Limits of pathline control using electric field

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***Abstract*—Nowadays, CubeSat-sized satellites have become popular. A possible propulsion system for these satellites can be based on an ion thruster. In an earlier paper, we presented a possible way of calculating control parameters based on a prescribed ion pathline. This paper presents the limits of realizable paths based on theoretical calculations and 3D simulations.**

***Index Terms*—electrostatic model, ion thruster, optimization, limitations**

I. INTRODUCTION

In the recent years a lot of small satellites were launched that were designed and manufactured at our department (MaSat-1, SMOG-P [1], ATL-1[2], HRC-100) 1. In the next decade there will be the dawn of tiny sized satellites due to its realtively low cost of fabrication and space launch. There is a theoretical elkepzeles that control of satellites in orbit can be achieved using a small sized ion thruster (concept of ionthruster shown on Fig. 2).

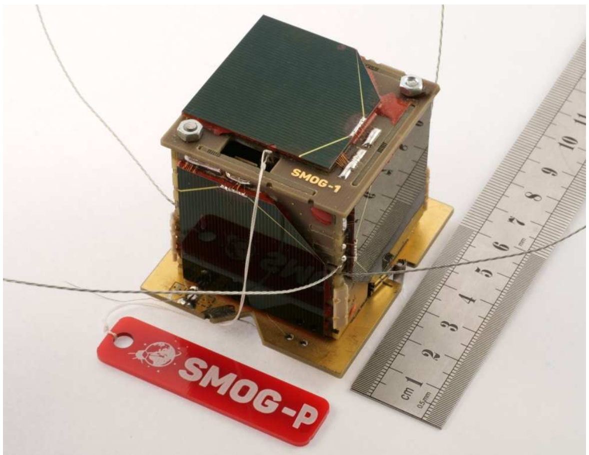

Fig. 1. Pocketcube (5cm×5cm×5cm sized) satellite [1]

II. ION PROPULSION SYSTEM OF SMALL SATELLITES

Az ionhajtomuvek az elektromos meghajto rendszerek egy fajtaja. Mukodesuk alapjat Newton 3. torvenye adja. A hajtoerot ionok gyorsitasaval es kifele torteno lovesevel erjuk el. Az ionok haladasabol keletkezo impulzussal ellentetesen iranyban lokodik a satellit. A rendszer fo reszeit bemutato abra lathato see Fig. 2.

A vakuum kamra (1), amelyben elektromos ter segitsegevel a bearamoltatott xenon-bol ionokat hozunk letre ((2) - confined plasma). Ennek egy reszet a plama fenntartasaea hasznaljuk el. Egy masik reszet a gyorsito racsokra kapcsolt elektromos feszultseg keltette (kozel) egyenletes elektromos ter segitsegevel felgyorsitjuk es egy fuvonkan keresztul a kulvilag fele lojuk. Az AG felso reszen helyezkedik el egy fuvoka, amelynek feluleten elektrodak helyezkednek. Az elektrodak potencialja valtoztathato relative to the top of accelaration grid.

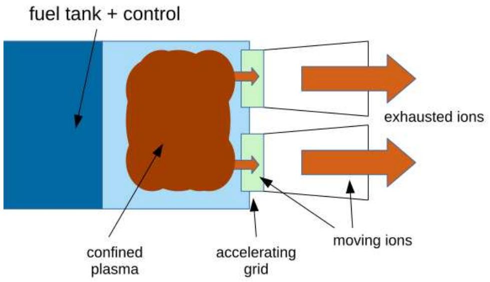

Fig. 2. Outline of an ion thruster system

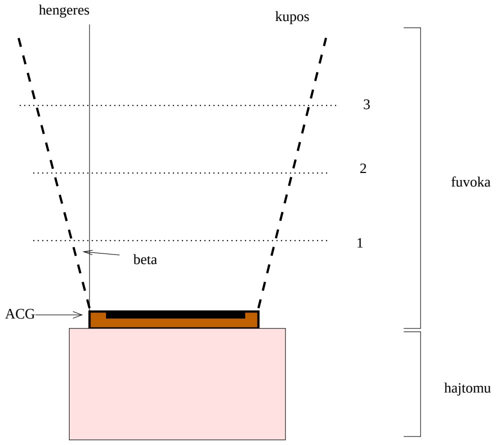

Fig. 3. Schematic of the nozzle with control electrodes on the surface

Az elkepzelesek szerint a 3 alapjan a fuvoka feluleten levo elektrodak feszultsegevel letrehozott nem egyenletes elektromos hatasara az elektromosan toltott ionok mozgasiranya megvaltozik. On Fig. reffig:out1. lathatoan a fuvokan tobb layerben helyezkednek el a vezerlo elektrodak. A felgyorsitott ionok hatasara letrejovo toloero iranyat az ionnyalab kilepesi iranyanak megvaltoztatasaval lehet befolyasolni.

In an earlier work [6] we showed the possiblity of

Krisztián Vida is at that time a graduating student of the department.

optimization of ion trajectories (ion pathes) in two-dimensional cases. In this paper we analyze the maximum of the achievable declination angle in case of 2- and 3-dimensional nozzle designs.

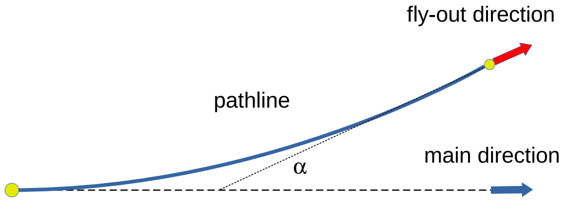

Fig. 4. Definition of declination angle (α) as tilt angle of two lines (line of main direction and line of fly-out direction). Ion starts from the left and travels through pathline.

III. PHYSICAL MODEL OF PROBLEM

We used a simple electrostatic model of the nozzle that consists of control electrodes and a plate at a given elektrostatic potential as boundary conditions [3]. Usage of electrostatic approximation is acceptable due to low potential change rates and relatively high ion speed.

$$\nabla\left(\varepsilon\nabla\varphi\right) = 0 \tag{1}$$

Using calculated potential we can determine the pathline of ions starting from the top of acceleration grid, solving the following equation [4]

$$m \cdot \frac{\mathrm{d}^2\vec{\mathbf{r}}_{\text{ion}}}{\mathrm{d}\ t^2} = \vec{\mathbf{E}} = -\nabla\varphi + \vec{\mathbf{E}}_{ext} \tag{2}$$

where $\vec{\mathbf{r}}_{\text{ion}}$ is location of ion and $\vec{\mathbf{E}}_{\mathbf{ext}}$ models non-electric forces.

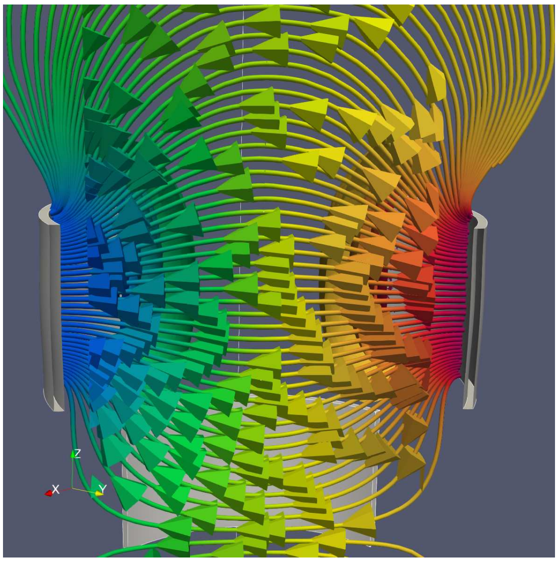

Fig. 5. Electric field lines shown between two electrodes. Color indicates electric potential of the point. Notable the nearly homogeneous field in the middle region and higher nonhomogenuity on the outer region.

IV. APPROXMATIVE MODEL IN ONE DIMENSION

In this case we are focused on the two-dimensional case of nozzles. It is a good approximation if control electrodes are

We use the simplest feasible model. Electrodes form a plane capacitor (infinite plane electrodes with constant distance, d) with length L and electric potential difference U as shown on Fig. 6. The declination angle can be calculated as function of potential difference, ion speed and electrode length [3].

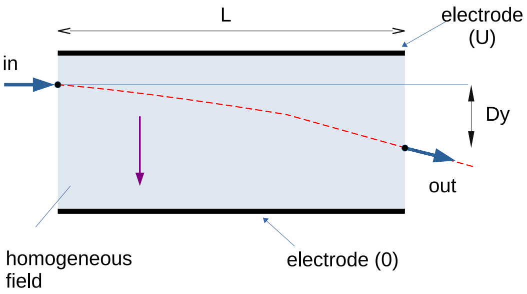

Fig. 6. Simple (plane capacitor) model to calculate an approximation of declination angle

By choosing potential of the electrodes properly, different types of control patterns can be realized. Usage of symmetrical potentials results simple bending of pathlines, that can be characterizes using a bending angle (α) [6].

In case of more complex potential arrangement more complex pathlines can be achieved. We examine these more complex effects using a 3D model. We present a 2D/3D FEM model solution with optimization.

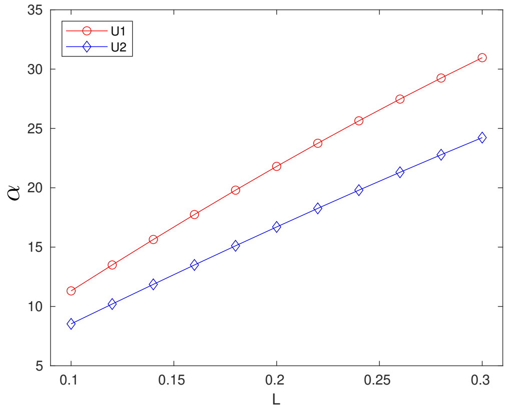

Fig. 7. Declination angle(α) as a function of electrode length(L) in case of different electrode potential difference.

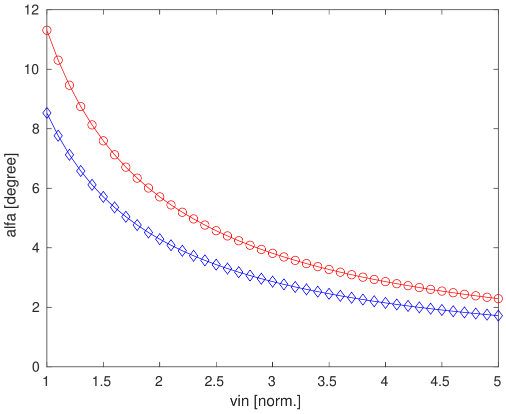

Fig. 8. Declination angle(α) as a function of starting speed of electrons entering electrode(v_{in}).

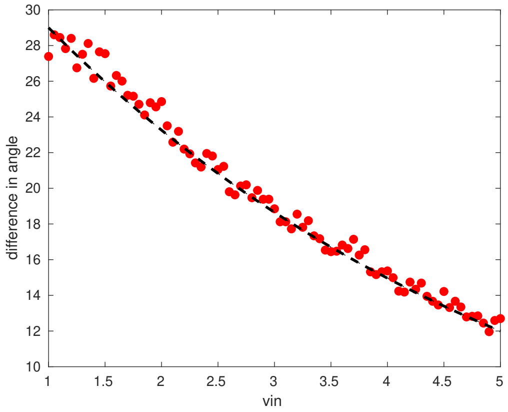

Fig. 9. Declination angle(α) as a function of starting speed of electrons entering electrode(v_{in}).

V. Three dimensional effects

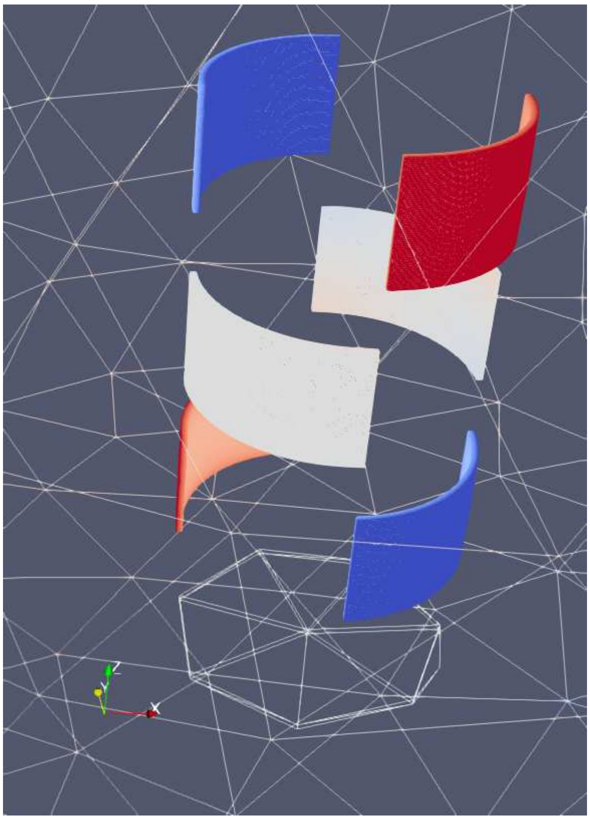

Fig. 10. Electrodes that control ion pathlines. Red electrodes are set to ”high” voltage, blue electrodes are set to ”low” voltage, grey electrodes are not connected.

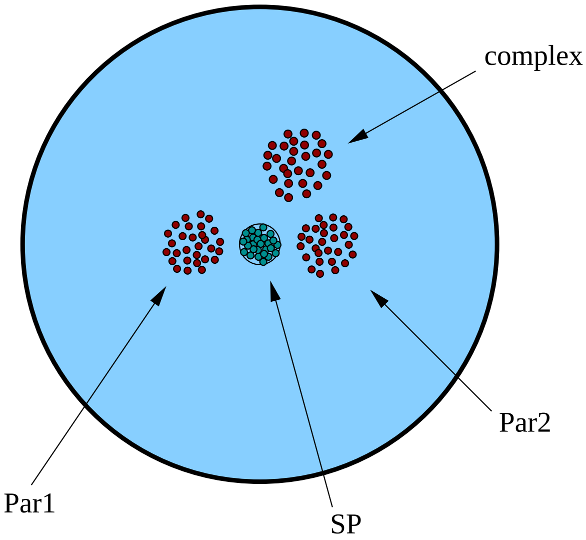

Fig. 11.

VI. Conclusions

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