Review of electric thrusters with low consumption power for corrective propulsion system of small space vehicles

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Abstract. This paper presents an overview of current world developments in the field of low-energy plasma propulsion systems for small micro- and nanoclass spacecraft. A promising direction of thrusters for devices of nanoclass are propulsion ion propulsion. The use of electrical energy and high-frequency electromagnetic radiation eliminates the problem of significant power losses, because at this level, the laws of optics (reflection and focusing of waves by metal surfaces and dielectrics) and electrical conductivity (energy transfer through metal conductors) work. This fact is an advantage of plasma installations over thermal ones.

1. Introduction
Currently, the relevance of the spacecraft (SC) with corrective propulsion systems (CPU) is becoming increasingly important, since modern SC require solving a wide range of orbital manoeuvring tasks: elimination of launch errors by launch vehicles, maintaining orbital parameters, inter-orbital maneuvrings, building SC orbital groupings, taking SC to the disposal orbit, inspecting other SC and orbital objects, observing near-earth space, etc.

In addition, they are used for solving applied and scientific problems, including: testing new technologies in space, obtaining information in the process of remote sensing of the Earth, solving communication problems, solving educational problems, conducting scientific research, primarily in the field of research of the upper atmosphere, ionosphere, magnetosphere, solar-earth communications. In this case, the scope of SC is largely determined by their standard size [1, 2].

Currently, a whole family of electric thrusters (ET) has been developed, which differ in the method of acceleration of the working body.

The basis of any jet thrusters is a certain process of acceleration of the substance (working fluid) with its subsequent expiration. Typically, ET uses three acceleration mechanisms: thermal, electrostatic, and electromagnetic.

2. Problem statement
This paper presents an overview and analysis of ET with a power consumption of no more than 500 W for CPU SC.

The task of the work is to search in open information sources for information about the design, technical and operational characteristics and the principle of operation of low-power electric rocket thrusters developed for SC micro- and nanoclass and compares with them the prototype of an ion thruster with a microwave plasma generator.

3. Theory
Active research in the field of electric CPU started in Russia about 50 years ago. Since then, almost all known types of electric rocket thrusters have been studied in a wide range of power consumption.

In thrusters with thermal acceleration, the thrust is obtained by converting the potential energy of the gas into kinetic energy in the nozzle. The energy of the expiring gas is determined by its temperature before the critical section of the nozzle. Thrusters of this class include induction, resistojet and arcjet [3, 4].

In resistojet, the temperature of the working fluid is increased by supplying energy from an electric heater. The value of the specific thrust impulse of these thrusters is limited by the maximum permissible temperature of the ohmic heater. The specific thrust impulse does not exceed 300 s (figure 1) [3].

Resistojet has been used on Russian satellites. Corrective propulsion systems based on END-15 thrusters have been successfully used in space since 1981 as part of the CPU of meteorological stations. They are equipped with low-orbit SC "Meteor-3", "Meteor-Priroda", "Resurs-O", as well as systems for correction and orientation of geostationary SC "Elektro". In total, more than 10 SC with a CPU based on END-15 were launched into space. Each CPU includes four thrusters (two main and two backup). The power consumption of the END-15 thruster, which uses ammonia as the working fluid, varies in the range from 100 to 400 W, the thrust level is from 50 to 300 mN, specific impulse is from 210 to 270 s [5, 6].

In [7], information about the characteristics of corrective propulsion systems with resistojet is presented. Part of the CPU includes two resistojet (one main and one backup). The power consumption of an resistojet using ammonia as a working medium is 100 W, the thrust is 30 mN, and the specific impulse is up to 230 s [7].

Resistojet is also routinely used in the United States. For example, the resistojet (MR-501, MR-502A, etc.) has been operated in the United States since 1965 on Board more than 75 aircraft. The resistojet MR-501 provides 330 mN of thrust at 510 W. Hydrazine is used as the working fluid in these resistojet. The scope of application is mainly for maintaining the standing point of the geostationary SC in the "North–South" and "West–East" directions, as well as for orbital maneuvering and orientation control of the SC. Resistojet used for geostationary SC middle class, developed by Lockheed Martin on platforms series 4000 and 5000, and on small geostationary communication SC, manufactured by the firm Orbital Science Company platform StarBus (Cakrawarta-1, etc.) and on SC low-orbit multi-satellite communication system Iridium SC upper stage on the target orbit. The Iridium SC systems were developed by Lockheed Martin based on the LM-700 platform [8 – 11].

In arcjet, the working fluid is heated by passing an electric arc current through it. In this case, the gas temperature can significantly exceed the temperature of the electrodes and the thruster and, consequently, the specific impulse of the thrust is noticeably greater than, in resistojet. Depending on the working fluid used, the specific impulse can reach up to 550 s for hydrazine and up to 1500 s for hydrogen (figure 2.).
The authors did not find information on the flight application of an arcjet with a power consumption of less than 500 W on the SC, but currently, development is underway to create an arcjet with low power consumption.

The LeRC developed an arcjet with a power consumption of 200 to 400 W, with simulated ammonia and hydrazine working bodies. Optimal operation of the arcjet was achieved at average mass flow rates of the working fluid above 10 mg/s. Arcjet flow rates of the working fluid less than 10 mg/s, the functioned unstable. The authors attribute this problem to large hydrodynamic losses of the nozzle at very low mass flow rates. Thus, the geometry of the nozzles was studied. It turned out that the double-cone nozzle eliminates this problem [11, 12].

Another low-power arcjet is developed on ISAS called SAGAMI-III. The first experiments were carried out with a relatively large nozzle neck of 0.5 mm based on the design of a low-power Sagami-II. But further research has shown excellent performance in terms of efficiency and stability thanks to the smaller 0.3 mm nozzle, especially for low mass flow rates. Interestingly, although LeRC demonstrated lower performance for simulated hydrazine compared to simulated ammonia, ISAS surpassed the performance of the LeRC ammonia thruster when running on hydrazine [13].

In [14], the results of experimental studies of arcjet VELARC on various working bodies (argon, hydrogen and ammonia) and various geometric characteristics of the nozzles are presented. So, when the discharge power from 240 to 375 W, using a two-cone nozzle and ammonia as a working fluid, the following characteristics were achieved: thrust from 27.5 to 35 mN, the specific impulse from 350 to 520 s. the authors also note that the thrust efficiency of all types of working bodies is about 20 % and falls with a decrease in the mass flow of the working fluid. There is an instability in the functioning of the arcjet when the current strength is less than 3.5 A.

Figure 3 shows some arcjet schemes.

In the United States, there are developments to create a pulse arcjet [15]. For example, arcjet on helium with a power consumption of 100 to 200 W, a specific impulse of up to 180 s, and a thrust of 2.8 to 4.8 mN. The disadvantages of this device include a high peak discharge power consumption of more than 100 kW, which leads to increased wear of the electrodes.

In the early 90's of the XX century, special attention was drawn to low-power devices, less than 100 W. This class of thrusters is intended for the tasks of controlling the orientation and orbit of the SC operation.

In Japan, arcjet were developed with a power consumption of less than 20 W. For example, an thruster running on nitrogen with a specific impulse of up to 270 s, a thrust of 0.5 to 6 mN with a power
consumption of 2 to 20 W. Or arcjet, running on nitrogen with a specific thrust impulse of up to 100 s, a thrust of 1.5 to 2 mN with a power consumption of 1 to 5 W. The arcjet data may be relevant for use in the CubeSat SC format. When using ammonia as a working medium, it is possible to achieve a specific thrust impulse of up to 400 s [16 – 17].

Table 1 shows the characteristics of ET with a power consumption of less than 500 W with thermal acceleration of the working fluid, developed in different countries of the world.

### Table 1. Characteristics of ET with thermal acceleration of the working fluid

| EPS          | Propellant | Power consumption, W | Thrust, mN | Specific impulse, s | Efficiency, % | Developer country | References |
|--------------|------------|----------------------|------------|---------------------|---------------|-------------------|------------|
| VELARC       | Ar         | 100                  | 27.5       | 170                 | 22.5          | Germany           | [14]       |
| VELARC       | NH₃        | 375                  | 35         | 520                 | 18.5          | Germany           | [14]       |
| VELARC       | H₂         | 240                  | 27.5       | 350                 | 25            | Germany           | [14]       |
| VELARC       | H₂         | 365                  | 22.5       | 865                 | 26            | Germany           | [14]       |
| VELARC       | SN₂H₄      | 310                  | 14         | 820                 | 18            | Germany           | [14]       |
| Sagami-III   | sNH₃       | 300                  | 47         | 480                 | 34            | Japan             | [13]       |
| Mini LPATS   | sNH₃       | 250                  | 30         | 470                 | 28            | USA               | [11, 12]  |
| -            | N₂         | 2…20                 | 0.5…0.6   | up to 270           | -             | Japan             | [16]       |
| -            | N₂         | 1…5                  | 1.5…2     | up to 100           | -             | Japan             | [17]       |
| -            | He         | 100…200              | 2.8…4.8   | up to 180           | -             | USA               | [15]       |
| DENV-15      | NH₃        | 100…400              | 50…300    | 210…270            | -             | Russia            | [5, 6]     |
| -            | NH₃        | 100                  | 30         | 230                 | -             | Russia            | [7]        |
| -            | N₂H₄       | 510                  | 330        | 300                 | -             | USA               | [8-11]     |
| -            | NH₃        | 472                  | 50         | 255                 | -             | Ukraine           | [18]       |
| Busek Micro  | NH₃        | 3…15                 | 2…10      | 150                 | -             | USA               | [19]       |
| Resistojet   | C₂H₁₀      | 30                   | 50         | up to 80            | -             | Great Britain     | [20]       |
| -            | Xe         | 30                   | 10…100    | 50…100             | -             | Great Britain     | [20]       |
| K50-10.1     | NH₄        | 3.3…37               | 370…548   | 176…216            | -             | Russia            | [21]       |
| K50-10.5     | NH₄        | 3.3…37.5             | 113…548   | 176…216            | -             | Russia            | [21]       |
| TK500M       | NH₄        | 10…14                | 1000…7000 | 170…220            | -             | Russia            | [21]       |

In thrusters with electromagnetic acceleration, the working body is a quasi-neutral plasma that is accelerated by electromagnetic energy. The most promising variants of these thrusters are the Stationary plasma thrusters (SPT) [22-23].

SPT has been used in space since 1971, and since then it has been regularly used in SC orbit correction systems. The main developer of SPT flight structures and supplier of such SPTs in Russia is the experimental design bureau «Fakel» (EDB «Fakel»). Hall-effect thrusters with a power consumption of less than 500 W, such as the SPT-25 and SPT-50, are being developed for use in small-size SC ET [24].
EDB "Fakel" developments are SPT-50 and SPT-60 thrusters with a rated power of 350 and 500 W, respectively. Flight tests were completed in 1971...1977 (figure 4) [25].

In [26], the results of studies of the SPT-50 thruster with a discharge power of 100 W (discharge voltage of 200 V, discharge current of 0.5 A) are presented. It is shown that in this case, the anode efficiency can be provided at the level of 28...33 % with an anode specific impulse of 1000...1200 s.

Reducing the power consumption of the SPT-20 and SPT-25 is achieved by using a single magnetization coil offset to the back cover to the discharge chamber area. Parametric tests of the SPT-20 and SPT-25 thrusters showed that the discharge capacity range is from 60 to 100 W can be obtained anode efficiency from 17 to 25 % with an anode specific impulse of 600 to 1000 s. The paper provides information about the completion of the SPT-25 in order to reduce the power cost of creating a magnetic field. With a power consumption of 100 W, the modified thruster provides a thrust of 5.3 mN, an efficiency of 20 %, and a specific impulse of 770 s (figure 5) [26, 27].

In [28], information is provided on the development of a plasma thruster with a hollow magnetic anode in order to increase the magnetic field to prevent a decrease in traction efficiency in operating modes with a high specific thrust impulse.

A distinctive feature of thrusters with a full magnetic anode is the combined discharge chamber. The authors of the work [28] believe that the performance of a discharge chamber in the form of a combination of metal-ceramic materials can significantly reduce the risks of static electricity and the occurrence of electrical breakouts along the walls of the chamber. The paper also presents the characteristics of the thruster: power range from 80 to 375 W, thrust up to 20 mN, specific impulse up to 1330 s and efficiency up to 37 % (figure 6) [26, 28].

Research is being conducted abroad on traditional circuits, as well as research on changing the geometric appearance of thruster components, which entail changes in both the magnetic system and the configuration of the magnetic field.

For example, an example of changing the geometric appearance of a discharge chamber is the CHT (Cylindrical Hall Thruster) (figure 7) which consists of a cylindrical discharge chamber, an annular anode that also serves as a gas distributor, a magnetic core and two coils. The cylindrical discharge chamber has a short annular zone and a longer cylindrical part. To maintain ionizing collisions, the anode (gas intake) is placed in a short annular part of the channel. The length of the annular part of the channel is designed to minimize the average free path of neutral atoms, which makes it possible to
localize the ionization of the working medium at the boundary of the annular and cylindrical zones [29, 30].

Tests of the CHT thruster with a diameter of the annular part of the channel of 3 cm showed that in the power range from 90 to 185 W he develops a thrust of 3 to 6 mN and an anode specific impulse from 1100 to 1650 s, which corresponds to the anode efficiency of 20 to 27 % [31].

In [32, 33], information is provided on the development of the CAMILA thruster (co-axial magnetically isolated longitudinal anode) in which the anode cavity is formed by two concentric cylindrical electrodes that perform the function of the anode. The anode cavity consists of two segments, the first segment forms the thruster channel, the other segment is formed by dielectric walls. The magnetic circuit consists of two coils. To create a longitudinal magnetic field inside the anode cavity, additional magnetic coils and magnetic screens are inserted parallel to the anodes. The authors of [32, 33] believe that by applying a longitudinal magnetic field, the radial mobility of electrons inside the anode cavity is reduced and will allow creating a radial electric field directed to the center of the channel to maintain the discharge. If the longitudinal magnetic field is strong enough, the radial electric field will increase the electron energy enough to ionize the gas inside the anode cavity. Further, the entire length of the anode can be used to ionize the gas, since the electrons oscillate between the gas distributor and the output from the anode cavity. The efficiency of the thruster is increased by the fact that the ions do not recombine on the anodes, due to the presence of a radial electric field. The authors of this work could not find information on the achieved characteristics of this thruster (figure 8).

In [34], information about the development of the T-40 thruster is given. The distinctive feature of the thruster is the conical profile of the discharge chamber, which expands from the near-anode region to the thruster section by reducing the diameter of the inner wall. This solution, according to the developers, should provide a high density of gas in the ionization zone and reduce the loss of accelerated ions on the walls in the acceleration zone. This design of the discharge chamber makes the placement of the internal magnetization coil on the central core of the magnetic circuit very difficult, so it is located behind the discharge chamber, in the back of the thruster. Characteristics of the T-40 thruster: power consumption from 75 to 250 W, specific impulse from 638 to 1274 s, full efficiency from 19 to 37 %.

Work [35] provides information about the development of the HT-100 thruster. A distinctive feature of the thruster is the use of two permanent magnets as a source of magnetomotive force. The authors of the paper [35] believe that the use of permanent magnets instead of electromagnets should reduce the power consumption and temperature of the thruster, as well as lower weight and size parameters of the thruster.

Characteristics of the HT-100 thruster: power consumption from 10 to 235 W, thrust from 3.5 to 10 mN, specific impulse from 750 to 100 s [35].
Figure 8. Scheme of CAMILA thruster [32]

Table 2 shows the characteristics of ET with a power consumption of less than 500 W with electromagnetic acceleration of the working fluid, developed in different countries of the world.

**Table 2. Characteristics of ET with electromagnetic acceleration of the working fluid**

| EPS    | Propellant | Power consumption, W | Thrust, mN | Specific impulse, s | Efficiency, % | Developer country | References |
|--------|------------|----------------------|------------|--------------------|---------------|-------------------|------------|
| SPT-50 | Xe         | 500                  | 30         | 1300               | -             | Russia            | [27]       |
| SPT-50M| Xe         | 500                  | 30         | 1800               | up to 41      | Russia            | [40]       |
| SPT-35 | Xe         | 200                  | 10         | 1200               | 30            | Russia            | [27]       |
| SPT-25 | Xe         | 100                  | 7          | 800…1000           | 20            | Russia            | [26, 27]  |
| KM-45  | Xe         | 200…450             | 10…28     | 1250…1500          | -             | Russia            | [24]       |
| PlaS-34| Xe         | 80…375              | up to 20   | up to 1330         | up to 37      | Russia            | [28]       |
| PlaS-34| Xe         | 100…675             | up to 40   | up to 1880         | up to 50      | Russia            | [28]       |
| PlaS-34| Xe         | 200                  | 13         | 1375               | -             | USA               | [36]       |
| CHT    | Xe         | 90…185              | 3…6       | 1100…1650          | 20…27         | USA               | [29-31]   |
| T-40   | Xe         | 75…250              | 7…14      | 638…1274          | 19…37         | USA               | [34]       |
| HT-100 | Xe         | 10…235              | 3.5…10    | 750…1000          | 21…29         | Italy             | [35]       |
| TCHT-4 | Xe         | 10…240              | 0.3…3.5   | 350…1200          | 7…18          | Japan             | [37]       |
| PHALL-2| Xe         | 500                  | 23…150    | 1500               | 45            | Brazil            | [38]       |
| Micro- | Xe         | 10…40               | 0.6…1.6   | 300…850           | less than 3   | USA               | [39]       |
| Hall   |            |                      |           |                    |               |                   |            |
| IHET   | Xe         | 300                  | 13         | 1500               | -             | Israel            | [41]       |
| CAM-200| Xe         | 120…250             | 5.5…14    | 1250               | -             | Israel            | [42]       |

In thrusters with electrostatic acceleration, the fuel atoms are ionized and accelerated under the action of the electrostatic field. The spent ions of the working medium are neutralized by electrons emitted from the external cathode. The most promising variants of these thrusters are ion thruster, in which positively charged ions are accelerated [43-45].

Currently, there are ion thruster with DC discharge, high-frequency discharge, and ultrahigh-frequency discharge (electron-cyclotron resonance) [26, 46].

In DC ion thruster, ionization of the working body atoms occurs in the gas-discharge chamber due to the collision of atoms with electrons emitted by the cathode and gaining energy from a constant electric field. To prevent electrons from leaving the anode, a magnetic field is created in front of it (figure 9) [26].

In thruster with high-frequency discharge, ionization of the atoms of the working body occurs due to the collision of atoms with electrons that receive energy from a time-varying electric field. Depending on the frequency of electromagnetic radiation and the presence or absence of an external magnetic field, different thruster models can be implemented. The advantage of thrusters with a discharge in an electromagnetic field is that there are no electrodes needed to maintain the gas discharge (figure 10) [26].
The paper [47] provides information about the characteristics of an 8-cm XIPS© DC discharge ion thruster consisting of a sectional conical-cylindrical discharge chamber, a cathode, a neutralizer, permanent magnets, a magnetic core, and an optical system. An anode insert was included in the cylindrical section of the discharge chamber. Engine specifications 8-cm XIPS©: power consumption from 100 to 350W, thrust from 2 to 14 mN and a specific impulse from 2000 to 3000 s. Also in [48], information is provided about the characteristics of an ion thruster with a DC discharge of 13-cm XIPS©: power consumption 450 W, thrust 18 mN and specific impulse 2350 s.

The paper [49] presents information about experimental studies of an ion thruster with a high-frequency discharge with an optical system consisting of 4 gratings for separating the processes of extraction and acceleration of ions. Characteristics of a high-frequency thruster with an optical system consisting of 4 grids: thrust 2.7 mN, specific thrust 14000 seconds with a power consumption of 300 W.

Work [50] provides information about high-frequency ion thruster of the RIT series. Characteristics of a high-frequency RITµX thruster: thrust from 50 to 500 µN, specific impulse from 300 to 3000 s with a power consumption of less than 50 W. Characteristics of high-frequency thruster RIT 10 EVO: 5 mN thrust, a specific impulse of more than 1900 s with power 145 W, and the thrust of 15 mN, a specific impulse of over 3000 s with power of 435 W.

In [51], information about high-frequency ion thruster of the BIT series is given. Characteristics of the high-frequency thruster BIT 1: thrust 185 µN, specific impulse 1600 s at power consumption 28 W. Characteristics of the high-frequency BIT 3 thruster: 1.15 mN thrust, 2100 s specific impulse with 75 W power consumption. Characteristics of the high-frequency BIT 7 thruster: thrust 11 mN, specific impulse 3300 s with a power consumption of 460 W.

In [52], we present a method for designing antennas for ion thrusters with microwave (electron-cyclotron resonance) low-power discharge and present the results of experimental studies of the thruster µ1 during which the minimum power consumption for the operation of the thruster was determined, which was 1 W.

In [53], information is provided on an improved ion thruster with microwave (electron-cyclotron resonance) low-power discharge µ10 (figure 12) with characteristics: thrust 10 mN and specific impulse 3000 s at a power consumption of 400 W. The thruster consists of a waveguide, a discharge...
chamber, an optical system, and a neutralizer. The discharge chamber consists of two circular magnetic arrays.

Figure 12. Scheme of an ion thruster with microwave discharge μ10 [53]

The paper [54, 55] provides information about an ion thruster with microwave discharge MIPS-EM and I-COUPS. Characteristics of the MIPS-EM thruster: thrust of 300 µN, specific impulse of 1200 seconds with a power consumption of 39 W. Characteristics of the I-COUPS thruster: thrust 350 µN, specific impulse 1000 s with a power consumption of 38 W.

Work [56] provides information about an ion trust with a microwave discharge (figure 13): thrust 392 µN, specific impulse 7200 s at a power consumption of 8 W.

Figure 13. Scheme of an ion thrusters with microwave discharge MMIT [56]

Table 3. Characteristics of ET with electrostatic acceleration of the working fluid

| EPS       | Propellant | Power consumption, W | Thrust, mN | Specific impulse, s | Efficiency, % | Developer country      | References |
|-----------|------------|----------------------|------------|--------------------|--------------|------------------------|------------|
| 8-cm XIPS | Xe         | 100…350              | 2…14      | 2000…3000         | -            | USA                    | [47]       |
| 13-cm XIPS | Xe         | 450                  | 18         | 2350              | -            | USA                    | [48]       |
| -         | Xe         | 300                  | 2.7        | 14000             | -            | Netherlands, Australia and great Britain | [49]       |
| RIT μX    | Xe         | less than 50         | 0.05…0.5  | 300…3000         | -            | Germany                | [50]       |
| RIT 10    | Xe         | 145                  | 5          | 1900              | -            | Germany                | [50]       |
| EVO       | Xe         | 435                  | 15         | 3000              | -            | Germany                | [50]       |
| BIT 1     | Xe         | 28                   | 0.185      | 1600              | -            | USA                    | [51]       |
| BIT 3     | Xe         | 75                   | 1.15       | 2100              | -            | USA                    | [51]       |
| BIT 7     | Xe         | 460                  | 11         | 3300              | -            | USA                    | [51]       |
| μ10 MIPS-EM | Xe         | 400                  | 10         | 3000              | -            | Japan                  | [53]       |
| I-COUPS   | Xe         | 39                   | 0.3        | 1200              | -            | Japan                  | [54]       |
| -         | Xe         | 8                    | 0.392      | 7200              | -            | USA                    | [56]       |
The conceptual model of the ion thruster presented in figure 14. Since the practical implementation, the model has changed, but the main elements presented in the figure remain. Figure 13 shows the following positions: 1 – first accelerator, plasma generator (ion source); 2 – cylindrical volume resonator; 3 – toroidal volume resonator; 4 – dilatometric valve.

![Figure 14. Conceptual model of an ion thruster with a solid-state microwave plasma generator and an accelerating gap](image)

Theoretical output characteristics of this type of ion thruster are presented in the work [57]. Currently, the parameters of the workflow and output characteristics of the prototype of the first ion thruster accelerating system are being investigated. Tests are carried out on nitrogen. In contrast to the conceptual model implemented in "live" this system has significant differences. The diagram of the first accelerating system is shown in figure 15.

![Figure 15. Scheme of the accelerating system and the plasma generator](image)

According to the results of the latest tests: thrust 0.02 μN, specific impulse of the ion thruster 3500 s at a power consumption of 4 W. This prototype implements a scheme for accelerating ionized gas with a combined field consisting of a high-frequency electric field of the gap and a constant electric field between the electrodes.

4. Discussion of results

The following generalizations can be made from the review of propulsions systems of small spacecraft:

1. According to the principle of acceleration of the working body, there are two ways to create a reactive thrust – gas-dynamic and electro-dynamic. According to the first method, the aggregate state of the working substance does not change during the energy supply process, its total energy changes by supplying heat. According to the second method, the energy is used to create a new working body – plasma and accelerate it with the Lorentz force;

2. The increase in the specific thrust impulse of heat thrusters is proportional to the pressure and the amount of energy supplied to the working body. Such propulsion systems require a continuous working environment. Miniaturization of propulsion systems of this type for use in nanosatellites is
not appropriate because of the large values of the implemented thrust, significant heat losses and low specific thrust impulse;

3. The increase in the specific thrust impulse of ion and plasma thrusters is inversely proportional to the pressure of the working fluid in the thrusters chamber, since the existence of a "cold" plasma is limited to 200 PA. The increase in pressure translates the smouldering discharge into an arc. The amount of power supplied is limited by the breakdown voltage through the ionized gas in the electrostatic acceleration system. A promising direction of thrusters for devices of nanoclass are propulsion ion propulsion. The use of electrical energy and high-frequency electromagnetic radiation eliminates the problem of significant power losses, since the laws of optics (reflection and focusing of waves by metal surfaces and dielectrics) and electrical conductivity (energy transfer through metal conductors) work at this level. This fact is an advantage of plasma installations over thermal ones;

4. Arcjet are more related to thermal than electrostatic. Although, a number of authors consider AT as plasma thrusters with electrostatic acceleration of plasma in the electrodes. However, the regimes of gas flow. The gas flow rates necessary to maintain the arc discharge and the realized temperature allow US to consider AT as ohmic installations, where the resistance element is an electric arc. Apparently, it is necessary to treat AT as a transitional link between thermal and electrodynamic installations, in which, depending on the pressure, the working fluid, and the power, either the pressure or the Lorentz force is the main thing in creating traction;

5. All considered ion propulsion systems have the same design principle: a cavity for generating plasma, a magnetic system for isolating and ejecting plasma, and an optical system for electrostatic acceleration or a magnetic field acceleration system. The method of plasma generation is being modified: on propulsion systems with a large excess power –inductive ionization method, on miniature propulsion systems High frequency (HF) or microwave discharge. HF and microwave generators are only necessary for generating plasma and do not participate in its acceleration. The most common working gas is xenon. The power consumption of HF and microwave propulsion systems is from 5 W. The specific impulse depends on the voltage value on the ion optics grids, and the thrust value depends on the ion concentration, which is proportional to the HF or microwave radiation power introduced into the reactor;

6. The review showed that there are no propulsion systems with acceleration of the working body in the high-frequency gap between the volume resonators, which indicates a high degree of originality and novelty.

5. Conclusion
The ion thruster being developed with a gap acceleration of ions in a high-frequency electric field opens up the possibilities of accelerator technology in a new field –the field of thrusters building for unmanned small spacecraft. Tests of the prototype of the first accelerator system of such propulsion systems showed that at a power consumption of up to 5 W (3 W for a microwave-plasma generator and 1 W for creating a potential difference of 165 V), an ion thrusters with a speed of 35 km/s with a theoretical thrust of 0.02 microns was obtained.

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