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Progress in electric propulsion numerical simulation

Sai Vigness Ramasamy
Postgraduate student, department 402, diykingindia@gmail.com
National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine

Leonid Bazyma
Assistant professor, PhD, department 402, leonid.bazyma@khai.edu
National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine

Electric propulsion has have been developed since the early 1960s, and its use onboard satellites, orbiting platforms, and interplanetary probes has increased significantly in the 21st century. While there is ample motivation for the use of numerical modelling in electric propulsion, much of the thruster design and spacecraft integration work continues to be experimental and empirical. This is largely due to the technical challenges of creating physically accurate models of these complex systems.

The need for a detailed understanding of the working physics and a more accurate assessment of performance to create innovative designs has stimulated the development of a large number of numerical simulation codes.

The choice of method for modelling a specific thruster should be dictated by the physical characteristics of the flow in the device, and by the level of accuracy required from the simulation. There is a wide range of conditions in different types of thrusters. This means that different methods and computer codes must be developed for each of the different thrusters.

Plasma thrusters can be classified in terms of the gas ionization process, the basic conversion mechanism for the kinetic energy gained by the ions, the main acceleration mechanism of the plasma, or the modeling needs. Electric propulsion thrusters (with the exception of electro-thermal thrusters) fall within the electrostatic and electromagnetic categories. Thrusters belonging to the former can be modeled by retaining only Poisson's equation, while the second category requires including the full set (or a subset) of Maxwell's equations.

In recent years, numerical simulations have increasingly benefited the basic understanding and engineering optimization of electric thrusters. This is due to several concurrent contributions: the evolution of computer hardware that has allowed the representation of multi-dimensional geometries and multi-scale phenomena; implementation of sophisticated new algorithms and numerical diagnostic tools; and the availability of new collisional and surface interaction data.

This paper outlines efforts to develop models of various electrical propulsion concepts, from the first attempts in the early 90s to the latest sophisticated multidimensional simulations.

The successful development of physically accurate numerical methods for simulating the gas and plasma flows in electric propulsion thrusters has the potential to significantly improve the design process of these devices. This goal has been partially realized with numerical simulations playing an increasing role in the design, particularly of ion thrusters and Hall thrusters. In terms of predicting thruster performance, accuracy of the existing numerical methods ranges from within 5% for resisto-jets and ion thrusters, to within 10- 20% for arcjets and Hall thrusters.

There are two main directions for future work to continue to improve the numerical modelling of electric thrusters. First, the numerical methods themselves must be improved in terms of their physical accuracy and their computational speed. The second main direction for improvement in the simulations involves the more accurate determination of physical parameters that are required by the numerical formulations. Examples of such information include sputter yields for new grid materials that might be used in gridded ion thrusters, secondary electron coefficients of wall materials used in Hall thrusters, electron mobility and other transport coefficients, and cross sections for new propellant species. These data are most likely to be obtained computationally due to the development of molecular dynamics simulation methods, and the expense and difficulty of performing laboratory experiments to measure such data.

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ДОСЛІДЖЕННЯ ТЕМПЕРАТУРНИХ ДЕГРАДАЦІЙНИХ ПРОЦЕСІВ ЛІТІЙ-ІОННИХ АКУМЛЯТОРІВ

А.П. Чухнов студент гр. 441.
Национальный аэрокосмический университет им Н. Е. Жуковского «ХАИ»

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