# SSC ZOND with APPT-95 Based EPS

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**Abstract: Ablative Pulsed Plasma Thrusters (APPT) have more than 50 year history of the development and application. APPT are simple, low mass, flexible power level, high specific impulse and low cost devices. Last developments of APPT have resulted to appearance the thrusters in energy range 30 J -150 J with thrust efficiency from 15 to 40%. These are high promising thrusters to serve as the base of OCPS for SSC LEO applications. Paper presents the description of planned APPT propulsion system application in ZOND satellite. This SSC is included to IONOZOND constellation having also 4 satellites IONOSFERA. IONOZOND constellation is created JSC "Corporation" VNIIEM". The main tasks of considered SSC constellation are: the monitoring of ionosphere state, magnetosphere and solar activity. It is planned the diagnostics of corpuscular, electromagnetic radiation, acoustic waves and ozone. SSC ZOND should operate on circular sun-synchronous orbit (SSO) with a height of about 650 km to be synchronized with IONOSFERA satellites. Earlier, stationary plasma thrusters SPT-50 were planned to apply in SSC ZOND. Produced analysis has shown that APPT-95 based OCPS is capable to correct launch errors and perform the synchronization with IONOSFERA satellites.**

## I. Introduction

Information obtained from spacecrafts is very important to study the processes occurring on the Earth and near-Earth space. Observations from space yields information about the processes in the sun, in interplanetary space, in the atmosphere, on the earth's surface, and in the lithosphere of the Earth. The response of the ionosphere state on solar and magnetosphere disturbances, current systems behavior in the polar and equatorial regions, the dynamics of circulations of the middle and upper atmosphere are well-known factors. In recent years, new information about various modifications of the ionosphere associated with its heat, approaching earthquakes, ground-based chemical and underground nuclear explosions, launch and operation of space objects has been added[1]. For these works SSC constellations exhibit great interest due to rather low cost their development and manufacturing, as well as the price reduction of the orbital injection. Quite a number of small LEO constellations having SSC mass from 60 to 500 kg are now under consideration and development in Russia. Due to the urgency of the above studies of atmospheric and ionosphere

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processes, Russian 'VNIIEM Corporation' by order of the Federal Space Agency creates space constellation IONOZOND, intended to monitor the geophysical conditions ("space weather"), by measuring the basic parameters of the processes in the upper atmosphere, the ionosphere, magnetosphere, solar activity. The data will be transferred to the Earth for processing and dissemination of information for RF Hydrometeorology, Roscosmos, Russian Emergencies Ministry, Ministry of Communications, Ministry of Transport, etc.

IONOZOND constellation includes 4 satellites "IONOSFERE" and 1 SC "ZOND". IONOSPFERE satellites constellation is designed for the operational monitoring of the magnetosphere and ionosphere. In [2] the description of IONOSFERE propulsion system is given. Orbit correction propulsion system (OCPS) on the basis of APPT-95M, having the most acceptable characteristics has been selected. APPT-95M OCPS flight model has high level of readiness and is under qualification testing. The existence of single satellite ZOND on the target orbit for the duration of lifetime is possible in uncorrected mode, but it needs to maintain a phase position with IONOSFERA. This requires the use of OCPS with a relatively small total impulse required sustaining the phase shift between the spacecrafts.

The paper describes the spacecraft ZOND, the main characteristics of constellation "IONOZOND", the parameters of the OCPS of SSC ZOND based on APPT-95M, developed in RIAME. Prospective of APPT applications in some planned in Russia LEO SSC missions are given.

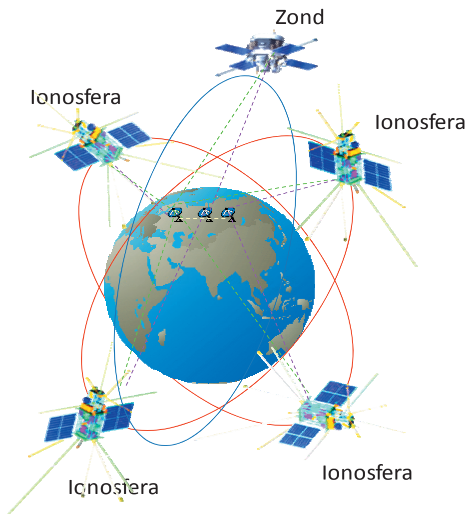


**Figure 1. SC IONOZOND constellation.**

## II. SC ZOND in IONOZOND Mission

IONOZOND constellation (Fig. 1) includes 4 SC IONOSFERE and one SC ZOND. The SCs IONOSFERE is designed for the operational monitoring of the magnetosphere and ionosphere.

**Table 1 - Main characteristics of the SC "ZOND**

| № | Parameter | Value |
|---|---|---|
| 1 | Orbit | Circular sun-synchronous |
| 2 | Average orbital altitude | ~ 650 km |
| 3 | Inclination | 97 degrees |
| 4 | Revolution period | 98 min |
| 5 | Mass / Payload mass | 500 kg/105 kg |
| 6 | Dimensions | 1600 x 1400 x 1400 mm |
| 7 | Lifetime | Not less than 8 years |
| 8 | Orientation | Triaxial, Sun - Earth |
| 9 | Orientation accuracy to Sun | better than 3', |
| 10 | Stabilization accuracy | better than $10^{-3}$ deg / sec |
| 11 | Orbit correction | To maintain the orbit phase of the SC located in the same plane |
| 12 | Accuracy of the orbital position of SC center of mass | 100 m (only on-board equipment ), 10 m (on-board and ground-based ) |
| 13 | Average consumption service equipment (average/maximal) | 100/120 W |
| 14 | Average consumption of the target hardware (average/maximal) | 100/255 W |
| 15 | Solar array power | > 700 W |
| 16 | Information transmitted | Up to 20 GB / day |
| 17 | Lunch type | Joint |

The main tasks of SC ZOND are monitoring of the ionosphere, atmosphere and solar activity. Accordingly, SC ZOND has solar pointing and SC IONOSFERE is earth oriented. Characteristics of SC IONOSFERE in detail are given in[2]. Initially, it is proposed to create SC ZOND on the basis of "Canopus - V". Today, it is planned to produce SC ZOND similar to SC IONOSFERE. It based in the same platform and should operate on circular sun - synchronous orbit (SSO), with a height of about 650 km. SC ZOND mass is equal of 500 kg with payload of 105 kg. Characteristics of the SC ZOND are presented in Table 1. Layout of the SC ZOND in orbit is shown in Fig. 1. Appearances of SC ZOND in a transport position and in orbit position are shown in Figure 2 and Figure 3, respectively.

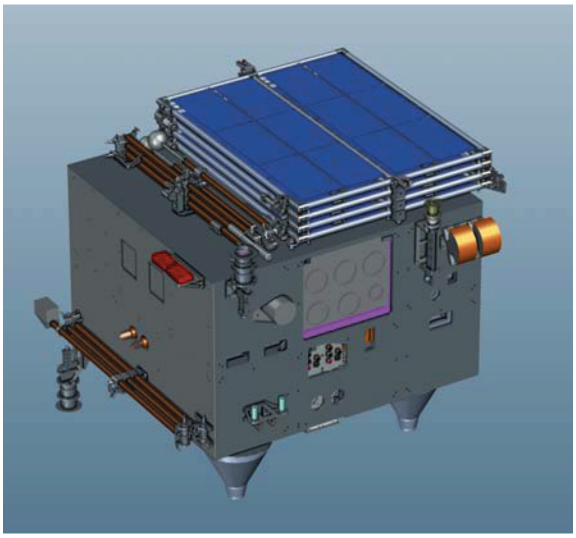

**Figure 2. SC ZOND in a transport position.**

**Figure 3. SSC ZOND in a space position.**

## III. EPS Based on APPT

Ballistic analysis of IONOSOND mission has shown that the existence of a single SSC on the calculated target orbit for planned service life is possible without correction. But maintenance of a group phase position requires the use of OCPS. A comparative analysis of different types of OCPS showed that a relatively small total impulse (26 kN) required for sustaining the phase shift between spacecrafts can be provided with OCPS based on Ablative Pulse Plasma Thruster (APPT) with redundancy of acceleration channel, developed earlier in RIAME[3,4]. This OCPS is simple and low cost compared to, for example, SPT-50 based OCPS used in CANOPUS - V.

**Table 2. Main characteristics of the ZOND OCPS based on APPT- 95.**

| № | Parameter | Value |
|---|---|---|
| 1 | The total thrust impulse kNs (including 2 acceleration channels) | 42 |
| 2 | Thrust, mN | 3,6 |
| 3 | Specific impulse, s | 1600 |
| 4 | Power consumption, W | 175 |
| 5 | Time to realize nominal value of a thrust from moment of the command to switch on of OCPS, s | 1,0 |
| 6 | Total mass (with propellant and fixing elements), kg | 19 |
| 7 | Structural configuration | Monoblock together with PPU |
| 8 | The share of time spent to carry out the correction, (8 years service), % | 3,0 - 5,0 |
| 9 | Working voltage of capacitors, V | 1500 |
| 10 | Energy stored in capacitors, J | 155 |
| 11 | Readiness to execute commands after the power supply switch on, s | Less than 1 |
| 12 | The total number of pulses during operation | Not less $20 \times 10^6$ |
| 13 | Total number of switching during the operation | Not less 4000 |

ZOND OCPS are analogous to RIAME designed and built two OCPS prototypes developed on the basis of APPT-95[3], successfully passed acceptance tests. One thruster transferred to VNIIEM Corporation, where it passed integrated testing. The second sample is designed for qualification testing. The sample was tested for compliance with the Technical Requirements, and also for resistance to mechanical stresses. A considerable amount of qualification testing, which requires working off ZOND OCPS in a vacuum, is made on RIAME vacuum stand. Table 2 summarizes the main characteristics of the ZOND OCPS. Advantages of OCPS are a constructive simplicity and convenience in the dynamic control. It made in the form of monoblock, they have not storage and propellant supplying unit together with additional elements (valves, gear jets, etc.). Also, they do not require special measures to prepare the work, and the nominal mode is set almost immediately after the command to activate the thruster.

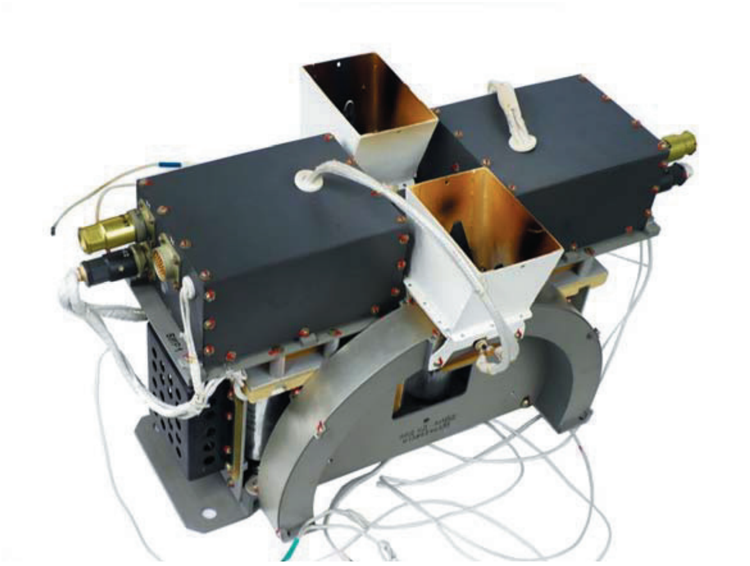

**Figure 4. EPS based on 2-channel APPT**

Structurally, ZOND OCPS (Figure 4) is also similar to IONOSFERE OCPS. It fits well with the spacecraft frame design of rectangular shape. The drawback of this OCPS is relatively low thrust, which lead to an increase in the time for orbit correction maneuvers. However, in general, for ZOND and also for IONOSFERE SC, estimated time spent on carrying out the correction is small, it is not exceeds 3 - 5% of the residence time of the SC in orbit. This is quite acceptable. The design feature of ZOND OCPS is full redundancy. This fact, as well as the use of digital system orientation, providing the turns of spacecraft and the presence of the drive of solar cell allow for the installing only one thrust unit (X - axis). The correction in the opposite direction can be provided on 180-degree rotation of the spacecraft.

## IV. APPT Prospective for LEO Applications

As known, the possibility of the electricity production at SSC is limited. The electric power available for on-board EPS usually does not exceed of 200 W. The experience in producing of EPS based on SPT having power level of 200 W and below show that their specific characteristics are reduced. At power levels below 100 W, these thrusters are inefficient and their working process becomes unstable. Difficulties with the development of a simple effective and inexpensive low-power electric thruster increased the interest in APPT R&D having stable operation at powers from a few Watts. However, low efficiency of this thruster leads to a restriction of its field of application by power levels that significantly smaller of 100 W. At the same time realistic goals of SSC missions, require the use of EPS with power of 100 - 200 W.

The selection of APPT for SSC orbital control became possible due to considerable progress reached in researches and development of the competitive APPT. This thruster having thermal operation mode was the first application of electric propulsion in space 50 years ago[5]. Now APPTs with bank energy in a range (20-100) J are electric propulsion devices working mainly in electromagnetic mode of operation, that have increased specific impulse on the level of (850-2200) s. Experiments have shown relatively high efficiency of input energy transfer to energy of directed plasma flow. Main energy sinks for losses are in electrodes, energy source and plasma irradiation. Optimization of APPT performance have been done due to finding the optimum relations between the electric circuit parameters and the discharge channel dimensions, realizing the quasi-aperiodic discharge in the thruster and optimizing the current distribution in the discharge channel[6,7]. Upgraded APPTs have a very competitive characteristics among other thrusters planned for SSC. Actually, today APPT is one of the most promising technologies for on-board propulsion to achieve good performances.

Engineering samples of the APPT with improved efficiency have caused interest in the organizations of space industry that allowed transferring the work to the stage of R & D and to create Technical Specifications for some

enterprises Roskosmos and produce flight prototypes of EPS based on APPT, with the realization of full cycle of ground testing. There is the number of Russian space projects, including the use of low-orbit SSC:
- IONOZOND project creates a satellite system of five satellites weighing 350 - 400 kg each;
MONITORING-SG, having up to nine SSC weighing 150 - 200 kg each;
MKA-FKI a series of SSC having weight from 120 kg to 240 kg is under space testing.
All these projects will use APPT based EPS.

**Table 3. Characteristics of EPS based on APPT developed in RIAME.**

| EPS Type | APPT-20 | APPT -45-2 | APPT -155 | APPT -95 |
|---|---|---|---|---|
| Status | Flight prototype | Flight model | Flight model | Flight model |
| Bank energy, J | 20 | 55 | 88 | 155 |
| Maximal working frequency, $s^{-1}$ | 5 | 3 | 2 | 1 |
| Power, W | 60 | 75…150 | 70…140 | 170 |
| The number of pulses | $2{\cdot}10^6$ | $1{,}67{\cdot}10^7$ | $1{,}5{\cdot}10^7$ | $1{,}5{\cdot}10^7$ |
| Specific Impulse, s | 716 | 1100 | 1320 | 1600 |
| Thrust, mN | 0,9 | 1,44…2,9 | 1,4…2,8 | 3,5 |
| Total impulse, kNs | 0,7 | 20 | 30 | 52 |
| Total EPS mass, kg | 3,0 | 10,5 | 14 | 20 |
| Thrust/mass, mN/kg | 0.3 | 0.274 | 0.2 | 0.175 |

Currently, RIAME has developed a number of propulsion systems with discharge energy from 8 J to 155 J. The main characteristics of some EPS are presented in Table 3. All propulsion systems planned to correct and maintain LEO SSC. Developed EPS are based on upgraded APPT models in a range of bank energies (20 - 100) J. These optimized thrusters are electric propulsion devices working mainly in electromagnetic mode of plasma acceleration when magnetic pressure exceeds the gas-kinetic one, and plasma is accelerated mainly due to the Lorentz force[6,8]. This mode has an increased specific impulse on the level of (850-2200) s. Also, tests have demonstrated relatively high efficiency of input energy transfer to energy of directed plasma flow. Main energy sinks for losses are in electrodes, energy source and plasma irradiation. As a whole the family of high efficiency APPT have been studied and developed.

Thrust cost of APPT based EPS in dependence of power consumption and total impulse to EPS mass ratio depending on the EPS mass for a number of the flight EPS models developed in RIAME are given in Figures 5, 6. It is seen that beginning from power consumption at the level of 50 W thrust cost is stabilized at 50-60 W/mN. So, for high power APPT, average thrust is almost linearly dependent on the power consumption. A slight deviation from linearity is due to increasing specific impulse with increasing discharge energy. At the same time specific impulse exceeds 1000 s, providing significant mass saving. Fig. 6 illustrates modern status of mass characteristics of APPT based EPS. It is seen, these are practical and effective with EPS mass at the level more then 7-10 kg. Accordingly, competitive ability of considered EPS is relatively high, especially, for SC with mass more than near 100 kg.

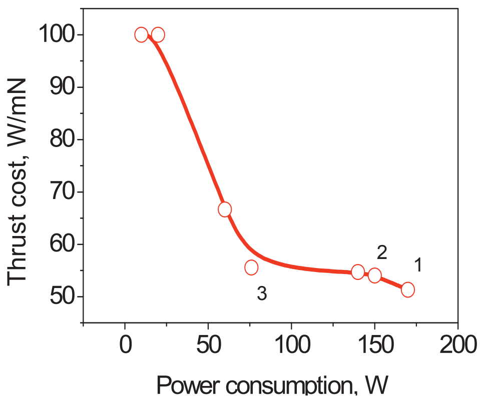


**Figure 5. Thrust cost of APPT based EPS. 1- APPT -95. 2 - APPT -155, 3 - APPT-45-2.**

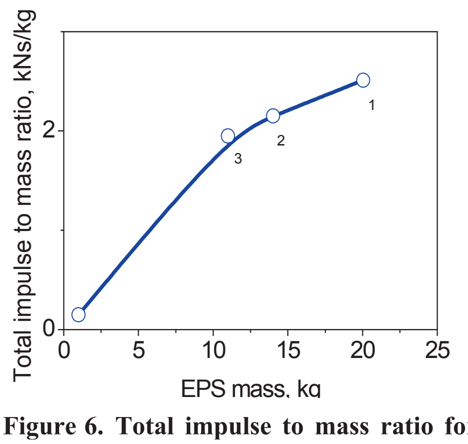


**Figure 6. Total impulse to mass ratio for a number of APPT based EPS. 1- APPT -95, 2- APPT -155, 3- APPT-45-2.**

## V. Conclusion

Analysis of tasks and a number of candidates for orbit correction propulsion systems for SC ZOND has shown that OCPS based on APPT-95M is acceptable. As a result the launch correction and phase position of IONOZOND constellation can be based on developed, designed, and produced OCPS flight model based on APPT-95. Qualifications testing of OCPS flight prototypes are carried out.

Developed APPTs in discharge energy range of 30- 150 J are low cost robust and high promising hardware to serve as a base of OCPS destined for SSC LEO applications.

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