The use of EPS in Russia began in 1964, when Pulsed Plasma Thrusters provided the attitude control on board of ZOND-2 spacecraft. Spacecraft METEOR was flown in 1971, having on board the Stationary Plasma Thrusters for the orbit maintenance. Since this moment SPTs are begun in Russia. In 1982 several SPT-70 were flown on KOSMOS and LUCH geostationary spacecraft to perform the station-keeping task. In 1994, new geostationary spacecraft GALS and EXPRESS carried SPT-100 based EPS, providing the accurate East-West and, first ever, North-South station-keeping. Principal parameters of this EPS: thrust - 83 mN, power - 1500 W, total thrust impulse - 750 kNs.

In 1992-1994, the SPT-100 qualification testing for conformance to Western standards was accomplished, including the unique life test, which went uninterrupted for 7440 hours. The thrust was stable at 81-83 mN level without degradation, efficiency - 45-47%, total thrust impulse - >2x10⁶ Ns. SPT-100 status is fully operational.

The SPT-100 modification - SPT-100N - is under study. At 1350 W power - thrust 86 mN, exhaust velocity - 19400 m/s, efficiency - 58%, plume aperture angle, containing 90% of ion current, - 30°.

Introduction

Design and Study of SPT at "Fakel" began in 1964. The idea of Prof. Morozov about extended acceleration zone with closed electron drift was put in basis. Work went on with close cooperation of Kurchatov Institute of Atomic Energy (A.I. Morozov, L.A. Artsimovitch, Y.V. Esipchuk), Moscow Aviation Institute, including RIAME (D.D. Sevruk, G.A. Popov, N.P. Burgasov, L.A. Latyshev, V.B. Tihonov) and MIREA (A.I. Bugrova). By 1971 study and experimental development were accomplished, and in December, 1971, METEOR spacecraft was launched carrying two SPT-60 for orbit maintenance.

All works were funded from USSR government space development fund.

Scientific reports with all analytic and experimental results since 1977 were presented in NIITP and TSNIMASH according to regulations.

SPT-70 have been flying since 1982 and SPT-100 - since 1994.

Level of design solutions, manufacturing and test quality allowed to delete special flight demonstration. All thrusters performed real work, and normal operation of spacecraft was not interrupted in no case.

During almost 25 years long use of SPTs, these thrusters did not change significantly as to operation process. FAKEL's efforts were directed at life increase (use of more environment resistant materials, improvement of specific part interfaces and technology).

In 1991 FAKEL started to study Western specifications on SPT and to determine action items and schedule of thruster qualification and accomplishment of these items.

Western standards have been incorporated in the following:
- due to more strict requirements on outgassing, several coatings and nonmetallic materials have been replaced with other acceptable Russian materials;
- thermovacuum cycling and random vibration were incorporated in acceptance test;
- full scope qualification test was completed at FAKEL (mechanical, thermovacuum, fire); mechanical stress was substantially higher than in Russian standard requirements;
- complete package of design and technological documentation was issued to satisfy the requirements of Western standards and Specification of International Space Technology, Inc. (ISTI).

In March, 1991, having completed qualification
testing successfully, FAKEL by the order of ISTI started to manufacture first ten thrusters for operation on Western spacecraft. Manufacturing will be completed in 1995.

At the same time FAKEL is working on SPT modernization to newly developed specification and on development of highly reliable and efficient PSMA, that would provide for significant improvement of SPT propulsion system performance.

**EPS with SPT for Russian spacecraft**

First generation EPS have been flying in 70-es on METEOR and METEOR-PRIRODA spacecraft. [1] They contributed significantly to development and application of SPT in space technology: demonstrated reliable SPT operation, good relationship between practice and ground test results and lack radio interference and adverse effect on spacecraft systems. These EPS based on SPT-60 and SPT-50.

For second generation EPS, FAKEL with RIAME MAI developed new module SPT-70 (Fig. 4), which completed the qualification testing both independently and within EPS. Second generation EPS on KOSMOS and LUCH spacecraft began in 1982 and have been continuing till this time. SPT-70 provide accurate orbit maintenance of geostationary satellites and east-west station-keeping.

Second generation EPS demonstrated high reliability of SPT, good integration with spacecraft systems, including operation with TOPAZ reactor, and provided for increase of spacecraft payload. In the first time SPT delivered station-keeping function; it stayed in constant readiness and provided almost immediate transit to operation mode. SPT-70 demonstrated life of 3100 hours and remained fully operational.

Expected life of SPT-70 is 5500 hours.

The position of EPS on LUCH spacecraft is pictured in Fig. 5.

For third generation EPS, FAKEL developed and qualified SPT-100 module (Fig. 6). SPT-100 have been flying on Russian spacecraft GALS and EXPRESS since January 1994, providing spacecraft insertion into specific point on orbit and east-west and north-south station-keeping. [2]

Fig. 7 shows EPS units separately and mounted on spacecraft.

Total quantity of SPT, operated in space, is indicated in chart (Fig. 9).

**Qualification of SPT to Western standards.**

Modified SPT-70 for Russian spacecraft COUPON and YAMAL have completed qualification testing at FAKEL. These thrusters have increased life and reliability. Russian customers received first SPTs and propulsion systems. These SPTs are intended for east-west and north-south station-keeping on board of geostationary communication satellites.

FAKEL developed a full SPT model row from 350 W SPT-50 to 25 kW SPT-290 (Fig. 10), which parameters are summarized in Table 1.

Completed life test of SPT-100 provided a more clear data on life of specific models, because relationship of total impulse of neighboring models in the row is known and is by a factor of 3. [3] Expected parameters of SPTs are provided in Table 2.

Modules SPT-50, SPT-70 and SPT-100 are flying. SPT-140, SPT-200 and SPT-290 are engaged in several projects. [4]

FAKEL developed several cathode models. KE-5 and KN-3 are being used with SPT-70 and SPT-100. K50A have been developed for powerful SPTs. [5]

SPT-100 completed qualification to Western standards at FAKEL. The results are discussed in [6]. Life tests completed at JPL (USA) and at FAKEL. 5700 hours at 6000 cycles obtained at JPL on single cathode. [7] 7440 hours life obtained at FAKEL. Both thrusters remained operational and performance complies with specification requirements.

**SPT investigation**

Low power modules SPT-50N, SPT-70N and SPT-100N are being tested at RIAME and FAKEL, which differ from normal SPT by conductive inserts at discharge chamber edge and significantly lower (in 1.5-2 times) lower plume divergence. [9]

1350 W SPT-100N thruster provides 86 mN thrust, specific impulse of 1940 s, efficiency 58% and plume angle, containing 90% of ion current, 30°.
SPT-70M and SPT-100M are being tested at FAKEL to develop a conventional SPT, having low plume divergence.

Fig. 11 shows comparison between parameters of plume of SPT-70 and SPT-70M, having different magnetic system configuration and magnetic field profile.

High power SPTs are being tested: SPT-140 and SPT-200, targeted at decreasing plume divergence and increasing efficiency and life.

RIAME have been tested two modifications of SPT-100 and SPT-160 with heaterless cathode. Performance is very close to conventional SPT. Expected life is up to 8000 hours. [10, 11]

**EPS subsystems with SPT**

Successful integration of SPT in world space technology depends not only on SPT itself, but on propulsion system subsystems as well - PSMA and PPU.

Specifically for Western customers SS/L developed and is qualifying a PPU for 2 SPT (Fig. 12), built without container.

FAKEL is developing a PMA, based on miniature electric valves with 30 g mass, designed for inlet pressure 150 at, and reducer with 240 g mass, stabilizing inlet pressure 6-150 at within 2.6±0.06 (Fig. 13).

One of Russian organizations is developing xenon tanks for 150 at operational pressure. Dry mass of such tank is about 10% of contained xenon mass.

New PSMA and PPU allow to develop a SPT propulsion system with dry mass by 1.5 time lower than of flying third generation SPT propulsion systems.

**SPT Dynamic Simulator**

The success of propulsion system usage depends heavily on completeness and quality of development and control both independent and on spacecraft.

On this purpose FAKEL developed SPT Dynamic Simulator for testing of PPU and propulsion system during development and testing phase, both independently and on spacecraft at manufacturer facility and on technical position. DS is a programmed computer-controlled device, equivalent of SPT electric load in start-up, overstress and stationary mode with simulation of discharge current ripple, maximally close to actual level.

Use of DS not only reduces time for PPU development, but also significantly decreases cost of development, because complex processes are excluded - vacuum test of SPT and Xe usage. Experience of work with DS-70 and DS-100 at SS/L demonstrated this and FAKEL received a positive report.

**Conclusion**

- SPT propulsion system on Xe have been flying successfully on Russian spacecraft since 1971.
- Totally during this period 21 propulsion system was flown with the following SPT modules: SPT-50 (2), SPT-60 (8), SPT-70 (60) and SPT-100 (16). All these propulsion systems have been developed and manufactured at FAKEL.
- SPT-100 completed qualification to Western standards. Life of 7440 hours at 6000 cycles on single cathode was demonstrated.
- New PPU and PSMA subsystems currently under development shall allow to increase efficiency of SPT EPS in 1.5 time.
- Dynamic Simulator of SPT is developed maximally close to actual SPT performance.

**Literature**


Table 1

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<td>5000</td>
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* - required by specification

** - experimentally proven

Table 2

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Fig. 5. EPS-70 for S/C "ALCH"
Fig. 8 "GALS" EPS-100 Units

Fig. 9

Fig. 10 Parametric Series. 1 SPT-50, 2 SPT-70, 3 SPT-100, 4 SPT-140, 5 SPT-200, 6 SPT-280

Fig. 11 SPT Plume Divergence

Fig. 12 SPT-100 PPC