Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 185 (2017) 31 – 38
Procedia Engineering
www.elsevier.com/locate/procedia

6th Russian-German Conference on Electric Propulsion and Their Application

Analytical Model of Radio-Frequency Ion Thruster

Stepan V. Kanev[a], Sergey A. Khartov[a], Vladislav V. Nigmatzyanov[a,*]

[a] RIAME (Moscow Aviation Institute); Moscow, 125080, Russia

Abstract

The radio-frequency ion thruster (RIT) is a gridded ion accelerator which is used as an alternating electro-magnetic field for plasma production. It is suggested to use the 0-D analytical model based on energy and particles balance equations for RIT integral parameters estimation as well as for quick analysis of the influence of RIT design modification on thruster performance improvement. The numerical results of 0-D model (geometry of the discharge chamber, input power, ion current) can be used as the first assumption for more complicated models (1-D or 2-D). The calculations are verified by experimental data. Such analysis is very helpful for an experimental research of the thruster. It gives the possibility to reduce the amount of hours of the experimental work, and consequently the cost of the experiment.

Peer-review under responsibility of the scientific committee of the 6th Russian-German Conference on Electric Propulsion and Their Application

Keywords: electric propulsion, ion thruster, analytical model.

1. Introduction

The trends of modern and perspective spacecrafts (SC) development are increasing in payload mass and available electric power; enlarging the time of SC active existence; as a result expansion of the range of its mass. To solve the thruster problems there is a need to create a new generation of thrusters, differed, in particular by higher specific impulse, efficiency and long operation time.

This problem can be solved by using electric propulsion.[1] One of such promising electric thrusters is Radio Frequency Ion Thruster (RIT). From the beginning of the 60s of XX century this type of thruster has been investigated in Giessen University under the leadership of Professor H. Loeb.[2] The RIT flight models for platforms Eureka and Artemis are developed jointly with industry. The whole family of RIT thrusters of 4 cm to 35 cm[3] was also developed.

Such type of electric thrusters have been investigated in Moscow Aviation Institute under the leadership of Professor H. Loeb since 2010.

At Fig. 1 presents the scheme of a typical RIT.

As we can see the RIT consists of a discharge vessel of cylindrical, conical or spherical shape, the coil (inductor) and system of electrodes (grids) accelerated ions. The process of propellant ionization takes place inside the ceramic discharge vessel. The main advantages of such thruster operation are the absence of electrodes in ionization zone and therefore possibility to use any gas as a propellant, but never the less it is usually xenon. A helical coil, with alternating (~1 MHz), current generates alternating magnetic fields in the discharge vessel. This field, due to Faraday's law of induction, generates induced electric field of the same frequency.

* Corresponding author. Tel.: + 79250560558;
E-mail address: carsten. vladtamgin@gmail.com

1877-7058
Peer-review under responsibility of the scientific committee of the 6th Russian-German Conference on Electric Propulsion and Their Application
doi:10.1016/j.proeng.2017.03.287

β	= mass efficiency coefficient
K_b	= coefficient for the reduction of charged particles near the wall
M_{Xe}	= atomic mass of the Xenon
n_i , n_e , n_n	= concentration of ions, electrons and atoms (neutral particles) respectively
q	= elementary charge
S_{wall} , S_{out}	= area of walls and optic of the chamber respectively
T_a , T_i	= transparency coefficients for atoms and ions respectively
T_{eV}	= temperature of electrons
V	= volume of discharge chamber
v_{nT}	= mean velocity of neutral particles
U_{ion} , U_j^* , U_{di}	= ionization potential, excitation potential, double ionization potential
$<\sigma_i v>$,$<\sigma_j^* v>$,$<\sigma_{di} v>$	= ionization rate, excitation rate, double ionization rate

When this electromagnetic field penetrates inside the discharge vessel, it should not decay. For this reason it is necessary to use radio transparent material for discharge vessel walls, for example it can be aluminum oxide, silicon nitride and some other ones.[4]

There are induced electric field and gas propellant inside the vessel. In order to ignite the discharge the free electrons are required. They can be obtained from an external source – neutralizer, by switching on only positive potential at grids. Acquiring energy from alternating electric fields, electrons are heated and collide with neutral particles. Such collisions lead to excitation and ionization of the last ones. As a result, not only ions appear, but new electrons. Thus such discharge is self sustained.

During normal operation (not ignition regime) the first grid of electrodes is under a positive potential of about 1000-1200 V, it extracts ions from the plasma. The second grid is under negative voltage about 100-120 V, this electrode accelerates ions and prevents back-stream of electrons from neutralizer area. The third grid is under spacecraft ground potential. Such electrode system efficiently extracts ions from the discharge vessel and accelerates it.

As it was mentioned above the neutralizer is used for ignition of discharge. But the main function of this device is compensation of the positive charge of the exhausted plasma plume.

2. Analytical Model

2.1 Previous analytical and numerical works

The main purpose of our simulation is to understand in detail the processes which occur during RIT operation. Creation of simple models based on power and particle balance and more complicated models which include magnetohydrodynamic equations, leads to better understanding of the modeling object, and shows us the extent of the influence of the thruster construction on thruster performance. Also, as a consequence, there is reduction in experimental work. Hence this leads to reduction in cost of the thruster and more importantly, the computational models let us create a device with high performance which satisfies high requirements of contemporary space industry.

Computational modeling of radio-frequency discharges is widely used. There are a number of works which describe simulation of plasma for RIT, for example the analytical model of RIT by Goebel[5] as well as works of other authors.[6,7] These works are based on balance equation of power and concentration of particles. Models for radio-frequency ion sources[8-10] also use balance equations and transformer models for the plasma discharge.

Two-dimensional models[11-15] for RIT have been developed for decades and are still being developed. These models are based on magnetohydrodynamic equations for the plasma calculation and Maxwell equations for simulation of the electromagnetic field. Nowadays, models of PIC simulation of plasma inside RIT are being developed. [16] Unfortunately, PIC models require a lot of computational time.

Since there are no ready software for modeling low-temperature plasma,[17] for the fruitful research and development of RIT and radio-frequency ion sources, creation of a computational model is required. In this paper we present our analytical model for RIT, which allows for a short time optimized geometry of the discharge chamber and two-dimensional model, to describe in detail the plasma inside the chamber.