Development of Vernier Propulsion System for Micro Satellite on the Basis of Ablative Pulsed Plasma Thruster

IEPC-2007-130

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

A.V. Bogatiy, engineer, RIAME, boga-alex@yandex.ru
G.A. Diakonov, senior researcher, RIAME, riame3@sokol.ru

Research Institute of Applied Mechanics and Electrodynamics (RIAME) Moscow, 125080, Russia

Abstract: Propulsion system on the basis of an ablative pulsed plasma thruster (APPT) is developed at RIAME. It may be mounted on board micro-satellite as a part of three-axis attitude control system. This will allow to increase active lifetime of micro-satellite substantially. Successful tests of the APPT laboratory model allow to speak about the perspectiveness of the chosen research trend.

I. Introduction

According to the current classification, the class of micro-satellites includes satellites with the mass from 10 kg to 100 kg. Until now minimum requirements, which did not envisage the use of the three-axis attitude control systems and vernier propulsion systems (VPS) for keeping orbit parameters, were imposed to the accuracy of angular and orbital position of such satellites, low-orbit mainly, that were equipped with the simplest functional devices. In some cases, the simplest acceleration systems of the gas nozzle type were used for keeping orbit parameters of micro-satellites, but because of the low efflux velocities of the gas (about 70 m/s) and high enough thrust pulses such systems did not allow to secure high accuracy of the satellite control and long lifetime.

New electronic and optical technologies allow to alter external appearance and capabilities of micro-satellite radically. Currently, at the mass of about 50 kg such satellites may be equipped with the purpose-oriented devices, characteristics of which are comparable with the characteristics of equipment mounted on board large spacecraft. Purpose-oriented equipment of micro-satellites of the next generation imposes higher requirements to the flight control systems of micro-satellites, installation of three-axis attitude control system is required frequently, as well as of the VPS on the basis of electric propulsion securing micro-satellite active lifetime of not less than 3-5 years.

Such actual tasks, as the Earth remote sensing, navigation, cartography, and communication, may be efficiently solved by micro-satellites also, especially if they are combined into orbital systems comprising two and more satellites with optoelectronic, radar and other equipment on board, which secure high resolution due to the combination of apertures of equipment mounted on board individual satellites.

II. APPT Development

Ablative pulsed plasma thruster is simple in its design and principle of operation. Its flight model consists of the discharge channel unit, capacitive energy store, solid propellant feed system, power processing unit (PPU), discharge initiation unit (DIU), supply buses, etc. A variant of propulsion system is developed at RIAME for micro-satellites; it has rather high thrust and power characteristics, is equipped with the system securing store and feed of the required amount of propellant, and complies with a large number of tasks imposed to the thrusters of such class.

APPT for micro-satellite has the following basic parameters:

Total thrust pulse of propulsion system is not less than 10 000 N·s, including:

– total pulse of the vernier thrusters is not less than 9 000 N·s;

– total stabilization pulse of 1 000 N·s is distributed among six thrusters.

Power consumption is not more than 100 W.

“Dry mass” of propulsion system is not more than 11 kg.

Propulsion system is designed for:

– generation of thrust pulses required for keeping (correcting) parameters of the SC operational orbit;

– SC transfer from one orbital point to another;

– generation of thrust pulses securing SC damping after separation from the booster;

– SC stabilization in the operational orbit during the corrective pulses generation by propulsion system;

– SC attitude recovery (off-nominal situation).

Figure. 1 shows an example of propulsion system arrangement on board micro-satellite.

Micro-satellite has the shape of a cube, thrust units of propulsion system are located symmetrically on the parallel sides, thrust vectors of the middle thrust units are in the plane that is parallel to the upper side and includes the center of mass of micro-satellite.

SC heading hold is secured by the thrusters 5 and 6 (they secure micro-satellite rotation about axis Z), which fulfill another task also – generate correction pulse (simultaneous operation of the thrusters).

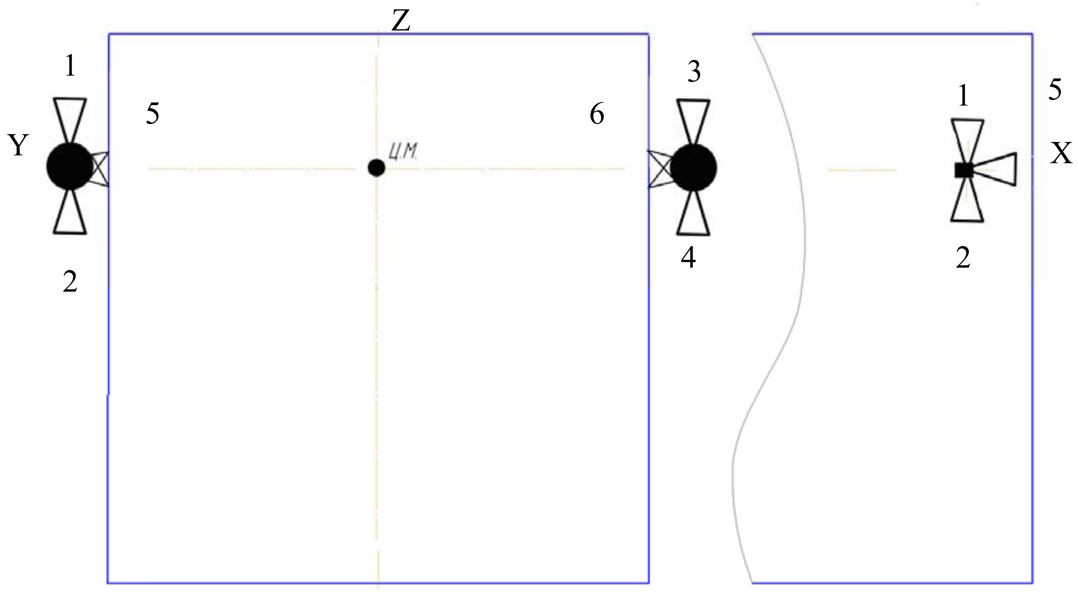

Figure 1. Propulsion System Arrangement on Board a Micro-Satellite

Thrusters 1, 2, 3, 4 start their operation according to the differential scheme – the same thrusters operate in the roll and pitch channels. Simultaneous operation of thrusters 2 and 4 or 1 and 3 provides micro-satellite rotation about axis Y, and simultaneous operation of thrusters 1 and 4 or 2 and 3 provides its rotation about axis X. Thus, the micro-satellite attitude control in space in three axes is secured.

According to the chosen arrangement of propulsion system on board small spacecraft, propulsion system consists of two propulsion units (Figure 2) and one common power processing unit (PPU). Three thrusters of each propulsion unit use common capacitive energy store, that allowing to reach small overall dimensions and mass. The order of thruster starting is defined by the operation of ignition system; thus, simultaneous operation of two thrusters of each propulsion unit is secured (up to 4 thrusters of propulsion system can operate simultaneously). In this case, there is an in-turn operation, and the frequency of the capacitor unit operation is two times higher than that of the thrusters.

Long active lifetime of SC in the orbit imposes strict requirements to the reliability of the propulsion system as a whole, and to the storage unit in particular. Capacitors used as the energy stores have lifetime corresponding to 1.5·109 pulses at the operating voltage of 1500 V. Design number of pulses during the entire active lifetime is ~ 3*107 pulses.

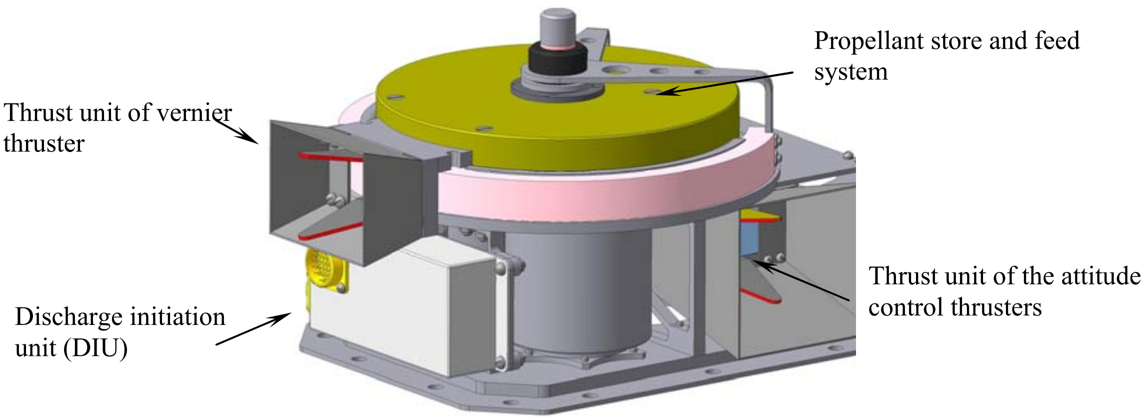

Figure 2. APPT propulsion unit

Joint use of three thrusters with one storage unit brings a number of questions up:

- Mutual influence of thrusters at the operation of propulsion system;
- Influence of current-conducting protective screens on the operation of thrusters.

In spite of the fact that thrusters are located at a considerable distance from each other, there is certain probability of their mutual influence during the operation.

A decision was made to use laboratory model of APPT with two discharge channels to study these issues (Figure 3).

Discharge channels are located one above the other and have common anode that plays the role of a screen simultaneously preventing plasma penetration during the operation of one of the channels. Protective screen is made of stainless steel, vertical walls of the screen are capable of moving apart changing the gap between them and the anode.

Each channel is provided with an igniter providing possibility for simultaneous operation of both channels, and with the Rogowski belt for the registration of discharge characteristics by the oscilloscope. It was determined after a number of tests that the protective screen made of the current-conductive material did not have influence on the propulsion system characteristics. In spite of the close arrangement of discharge channels, propulsion system was operating stably.

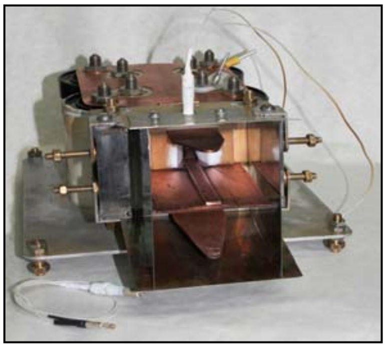

Figure 3. Laboratory model of APPT

Voltage, V	W, J	P, mN	Efficiency, η
1500	33.75	0.85	0.15
1400	29.40	0.60	0.10
1300	25.35	0.51	0.07
1200	21.60	0.41	0.05

To examine mutual influence of the channels during their operation, one channel was engaged and data corresponding to the second channel were taken off by the oscilloscope (Figure 4).

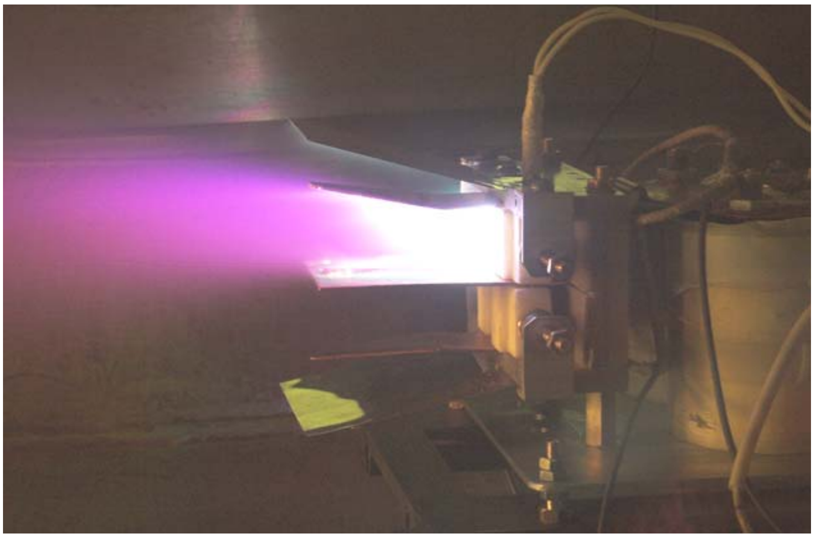

Figure 4. Tests of the APPT laboratory model

Test was made within the voltage range of 1200 – 1500 V. Test results are presented in the form of thrust efficiency as a function of discharge energy (Figure 5). Specific characteristics of the APPT developed at RIAME are compared with those of the foreign analogs in Figure 6.

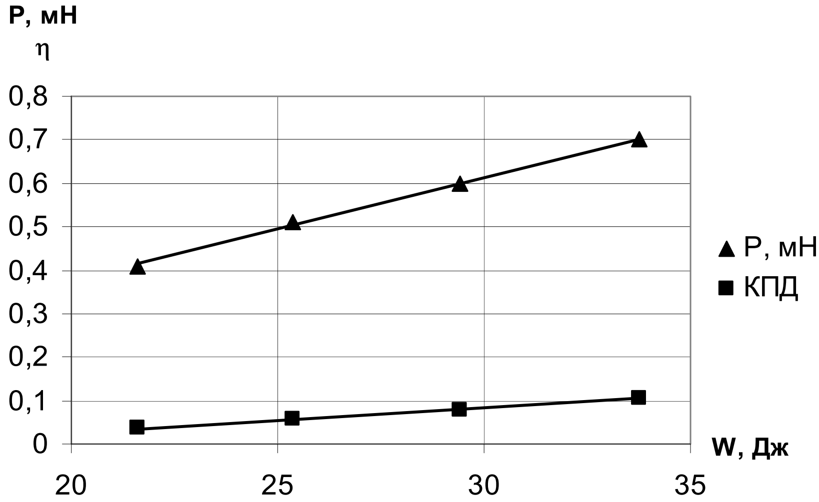

Figure 5. Characteristics of the laboratory model

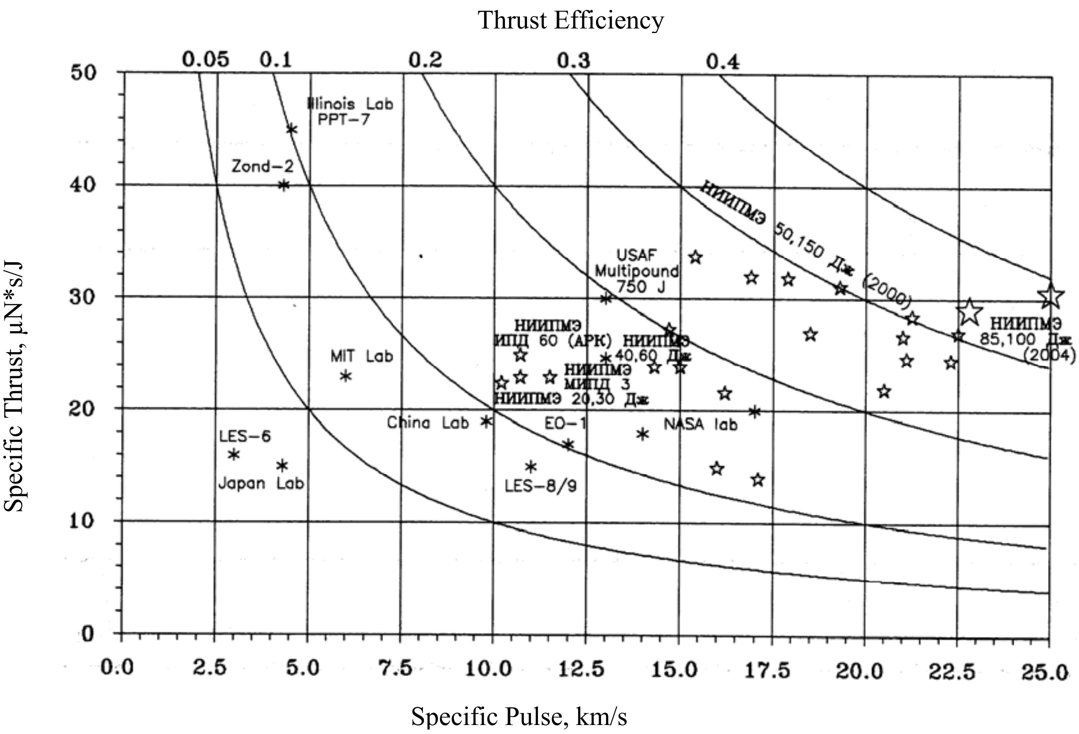

Figure. 6 APPT specific characteristics

It is evident from the oscillogram (Fig. 7) that pick-up currents being the result of ignition were only registered at the non-operating channel, and closing caused by plasma did not take place. Similar tests were made both with the protective screen mounted and without it. The same pattern was observed in both cases within the entire energy range.

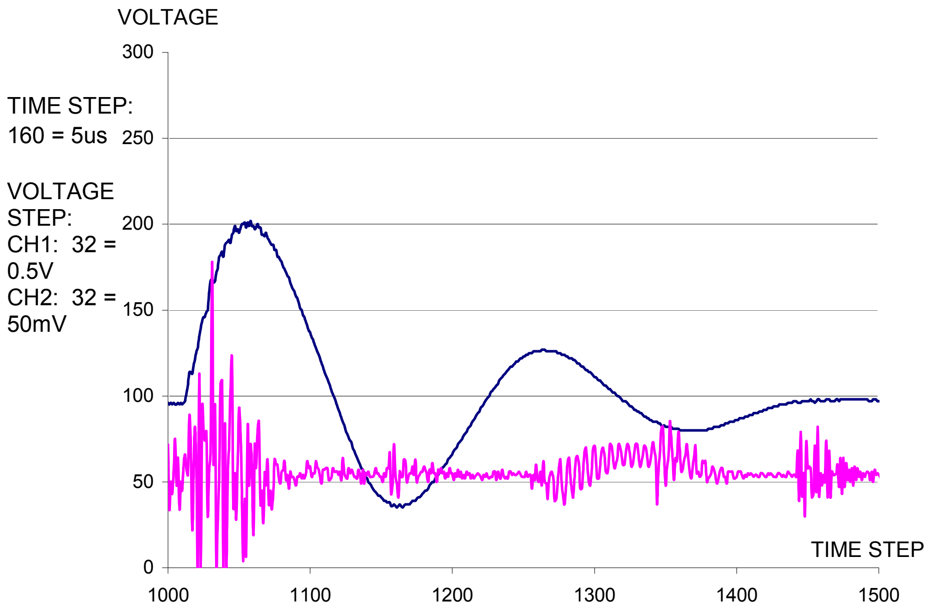

Figure 7. Discharge oscillogram for the laboratory model

Laboratory model developed for studying mutual influence during the operation of discharge channels mounted with the joint energy store unit, as well as for studying influence of metal protective screen on the discharge channel operation played an important role in the reliable prediction of operation of the designed prototype of the APPT-based propulsion system.

It was determined as a result of the tests that discharge channels located in the close proximity to each other did not have influence on the operation of each other both at the operation without the protective screen, and at the operation with such screen.

It is possible to state that the APPT-based propulsion system with thrust units provided with protective screens will operate stably in the design mode.

III. Conclusion

Next generation of the low-orbit micro-satellites, which according to many forecasts, [2] for example, will occupy considerable segment of the spacecraft market soon, has a need for a highly efficient, reliable and cheap vernier propulsion system consuming electric power at a level of some tens of Watt. It is shown in the report that the ablative PPT developed by RIAME is the best option for solving the tasks of the orbital attitude control for such satellites.

IV. References

[1]G.A. Avatinyan, N.P. Shelkov, N.N. Antropov, G.A. Diakonov, V.N. Yakovlev "Selection of the vernier propulsion system for the "Vulkan" small spacecraft" // The III International Conference-Exhibition "Small Satellites". New technologies, miniaturization, fields of efficient application in the XXI century, Korolev, 2002.

[2]V.V. Bobylev, B.K. Kuzminov, S.A. Kucherov, A.P. Soloviova "Analysis for basic distinctions of the small spacecraft market. // The III International Conference-Exhibition "Small Satellites". New technologies, miniaturization, fields of efficient application in the XXI century, Korolev, 2002.

[3]N.N. Antropov, G.A. Diakonov, N.V. Lyubinskaya, M.M. Orlov "Vernier propulsion system for the low-orbit micro-satellites of next generation // The III scientific and training conference "Micro-technologies in aviation and cosmonautics", Saint Petersburg, 2004.