Recent Progress in the USSR Electric Propulsion

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Abstract.

Since 1971 in the USSR the stationary plasma thrusters (SPT) are continuing to be utilized successfully. The main problem here for research scientists and engineers is to bring and verify thrusters resource up to 7-10 years.

Together with SPT in the combined plasma jet unit of space satellites and similar space apparatuses there is a significant interest now for electrothermal or thermocatalitic thrusters which have the lowest thrust pay (just a few units of Watts for a gram of thrust).

New promising results are received with magneto-plasmadynamic (MPD) thrusters, which allow to have the flow velocities in an order of value higher than in plasmatrons and the particles concentrations in an order of value higher than it in any other stationary accelerators. They are used widely in geophysical investigations, on satellites, for ballistic experiments and became indispensable in the technology of implantation of deposited material in a lining.

In these areas the pulsed plasma thrusters (PPT), which are actually MPD thrusters, can be considered as equal partners.

The MPD thrusters could be honoured to become the main performers for realizing the widely discussed recently international flight project to the Mars.

Starting 1971 the stationary plasma thrusters - SPT are continuing to be exploited successfully with "Meteor" type satellites / 1,2 /. Let us remind its scheme (Fig 1). At the level of consumed electrical energy about 0.5 kWt they create the thrust around 2 grams with specific impulse 2000 sec when working material is Xenon.

The system of collection and processing of measured information requires the transfer from a single satellite at conditionally synchronous orbit (satellite's passing of fixed region after some given time or after a definite number of turns) to the system of satellites from average height up to geostationary orbits / 3 /.

The utilization of EPS (Electric Propulsion System) solves the problem of development of similar space systems, providing the change or the stabilization of satellites relative placing in the system. The time of active functioning of EPS must be up to 7 - 10 years and must be verified by ground laboratory tests, in-spite of relatively difficult "heavy" shortened tests. It is clear that the real "firing" resource is less than the required time (7-10 years), but thruster must be ready to the next switching on. The summary impulse of EPS reaches several millions of Newton-seconds, and the thrust of EPS as the correction executing system has tenths fraction of Newton. The space apparatus energy capability composes Kilowatts of energy and will be increasing with time.

The thrust unsteadiness of EPS caused by shortened time of initial correction and increasing of accuracy of satellite correcting maneuvers, must be no more than 3-5% .The SPT dynamic characteristics, in particular, the activation time and after action time are determined by the requirement of operativity increase and must be no more than 1s and 0.3-1 Ns, correspondingly. The number of SPT switchings is required on a level of 10^4-10^5.

Together with SPT in combined EPS there is considerable interest to thermoelectrical or thermocatalitic thrusters working on hydrazine and ammonia, having the lowest thrust price (units of Watts for 1gram of thrust).

The new promising results were received with MPD (butt-end) accelerators, allowing to reach the plasma flow velocity in order of value higher than in plasmatrons or in electrothermal thrusters; also here particles concentrations are higher in order of value than in other stationary plasma accelerators. These high characteristics and pulsed plasma accelerators, which are in fact MPD-accelerators, allow to utilize them extensively in geographical studies on satellites and in ballistic experiments. The main problems which are solving here : physics of space plasma, investigation of structure and dynamics of artificial plasma creations in ionosphere, investigation of shock waves, plasma instabilities, induced stimulation of substorm phenomena, stimulated precipitation of captured particles, excitation of artificial luminescence of ionosphere, its

conductivity and so on.

The detailed analysis of results is published regularily in Soviet periodical scientific journals.

Let us give a small Table of most characteristic parameters of utilized Soviet accelerators / 4 / :

Table 1

N	Type of accelerator	Working material	Flow rate	Power, Energy
	Stationary Plasma Accelerators			
1	SPT	Xe	10^{-3} g/s	500 Wt
2	MPD	K	10^{-3} g/s	2.5 kWt
3	MPD	Air	$(1-3)10^{-3}$ g/s	3 kWt
4	MPD	Cs	0.3 g/s	4 kWt
5	MPD	Li	0.15g/s	15 kWt
	Pulsed Plasma Accelerators			
6	PPT	$BaCl_2$	10^{17} particles	100j
7	PPT	C_2F_4	10^{18} particles	600j
8	PPT	C_2F_4	10^{19} particles	1400j

The technological plasma accelerators discover quite a broad use in industrial applications. From the first industrial installations "Bulat", "Pusk", till appearance of modern advanced installations the different collection of means is accumulated for plating special covers and films, implantation and cementation, introduction into materials different other materials, creation of atomically pure surfaces, growing of different crystals and so on. The utilization of plasma accelerators provides the uniformity in width, the absence of porousity, the good adhesion with backing, the stability in time of perfoming characteristics, the mechanical strength, the thermal stability, the absence of impurities in pure metals films and conservation of stoichiometry composition in films of complex composition. One of new technology first users became the instrumentation industry because they found excellent proof of increasing in oder of value and more of instrument's wear resistance.

In the microelectronics (production of integral schemes and theirs elements), in the tensoprobes production, in the superconductivity technics, in the optical instruments production and other

spheres of technics the thin films of different types - conducting and dielectric, films of different composition found a very good application.

Few words on Marsian Program.

Now two space apparatuses "Fobos" are moving to Mars, in 1994 we expect to have there Marsian Balloons and Mars Vehicle, in 1998 the Marsian soil is planned to be returned to Earth and what else, we are waiting for preparations for Mars expedition (by the way the expedition was discussed during recent Moscow meeting of two leaders M.Gorbachev and R.Reygan).

In recent article by acad.V.P.Glushko et al. presented the following initial data for one year and half flight to Mars: for the start from the low Earth orbit of space ship using the chemical thrusters the initial mass of space ship will be 2500 tons, in case of nuclear thrusters with direct heating of working material, it will be 800 tons, but with nuclear electric propulsion - only 450 tons (Fig 2). Let us remind, that the useful loading, which can be transfered into near Earth orbit by rocket-carrier "Energia" (after it modification), will be 200 tons.

Even providing the acceleration in 10^{-4}g the summary EPS thrust will be 45 kg (450 N). It is clear that such propulsion system must be developed according to the module scheme. This is important factor for EPS reliability increase and for simplification of processing of each module unit.

At the characteristic resource of EPS in 10^4 hours and working material flow velocities up to 10^7 cm/s we can have the summary power in tens of MegaWatts.

As example of stationary high current MPD accelerator would be the thruster with Bismuth liquid-metallic cathode, shown in Fig 3. By the direct accelerators thrust and by the measurement of material flow the velocity plasma flow was determined and reached (4-6.5) 10^6 cm/s. At power supply voltage in 50-100 v the disharge current was 3-8 kA.

At common low voltage power sources placed on board of space apparatus such thrusters can be combined with them without any additional converters of high voltage in tens of MegaWatts.

As we could see from this brief review all mentioned developments in electric accelerators today already give very interesting results and later we expect much more.

It is worth to mention that in our country the regular USSR Conferences on Plasma Accelerators and Ion Injectors are continuing to have place.The last one was held in Dnepropetrovsk, September 16 - 18, 1986. About 160 papers were presented. The Conference showed more deep theoretical understanding of working processes and their's experimental support as in classical schemes of accelerators and a necessity for search of new schemes with new physical problems. For example, the group scientists, headed by Dr.V.E.Fortov / 5 /, studied the acceleration regimes of dielectric materials (in particular, polycarbonate with mass about 1g) and dynamics of plasma piston in the rail-type accelerator. It is shown that in such accelerator with length of electrodes about 1m the velocity can be reached up to 6km/s.

In order to give an impression on type of problems which were of main interest at last Soviet Conference, let us give the titles of 8 sections and a number of papers presented :

1. The accelerators with anode layer - 10 papers
2. The accelerators with closed drift of electrons and extended zone of acceleration - 28 papers
3. The ion and plasma-optical systems - 29 papers
4. The systems for plasma accelerators and ion sources - 14 papers
5. The high current plasma accelerators - 26 papers
6. The diagnostic methods - 10 papers
7. The numerical modelling - 15 papers
8. The applications of plasma accelerators in science and technology - 25 papers

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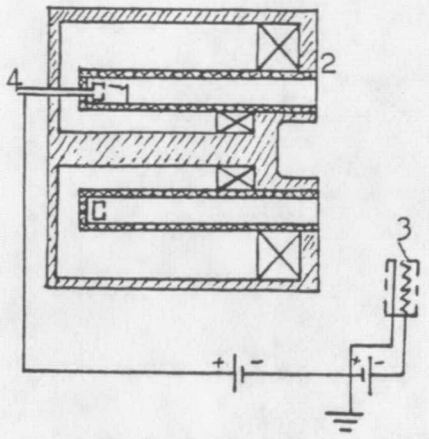

Fig.1 Accelerator with closed drift and extended zone of acceleration
1 - anode - gas distributor
2 - dielectric walls
3 - cathode neutralizer
4 - working material supply - Xe

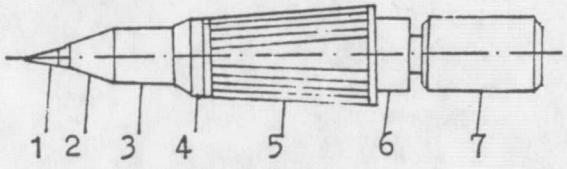

Fig.2 Electric Propulsion System (EPS) with nuclear reactor-generator :
1 - reactor-generator
2 - shield
3 - converter of electric energy
4 - EPS
5 - radiator- cooler
6 - room for equipment
7 - useful loading

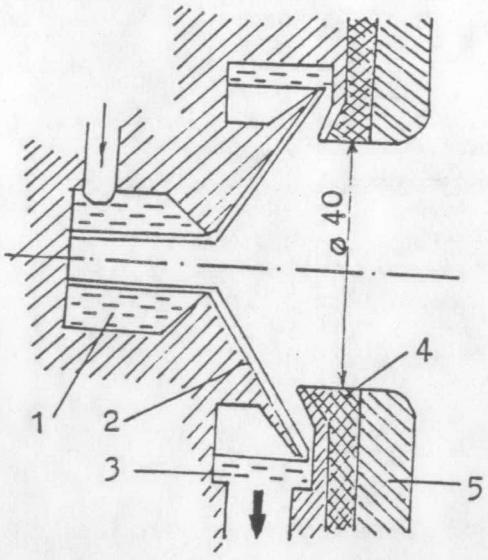

Fig.3 High current accelerator with liquid metal cathode
1 - centrfugal injector for liquid Bi
2 - conical cathode
3 - collector
4 - isolator
5 - anode

Active Experiments with Plasma Accelerators

Experiment title	Accelerator's parameters: working material flow	velocity km/s	working material	electron temperature, ev	Type of accelerator	Power or Energy	Main problems of experiment	Remarks
1	2	3	4	5	6	7	8	9
Ariel-1	10^{18} particls	5.7	$BaCl_2$	1-3	Electrothermal	100j	Magnetic field disturbances and its dependance on angle of injection; stimulated percipitation	Non-separated accelerator, injection parallel to geomagnetic H
Ariel-2	10^{17}	30	$BaCl_2$	1-3	Electrodynamic	100j	Radiophysical effects; artificial plasma creations	Non-separated accelerator ; injection accross to H
Ariel-3	10^{19}	10-15	C_2F_4	1-3	"same "	1400j	Plasma distribution in artificial creations; injection along and across to H	Same
Ariel-4	10^{19}	10-15	C_2F_4	1-3	same	1400j	Disturbances of electric and magnetic fields at plasma injection	Same
Ariel-5	10^{18}	10-15	C_2F_4	1-3	same	600j	Interaction with internal radiation belt; precipitation of protons	Separated accelerator injection accross H
Ariel-6	10^{18}	10-15	$BaCl_2$ with polyurethane	1-3	same	600j	Artificial disturbances of electric fields; electrostatic turbulence	Same plus injection along H

1	2	3	4	5	6	7	8	9
			MPD - Accelerators					
MPD-1 butt-end	0.1g/s	1	Cs	0.5	MPD	1kWt	Disturbances of electric field	Non-separated accelerator
MPD-2	0.3g/s	1	Cs	0.5	same	4kWt	Stimulated particles percipitation	Same
Aelita-1		10	Li	1-4	same	15kWt	Plasma distribution in artificial plasma creation	Non-separated accelerator; injection across H
Aelita-2		10	Li	1-4	same	15kWt	Artificial radiation of ionosphere and artificial plasma creations; disturbances of electric and magnetic fields; particle's percipitation	Separated accelerator; injection across H
Aelita-3		10	Li	1-4	same	15kWt	Generation of plasma turbulence, same as in Aelita-2	Separated accelerator, injection across H; use of regimes of generation of LF and HF radiations
Kust-1	$(1-3)\cdot 10^{-3}$ g/s		Air	1-10	same	3kWt	Influence of accelerator's work on SA potential	Non-separated accelerator
Kust-2	$(1-3)\ 10^{-3}$ g/s		Air	1-10	same	3kWt	same	same
Kust-3	$(1-3)\ 10^{-3}$ g/s		Air	1-10	same	3kWt	same	same
	Program with Hall accelerator on space satellites "Cosmos" series							
HA-1	10^{-3} g/s		K	1-2	same	2.5kWt	Influence of accelerator plasma flow on SA surface	Registration of deposited working material

1	2	3	4	5	6	7	8	9
Program with stationary plasma accelerator on space satellites "Meteor" series								
25th "Meteor"	3 10^{11} cm^{-3}	10-12	Xe	1-3	SPA with extended zone of acceleration	500Wt	Plasma flow interaction with ionosphere; dependance of flow scattering on injection pitch-angle	Flow injection along H in equatorial region and across H in polar region; registration of scattered flow and atmosphere ions
29th "Meteor"	3 10^{11} cm^{-3}	10-12	Xe	1-3	same	500Wt	Resonance heating of ionosphere ions at plasma injection across H; generation of LF and HF radiation	Registration of back scattered flow in four directions and atmosphere ions flow