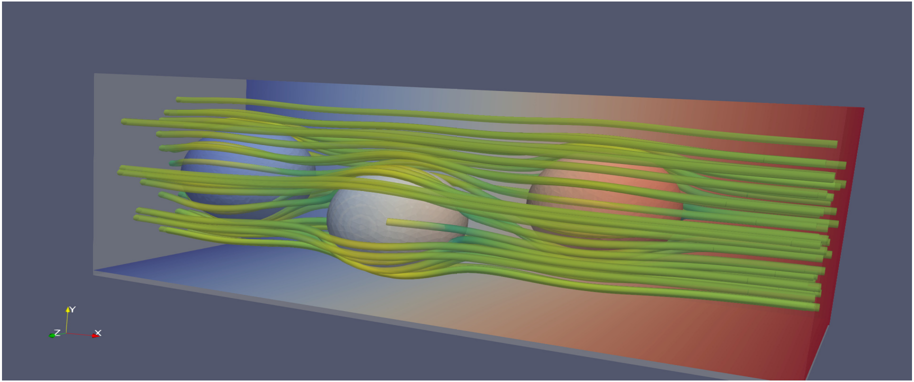
MŰEGYETEM 1782

Dept. of Broadband Infocomm. and EM Theory
Faculty of Electrical Engineering and Informatics
Budapest Univ. of Technology end Econ. (BME)

Limits of ion-trajectory controll using electric field

András Reichardt, Árpád Makara and László Csurgai-Horváth



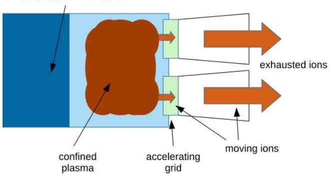
reichardt.andras@vik.bme.hu

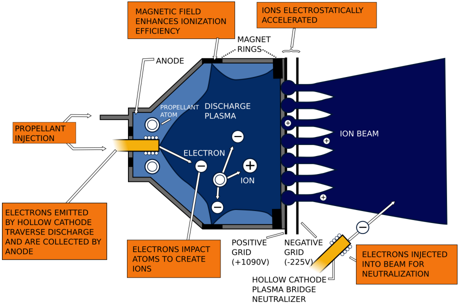
- normal sized satellites (communication satellites, astrophysical sat., ...) above 1000 kg
- small sized satellites
  - minisatellites : 500-1000 kg
  - microsatellites : < 500 kg
  - nanosatellites : < 50 kg
- CubeSats
  - multiple cubic modules
  - 10 cm per side
  - mass of 1.33 kg per unit
  - uses commercial off-the-shelf components

►components and methods that are commonly used in larger satellites are disallowed or limited (risk of explosion and weight restrictions)

- cold gas thrusters
  - inert gas stored and released through a nozzle to produce thrust
  - safe, but has low performance, attitude control usage
- chemical propulsion
  - a chemical reaction is used to produce a high-pressure, high-temperature gas that accelerates out of a nozzle
  - low complexity/high-thrust, but uses hazardous chemicals
- electric propulsion
  - electric energy used to accelerate propellant to high speed
  - only needs power, requires more solar panels, more complicated power distribution and larger batteries
- solar sail
  - using radiation sail (or solar pressure) to push ulatr-thin mirrors
  - no propellant required

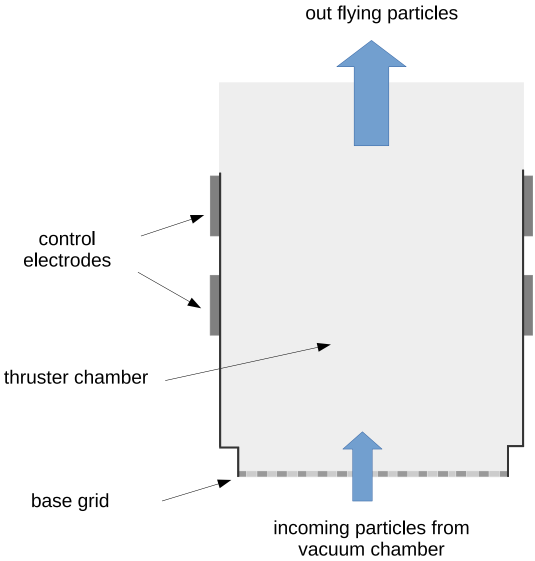
- creates thrust by accelerating ions using electricity
- neutral gas is ionized to create positive ions, that are accelerated by Coulomb-force along an electric field
- operation power : 1-7 kW (100 kW)
- exhaust terminal velocity : 20-50 km/s
- thrusts : 25-250 mN (5N)



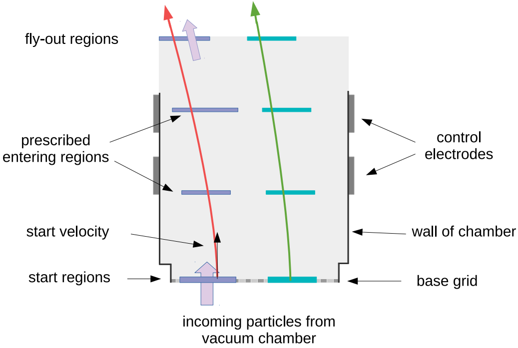


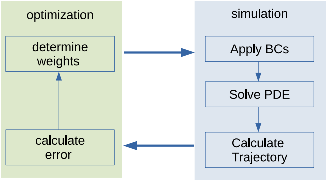
Model of an ion thruster's nozzle

- accelerated ions fly through nozzle
- directing ion-jets (a small amount of ions) means ability of steering
- electrodes on the surface of nozzles generates electric field
- electric field deviates ions through Coulomb-force from straight flying



Optimizing trajectories of ion jets





- accelerated ions fly through nozzle
- directing ion-jets means ability of steering
- prescribed path of ions are used for steering
- optimization algorithm determines electrode voltages

Simulation aspects of propulsion

- particle trajectory : path of ion that travels through nozzle
- particle's equation of motion :

$$m_{ion} \cdot \frac{\mathrm{d}^2\vec{\mathbf{r}}}{\mathrm{d}t^2} = \vec{\mathbf{F}}$$

- acting force calculated using electric potential
- electric potential is calculated using FEM (Finite Element) solver

equation to solve for

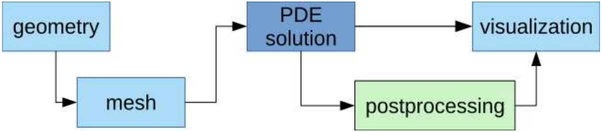
$$\nabla(\varepsilon\nabla\phi) = 0$$

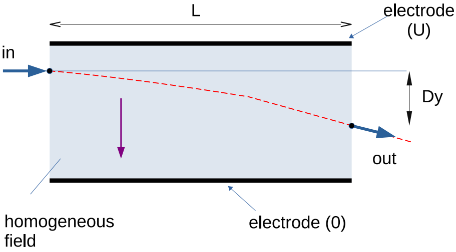
on surface of electrodes :

$$\phi_i = U_i$$

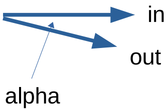
on other boundaries :

$$\left.\frac{\partial\phi}{\partial n}\right|_j = 0$$





- simple model to estimate maximum deviation

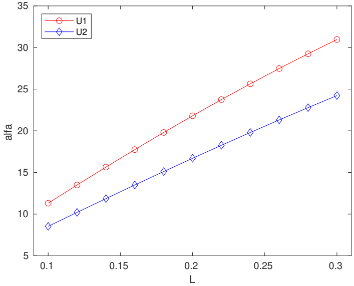


- angle between velocity of out-flying and in-flying ions

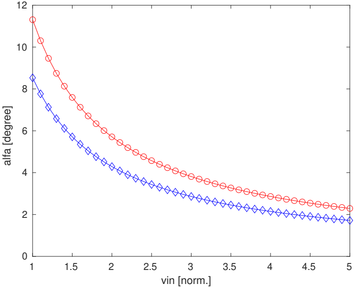
- plane capacitor (distance - D), maximum potential difference (U), length of capacitor (L)
- homogeneous field inside capacitor (purple arrow)
- angle of deviation (out - in) : α

$$\alpha \sim \arctan\left(K_0 \cdot U \cdot L \cdot v_{in}^2\right)$$

- thrust force of deviation $\sim v_{in}^2$

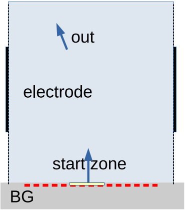


- deviation angle (°) as function electrode length (applied voltages : $U_1 > U_2$)
- longer electrode (along nozzle) means higher steering angle

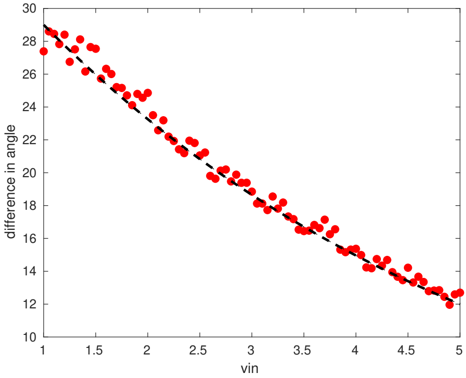


- deviation angle as a function ion's velocity (normalized) at start
- higher velocity (smaller

- Simulated results of maximum deviation differs from results of simple model by 10-30 percent
- ions started from middle section of base grid
- difference of predicted and measured caused by inhomogeneous field of real electrode-system



- Difference of calculated and measured steering angle in percent



Conclusions

- electrodes' potential causes deviation of flying trajectory of ions (steering angle)
- steering angle is **small** at *high* ion velocity but **relatively high** thrust force
- *low* ion velocity means **higher** steering angle with **lower** thrust force
- optimization algorithm can take account of predicted maximum steering angles for different sections of starting zone

What to do?

- 3D extension of estimation model
- generating a steering angle map for optimization algorithm