IONOSFERE Satellite with APPT Based EPS

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Nickolay N. Antropov[1]
Research Institute of Applied Mechanics and Electrodynamics, 4, Volokolamskoye shosse, Moscow, 125810, Russia,

Michael N Kazeev[2]
National Research Centre Kurchatov Institute, 1, Kurchatov sq., Moscow, 123182, Russia

and

Vladimir P. Khodnenko[3]
'VNIIEM Corporation' JSC, 101000, P.O. Box 496, Moscow, Russia

Abstract: Paper presents the description of planned APPT propulsion system application in IONOSFERE satellites. These form IONOZOND SSC constellation having 4 satellites. IONOSFERE is created JSC "Corporation" VNIIEM". The main tasks of considered SSC constellation are: the monitoring of the ionosphere state, magnetosphere and the Sun and solar activity. It is planned the diagnostics of corpuscular, electromagnetic radiation; acoustic waves and ozone. SSC IONOSFERE, included in IONOZOND constellation should operate on a circular sun-synchronous orbit (SSO) with a height of about 800 km and located in two orbital planes (two satellites in each plane). Satellites in each plane should be separated by an angle ~180°.

I. Introduction

Space-based information is one of the most important means of studying the processes occurring on the Earth and near-Earth space. Observations from space yield 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 magnetospheric disturbances, current systems behavior in the polar and equatorial regions, the dynamics of circulations of the middle and upper atmosphere has been well -known factors. In recent years, new information about the 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]. Due to the urgency of the above studies of atmospheric and ionospheric processes, Russian 'VNIIEM Corporation' by order of the Federal Space Agency creates space constellation (SC) "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 and the transfer of the data to the Earth for receiving, processing and dissemination of information for consumer RF Hydrometeorology, Roscosmos, the Russian Emergencies Ministry , the Ministry of Communications , Ministry of Transport , etc.

Space segment "IONOZOND" includes 4 satellites "IONOSFERE" and 1 SC "ZOND". IONOSPFERE satellites constellation is designed for the operational monitoring of the magnetosphere and ionosphere. The existence of

[1] Head of Department, e-mail: riame3@sokol.ru.
[2] Head of Laboratory, e-mail: kazeev@nfi.kiae.ru.
[3] Chief Scientist, e-mail: vniiem@orc.ru.

single satellite IONOSPFERE on the target orbit for the duration of lifetime is possible in uncorrected mode, but it needs to maintain a phase position of two devices. This requires the use of orbit correction propulsion system (OCPS). A comparative analysis of different types of OCPS showed that a relatively small total impulse (26 kN) required sustaining the phase shift between the two spacecraft can apply for these purposes OCPS based on Ablative Pulse Plasma Thruster (APPT) with redundancy of acceleration channel. This thruster named APPT-95 has been developed in RIAME. The paper describes the spacecraft «IONOZOND ", the main characteristics of constellations "IONOSFERE", the parameters of the OCPS, and the flight prototype APPT - 95M, developed and produced directly for "IONOSFERE" SC on the base APPT-95.

II. Missions Description

The main tasks of spacecraft "IONOZOND" are:

- monitoring of the ionosphere;
- monitoring and control of Sun and solar activity;
- monitoring of the magnetosphere condition;
- diagnostics of wave activity (electromagnetic and acoustic waves);
- diagnostics of corpuscular ionizing radiation;
- diagnostics of Ozone.

Space segment "IONOZOND" (Fig. 1) includes 4 SC «Ionosphere " and one satellite "Zond" The constellation of the SCs "Ionosphere" is designed for the operational monitoring of the magnetosphere and ionosphere.

SC should operate on circular sun - synchronous orbits (SSO), with a height of about 800 km and locate in two orbital planes (two satellites in each plane). Satellites in each plane should be separated by an angle 180° $\pm$ 30°. One of the planes of the orbits is located in the plane of the Earth's terminator (two spacecraft "Terminator "), and the second - at an angle of approximately 90 degrees to the terminator (two satellites "Meridian"). Planned changing the of the orbital plane position for SC life time not exceeded 10°. Layout of the SC «ionosphere" in orbit is shown in Fig. 1.

Characteristics of the SC "Ionosphere" are presented in Table 1.

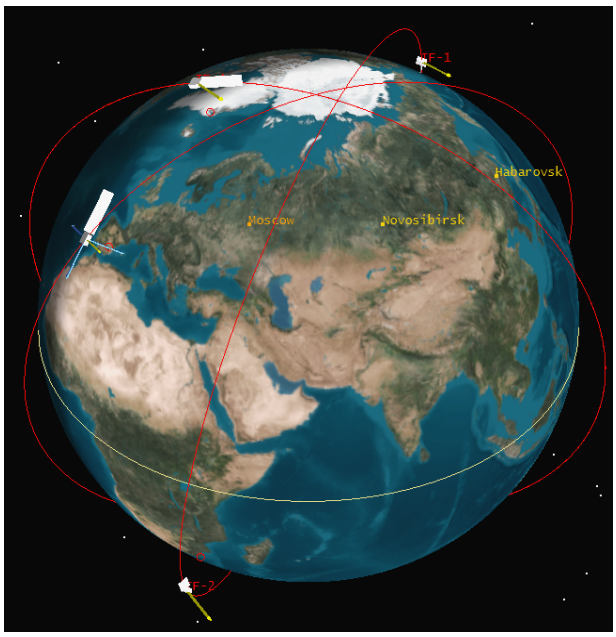

Figure 1. SSC IONOSFERE.

Table 1 - Main characteristics of the SC "Ionosphere"

№	Parameter	Value
1	Orbit	Circular sun-synchronous
2	Average orbital altitude	~ 800 km
3	Inclination	98 degrees
4	Mass	400 kg
5	Payload	100 kg
6	Orientation	Triaxial to Earth , to the SC velocity
7	Orientation accuracy	better than 0.5° , if necessary, better than 0.1°
8	Stabilization accuracy	better than 5 x 10-3 deg / sec
9	Orbit correction task	To maintain the orbit phase of the SC located in the same plane
10	Accuracy of the orbital position of SC center of mass	100 m (only on-board equipment), 10 m (on-board and ground-based)
11	Average consumption service equipment	Up to 100 W
12	Average consumption of the target hardware	Up to 150 W
13	Solar array power	> 700 Watt

14	Dimensions	1200 x 1200 x 800 mm
15	Information transmitted	Up to 20 GB / day
16	Control	One point
17	Lunch type	Joint
18	Lifetime	Not less than 8 years

Appearance of SC “Ionosphere” in the transport position in orbit is shown in Figure 2 and Figure 3, respectively. SC "Zond" is produced to observe the Sun, ionosphere and upper atmosphere. SC should operate on near- circular, SSO and near erminator orbit at an altitude of about 650 km. Assuming changing of the orbital plane for service life is not more than 10°. It is supposed to create SC "Zond" on the basis of "Canopus - V"[2].

III. APPT Based EPS

Ballistic analysis 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 of the two SC requires the use of OCPS. Comparative characteristics of a number of OCPS are shown in Table 2.

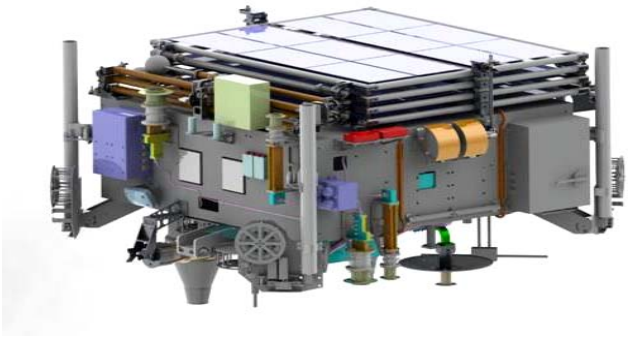

Figure 2. SSC IONOSFERE in the transport position.

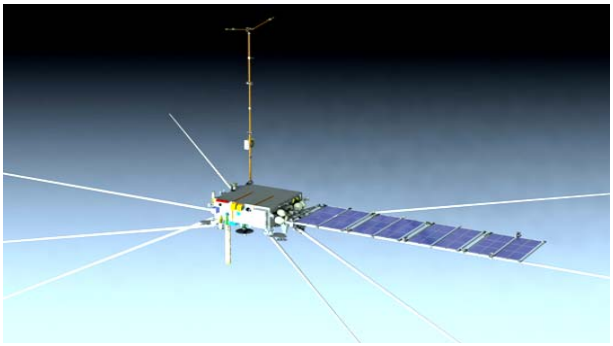

Figure 3. SSC IONOSFERE in a space position.

Table 2. Comparative characteristics of a number of OCPS

OCPS parameter	OCPS type					
	OCPS with xenon company SSTL	OCPS with APPT on PTFE NIIPME	OCPS on water propellant SSTL	Ammonium OCPS, VNIIEM Corporation	OCPS on hydrazine, DB "Fakel"	OCPS with xenon SPT DB "Fakel"
Total impulse thrust kNs	26	26	26	26	26	26
Specific impulse, s	60	1600	152	164	208	900
Thrust, mN	10-40	2,5-3,5	45	40	100	15
Power consumption, W	80	150	100	100	30	300
Propellant weight, kg	45	2	17	16	2,5	3
Total weight of OCPS, kg	68	16	30	28	38,5	22

A comparative analysis of different types of OCPS showed that a relatively small total impulse (26 kN) required sustaining the phase shift between the two spacecraft can apply for these purposes OCPS based on Ablative

Pulse Plasma Thruster (APPT) with redundancy of acceleration channel developed in RIAME. This OCPS is simple and low cost compared to, for example, SPT-50 based OCPS used in ”Canopus - V”.

RIAME designed and built two prototypes OCPS based on APPT-95[3-4] (OCPS-95), successfully passed acceptance tests. One thruster transferred to the VNIIEM Corporation, where it passed integrated testing in the electrical layout of the “Ionosphere” SC. The second sample is designed for qualification testing. The sample was tested for compliance with the requirements of the Technical Requirements, and also for resistance to mechanical stresses. A considerable amount of qualification testing, which requires working off OCPS-95 in a vacuum, is made on RIAME vacuum stand. In 2012-2013 the modernizations of the vacuum stand IU-1 with replacement of vacuum equipment produced that allows performing the planned full-scale life tests. Table 3 summarizes the main characteristics of the OCPS - 95. Table 3 summarizes the main characteristics of the OCPS - 95.

Table 3. Main characteristics of the OCPS based on APPT- 95.

№	Parameter	Value
1	The total thrust impulse kNs (including reservation of the acceleration channel)	52
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 $20x10^6$
13	Total number of switching during the operation	Not less 4000

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.

Structurally, OCPS - 95 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 «Ionosphere", estimated time spent on carrying out correction is small, not exceed 3 - 5% of the residence time of the SC in orbit. This is quite acceptable. The design feature of OCPS - 95 is full redundancy. This fact, as well as the use of digital system orientation, providing the turns for spacecraft and the presence of the drive of solar cell (SC) allow for the installing only one thrust unit (X - axis), and the correction in the opposite direction can be provided on 180-degree rotation of the spacecraft.

A. APPT-95M Flight prototype

APPT-95M and OCPS as a whole is created by well-known Russian space company, JSC "Corporation" VNIIEM "according to initial data and with the active participation of the RIAME MAI. Participation of space industry organization having advanced technologies in APPT-95M development is driven by the need to provide the required long-term operation unit. “Ionosphere” must have 8 years reliability for all on board systems. For the same reasons, the creation of the power supply and control (PPU-150) is tasked with the Russian company "AVEKS", specializing in the design and creation of on-board electronics for aviation and space technology.

APPT-95M is a modification of APPT-95. Energy of the storage unit has been increased up to 150 J. The need of the modification is due to the increase of SSC "Ionosphera" project mass from 280 kg to 400 kg. A significant change of storage unit energy required additional experimental testing. Tests revealed the existence of significant discharge current binding to the metal structural elements in the vicinity of the discharge channel. Significant current bindings have lead to decreasing of thrust and specific characteristics of APPT-95M. These became lower than those obtained in the APPT-95 with the discharge energy ~ 100 J.

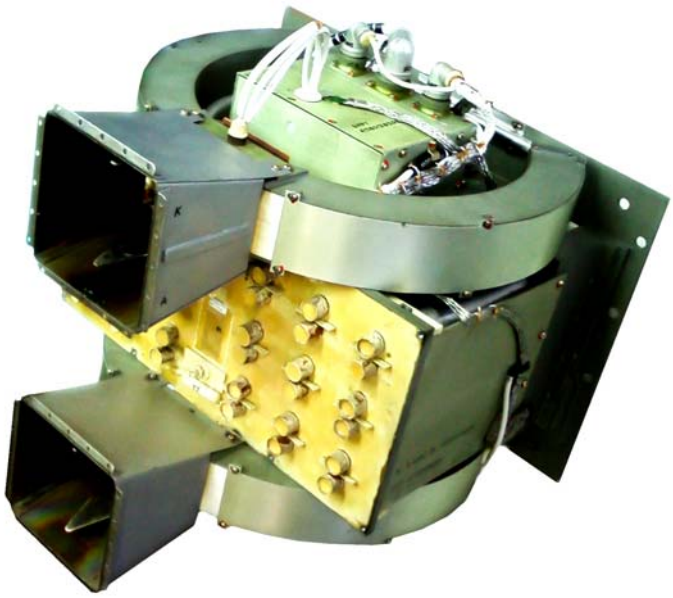

Figure 4. APPT-95M based EPS.

To eliminate the current bindings some changes were made in the geometric parameters of several components. APPT-95M top board (the main component of the engine power) and a screen that protects the SC elements located in the near zone of discharge channels from the deposition of carbon changed. The changes consisted in the maximum increase the distance from the metal to the discharge current distribution area, which was much wider than the area occupied by the electrodes of the accelerating channel. Removal of metal from the discharge area led to a dramatic decrease in losses of the discharge current and to growth of thrust and specific characteristics. These became close to the calculated values. As a result, the impulse bit of APPT-95M became 3.6 mNs and specific impulse-1700 s.

IV. Conclusion

Based on the analysis of a number of candidate orbit correction propulsion systems for SC "Ionosphere", OCPS on the basis of APPT-95M was selected. APPT-95M OCPS flight model have been developed and designed. The object is to maintain a phase position of two SC "Ionosphere». Qualifications testing of OCPS flight prototypes are carried out.

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