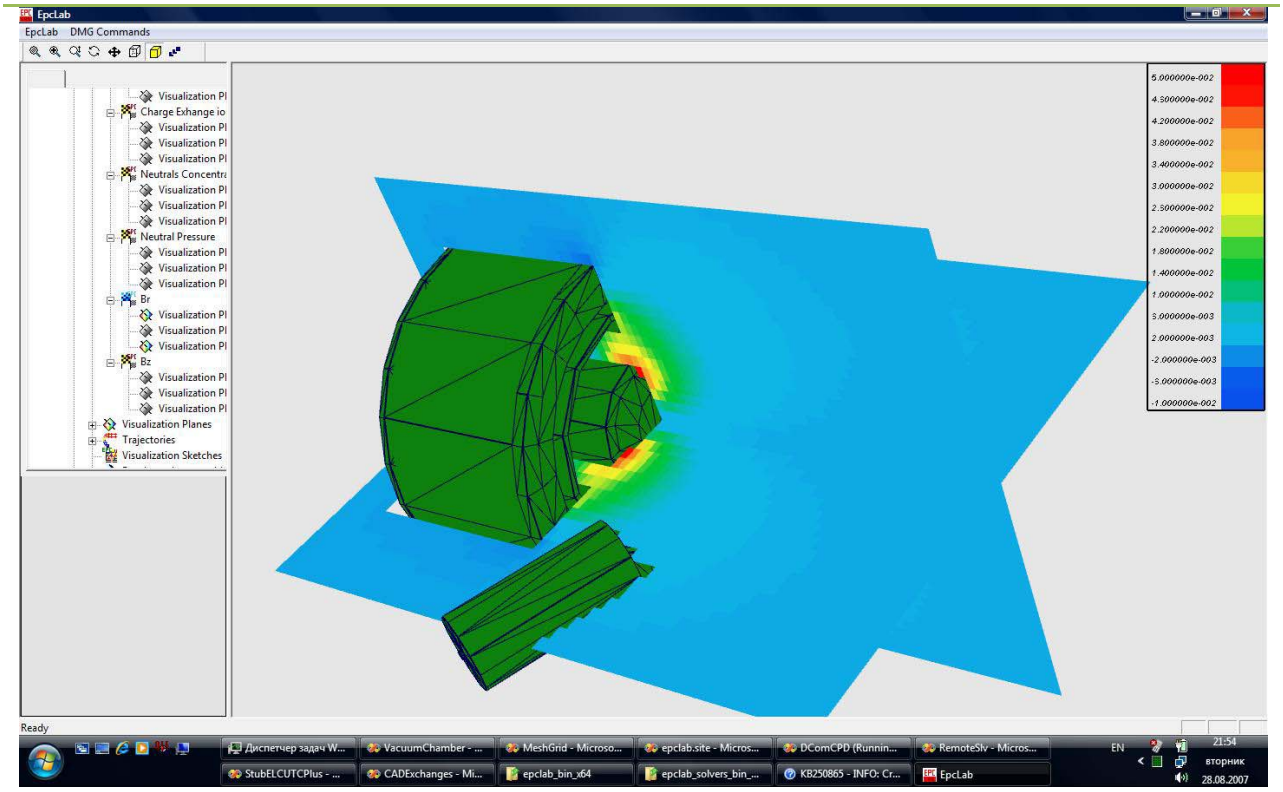


Electron trajectory k_Cell = 14 detalization 1400

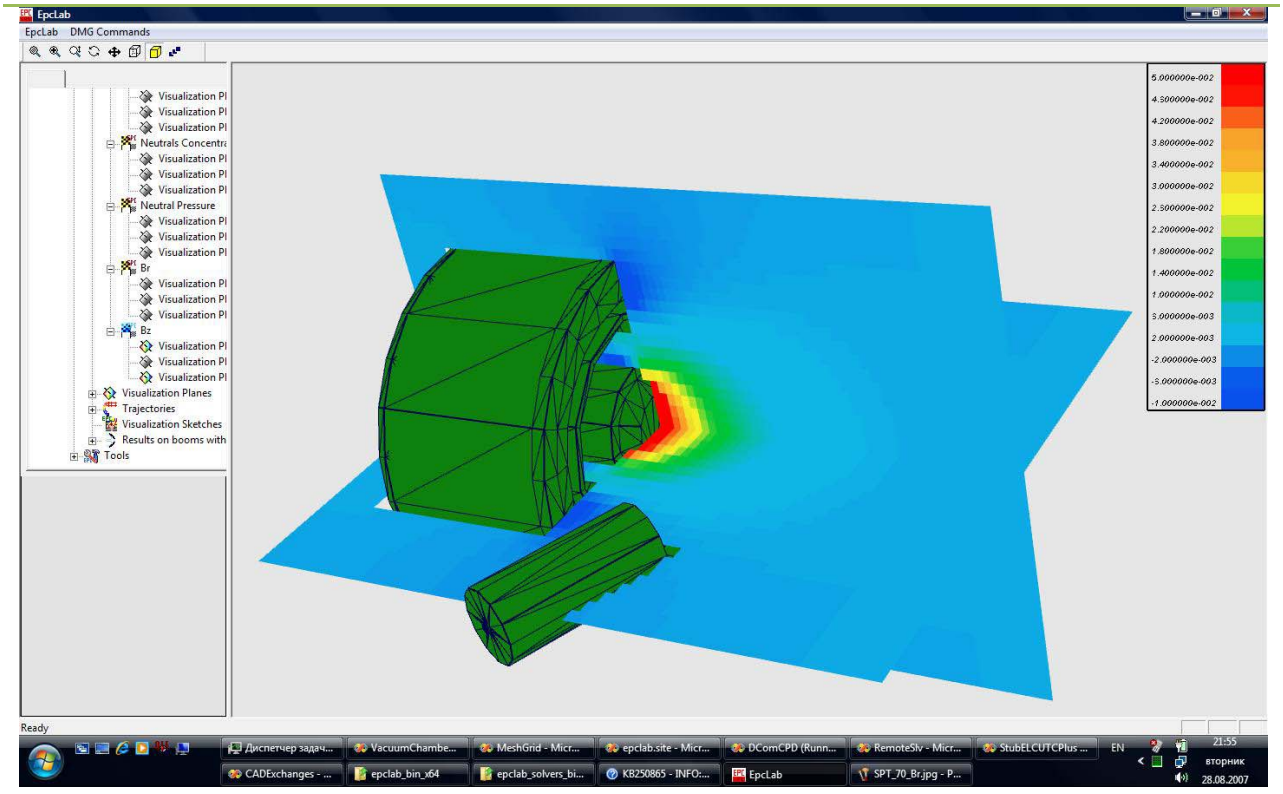
For the visualization purposes we've determine a little velocity in z direction.

Trajectory of electron from cathode:

Next two figures show the transformation of ELCUT calculation for the magnetic fields:



Br

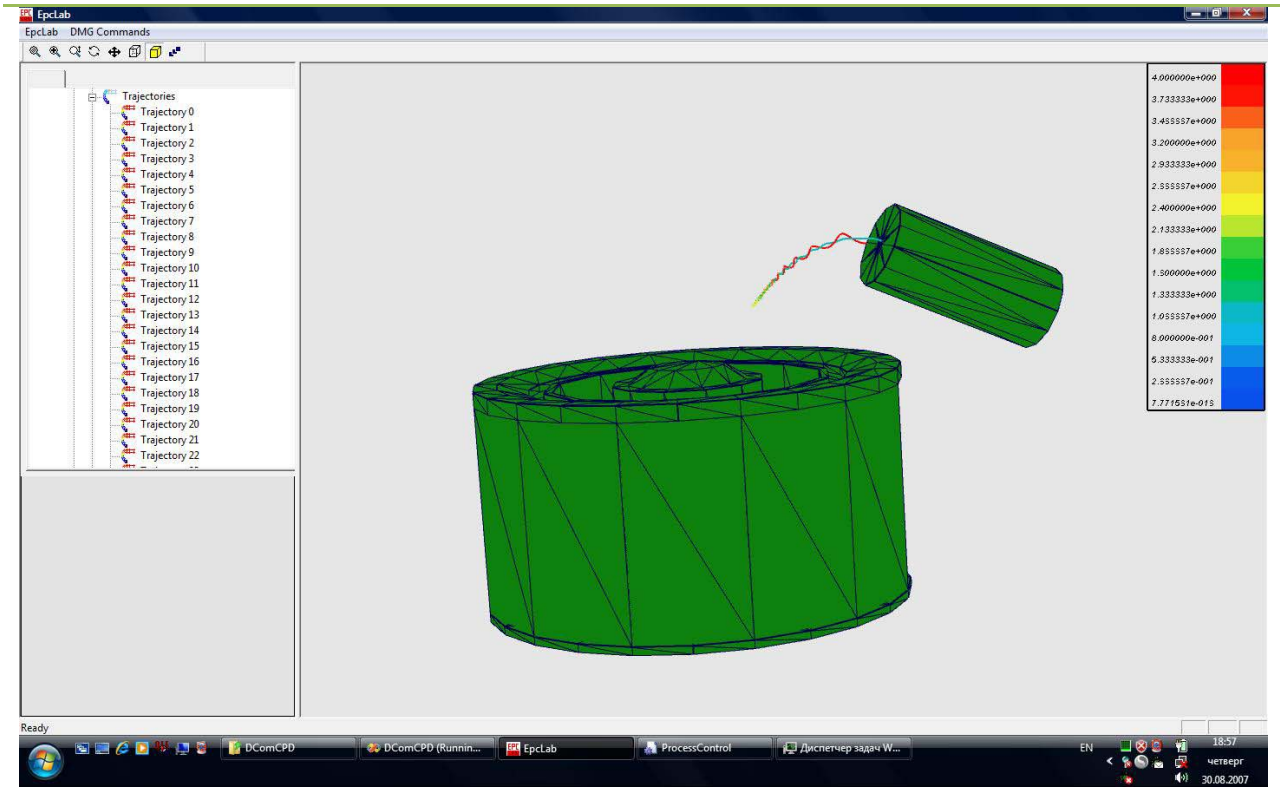


Bz

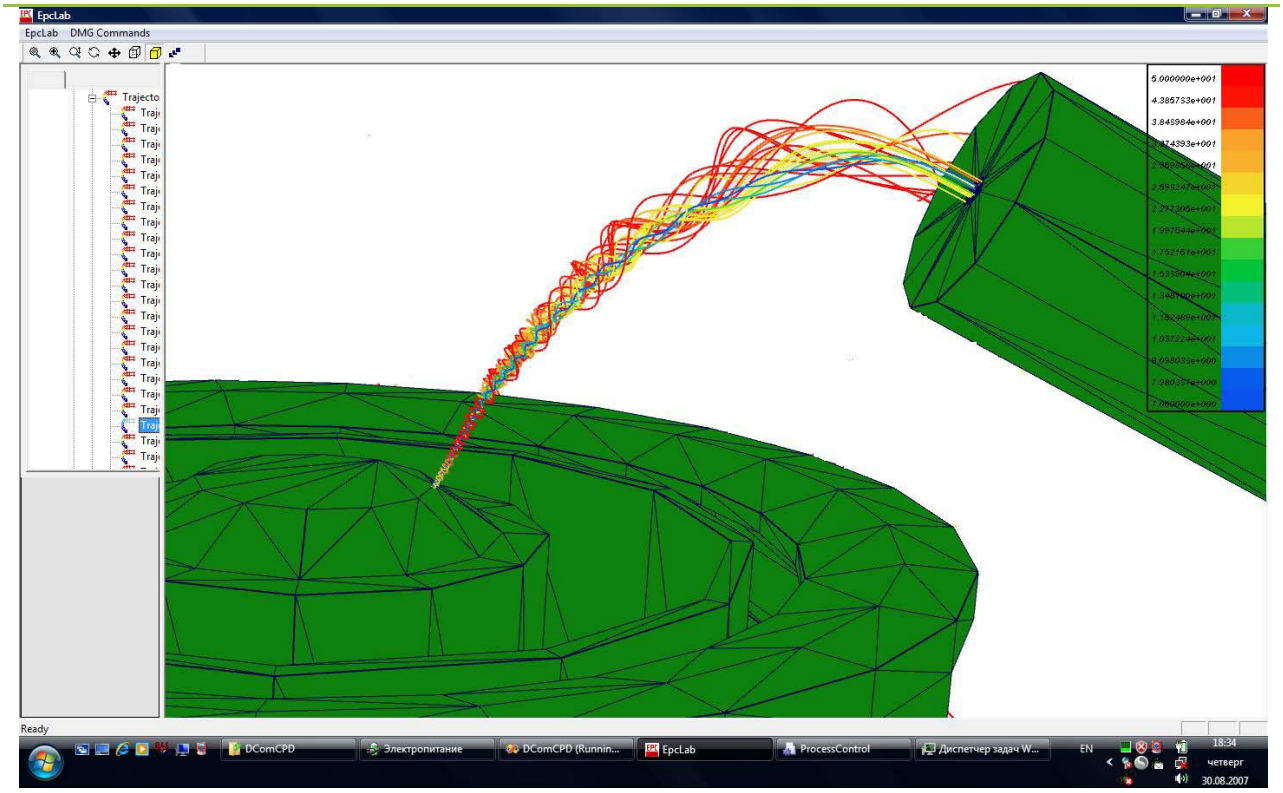
Interaction analysis during electron movement:

1. During electron motion it interacts with neutral particles and ions. The interaction process occurs by the next law for neutral: e+Xe -> Xe^{+}+2e; for ions interaction: e+ Xe^{+}-> Xe^{2+}+2e

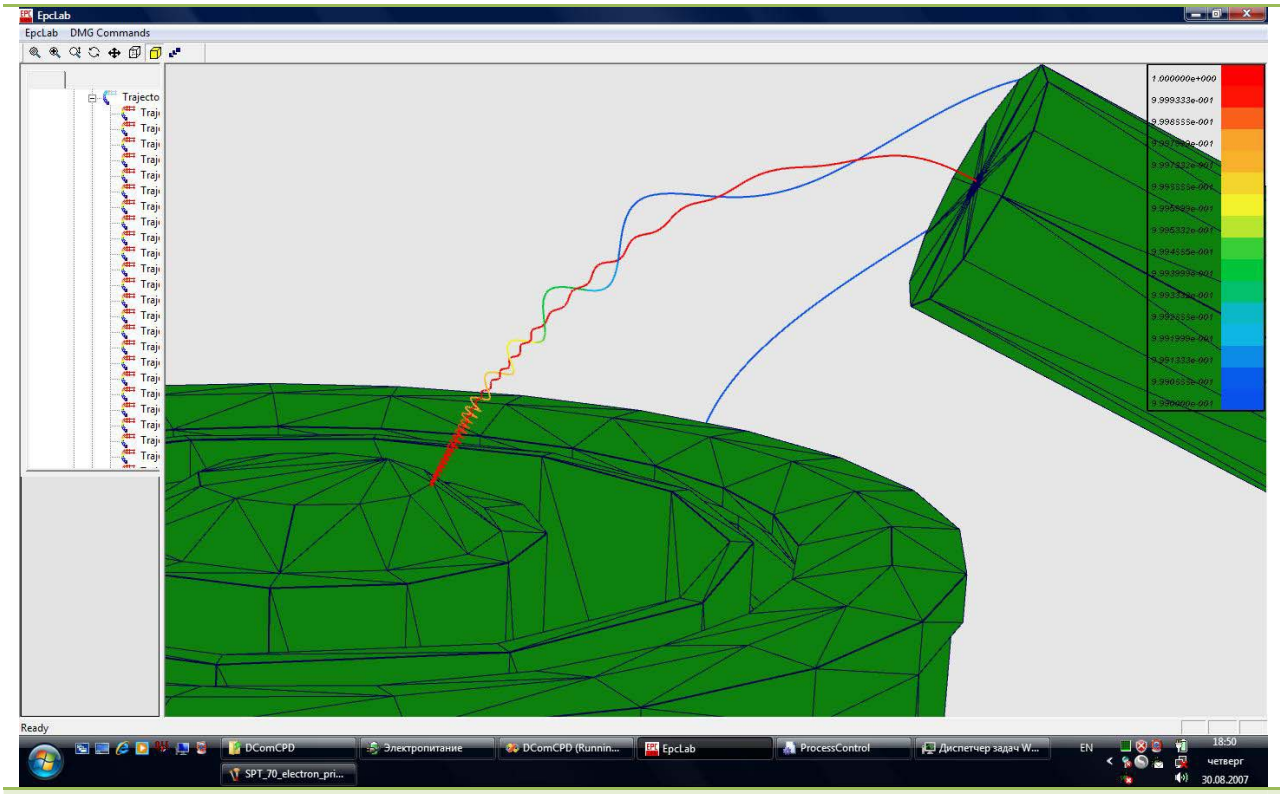
During interaction process the relative electron beam decrease. But in the cell two times more electron remains.



Trajectory of electron with 2eV start energy (color correspond the energy in eV)



Simulated beam of electrons with average start energy 12 eV (color correspond the energy in eV)



Simulated interaction with neutral gas and primary ions. Relative distribution show decreasing of electron intensity in beam (color correspond the relative number of electrons in beam)

Probably the electric field influence near the thruster outlet change the trajectory of electron and it will fall in the channel. This process will be probably developed further with the help of experimental data or fluid model simulations.

Conclusion

This research still has not finished yet. But there are some pre results which can have some further development. Such as: 1) electron concentration calculation with trajectory methods; 2) interacted electron trajectories analysis 3) Fluid model of potential calculation can be added. The probes also can measure simulated electron currents. Because of using time in our algorithm there can be added time dependent probe characteristics. And time-dependent electron oscillation on simulated probes can be analyzed.

References

Papers:

1 *G.Toropov S.Khartov "Numerical procedure permitting calculation of how a vacuum chamber influences Electric Propulsion Thruster jet expansion", IEPC-2007.*

2 *ELCUT 5.4. User Manual. Tor Ltd. Saint-Petersburg 2006.*

3 *http://www.opencascade.com*