IEPC-95-103

STATE OF THE ART AND FUTURE PROSPECTS OF COLLOIDAL ELECTRIC THRUSTERS

A.F.SHTYRLIN*

Abstract

This paper summarizes the research results on colloidal electric propulsion performed at Moscow Aviation Institute over the last 35 years.

Based on study of physical and engineering fundamentals of charged colloids electrostatic emission and emission cells with various diameters of the emission edges, there was developed a prototype of a flight unit which is a monoblock colloidal thruster of 0.5-1 mN thrust, 10^4 N·s total reactive impulse and 30 W DC power consumption from the onboard grid.

There has been shown usefulness of such thrusters for small and micro satellites of 25-250 kg mass and up to 1 W/kg onboard power and for the missions with ΔV 40-400 m/s as well as for reducing micro-accelerations of a satellite with rigid structure by 100-1000 times.

Nomenclature

a - acceleration
E - electric field intensity
F - thrust
I_{sp} - specific impulse
I - electric current
M_o - total mass of the satellite
$\dot{m}$ - mass flow rate
n - relative number
U - voltage
U_{br} - break-up voltage
V - velocity
ΔV - characteristic velocity
ρ - density
τ - time
$\Delta\tau$ - acceleration compensation system response time

The operating principle of a colloidal electric thruster was proposed by several scientists at the beginning of XX-century whereas scientific research in this field began in 1960. Basically, the efforts were concentrated in the USA, Russia and Western Europe. This paper presents the main results of research on this type of electric propulsion done at MAI over the last 35 years Physical and technical fundamentals of the thruster's operation are of electrochemical nature and the process occurs in strong electric fields at $E > 10^7$ V/m. There were obtained the calculation dependencies of the specific current emission per unit of the edge length

* - Moscow State Aviation Institute, Volokolamskoe sh., 4, Moscow, 125871, Russia

and particle specific charge as functions of the basic physical parameters. Energy balance and thruster's efficiency were studied [1,2].

Colloidal thrusters are referred to as micro thrusters, and compared to other types of electric propulsion, have low thrust cost, high thrust efficiency, moderate exhaust velocity, cold operation cycle and cheap and convenient working fluid.

Colloid thruster main parameters interconnection is shown in fig.1. Under both the measured accelerating voltage magnitudes to be in the range from 15 to 25 kV and experimentally obtained data for the particle specific charge of 200-10,000 C/kg the average pulse specific thrust forms 2,000-20,000 N·s/kg.

Fig.2 shows the generalized data on low power electric propulsion efficiency. Within the specific impulse range $(5\text{-}15)\cdot10^3$ N·s/kg the colloidal thrusters have the highest thrust efficiency being equal to 0.6-0.7. The parameters of considered colloidal thrusters are represented in the table 1 and they are taken from [2].

Table 1.

№	Power, W	Thrust, N	Specific impulse, N·s/kg	Voltage, kV	Specific charge, C/kg
1	5	$5\cdot10^{-4}$	10,000	15	3,330
2	15	$1.5\cdot10^{-3}$	10,000	15	3,330
3	100	0.011	10,000	15	3,330
4	250	0.020	15,000	25	4,500
5	10,000	0.780	15,000	50	2,250
6	25,000	1.270	23,000	100	2,650

The designed monoblock colloidal thruster shown on Fig.3 has the following performance: thrust up to 10^{-3} N, total impulse 10^4 N·s, specific impulse 10^4 N·s/kg, accelerating voltage 15 kV, specific charge of the particles 3,330 C/kg, the power consumed from the low-voltage onboard grid - 30 W, and mass 5 kg. Such thruster on small or microsatellites (25-250 kg) having the life time of 2,800 hours is capable of performing various flight tasks such as maneuvering, drag compensation, attitude and orbit control, the tasks with ΔV = 40-400 m/s, as it is shown on Fig.4. For example, a satellite, maneuvering around the Mir space station, may be equipped with a colloidal propulsion system. Nowadays it is feasible to build the colloidal thrusters of 0.1-50 mN thrust and 30-250 W power.

Some of the physical peculiarities of space conditions which stimulate development of space technologies using weightlessness are absence of gravitational convection, use of capillary forces of liquids and electrophoresis. On the basis of computational and experimental research sometimes for effectiveness of technological processes onboard the spacecraft the microaccelerations must not exceed 10^{-6}-10^{-4} m/s^2. In real conditions the external and internal forces acting in the Earth orbits cause

microaccelerations whose vector changes its direction in a three-dimensional space with an amplitude of 10^{-1}-1 m/s^2 and frequency of 400 Hz. Therefore, there is a need to develop techniques and structures to protect from such microaccelerations. An active way to reduce the microaccelerations onboard the satellites is proposed, it is done by means of electric propulsion, in particular, colloidal one [4]. Fig.5 shows the four blocks of thrusters having 5 vector thrusters each, and Fig.6 shows the computed data on microacceleration reduction depending on anti-phase propulsion system response time and frequency of disturbing pulsations. For rigid small satellites this technique allows to reduce the microaccelerations by 100-1000 times.

The developed sources of charged drops and scientific experience were used in thin polymer films technology. The electrostatic method of dispersing allows to obtain the dispersed polymer solution with the drop size of a micron and less. Electrostatic dispersion is possible only in a well-insulated gap between the electrodes. It can be reached in vacuum with pressure less than 10^{-2} Pa or in dense gas-air substance with the pressure more than 10^5 Pa [5,6].

During the experiments the solutions of polymethyl metacrylate (plexiglas), fluoroplast (teflon), polyimid resin and silicoorganics were dispersed. The parameters of these polymers are represented in table 2.

Table 2

Parameter	Plexiglas	Teflon	Polyimid	Silicoorganics
μ	$<2\cdot10^{-6}$	$2\cdot10^5$-$2\cdot10^6$	$5\cdot10^4$-$1.5\cdot10^5$	$4\cdot10^2$-$5\cdot10^3$
t_m, °C	70-90	260	300	350
ε	3.5-4.6	2.1	3.5	2.5-3.5
λ, W/m·K	0.183	0.24	0.148	0.13
ρ, Ω·m	10^{12}-10^{14}	10^{15}	10^{15}	10^{13}-10^{16}
γ, kg/m^3	1190	2100-2300	1350-1480	1300-1350

Fig.7 shows one of the experimental technological sprayers having 7 needles, and Fig.8 shows a histogram of polyimid film electric strength 4-μm thick. Average break-up voltage is about 1410 V and electric field intensity in the film is 350 MV/m.

The developed high-voltage technology of colloidal thrusters with operating voltage of 15-25 kV can be successfully used for ozone synthesis in the air. This process in the areas of the corona discharge which occurs on the sharpened electrode endings if the dielectric field intensity is sufficient for oxygen molecular dissociation, excitation and ionization by the accelerated electrons.

Three types of ozonizers are offered for constructor development: air ozonizers; ozonizers for automobile combustion engines; ozonizers of drinking water. Parameters of these devices are represented in the table 3.

Air ozonizers can be used for cleaning of technological equipment from different kind of surface films, reducing the amount of harmful exhausts into the atmosphere, desinfection of closed buildings i.e. hospital rooms, food storage. Automobile engines ozonizers improve the ignition, increase the efficiency of fuel use, improve the exhaust. Drinking water ozonizers are necessary for working with strong industrial biological and epidemic contamination for example in Russia, Middle East, Africa, Asia and South America.

Table 3

ozone productivity, g/hr	for air		for water		consuming power, W
	productivity, m^3/hr	ozone concentration, mg/m^3	productivity, l/hr	ozone concentration, mg/l	
0.1-5.0	5-250	5-100	25-250	4	25-350

Fig.9 shows the ozonized air generator GOV-01/40 with ozone concentration of 5-30 mg/m^3 and consumed power from the grid - 25 W, and Fig.10 shows volt-ampere curve of the discharge chamber. If the corona is positive the volt-ampere curve is very steep as compared to the negative corona.

At high-voltage corona discharge the air is accelerated and obtains a little of kinetic energy. For experiments there was used a single EHD cell shown on Fig.11 and which allows to change the basic geometry of the cell. The EHD parameters are shown on Fig.12. The experimental data of the velocities V^+ and V^- are little different from the theoretical velocity U_o, basically due to little gas-dynamic and electric losses. With a single cell the maximum velocity reached was 5 m/s and with a multi-stage cell - it may be significantly higher. Research is being carried out to increase the energy efficiency of this process.

References

1. A.F.Shtyrlin. Physics-chemic basis of the discharge creation under electrical atomizing the liquids with ion conductivity - Russian conference "Application of electron ion technology in industry. Physics and technics of monodisperse systems." Russia, Moscow, October 21-24, 1991.

2. A.F.Shtyrlin. Development of the Colloidal electric rocket engines in Russia - II-nd German-Russian conference on electric propulsion engines and their technical applications. Russia, Moscow, July 16-21, 1993.

3. G.Malyshev, V.Kulkov, A.Shtyrlin, I.Vyshedkevich, R.Bychkov. Comparative Analysis of Propulsion System for Small Satellites - 24th International Conference on Electric Propulsion. Russia, Moscow, September 19-23, 1995.

4. L.A.Latyshev, V.V.Savichev, A.F.Shtyrlin et al. Active way of reducing micro-accelerations of spacecraft by using electric thrusters - 24th International Conference on Electric Propulsion. Russia, Moscow, September 19-23, 1995.

5. M.A.Vinogradov, K.V.Evdokimov, L.A.Latyshev, A.A.Farmakovskaya, A.F.Shtyrlin. Deposition of thin polymer films using colloidal electrostatic sources - II-nd Russian conference "Modification of constructional materials with beams of charged particles." Russia, Sverdlovsk, May 21-24, 1991.

6. M.A.Vinogradov, A.A.Farmakovskaya, A.F.Shtyrlin. Electrostatic deposition of soluble polymer thin films - Russian conference "Application of electron ion technology in industry. Physics and technics of monodisperse systems." Russia, Moscow, October 21-24, 1991.

7. A.F.Shtyrlin, V.G.Lipovich, L.S.Yanovsky. Development of a lab prototype of an electro-gas-dynamic accelerator-ozonator. -Technical report of the stock-exchange society "Odin", MAI, 1992.

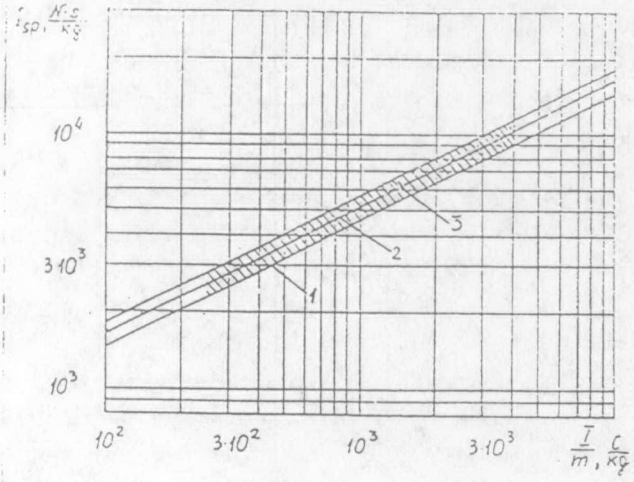


Fig.1. Colloid thruster calculated parameters
1 - U=15 kV; 2 - U=20 kV; 3 - U=25 kV
▨ - the most probable region

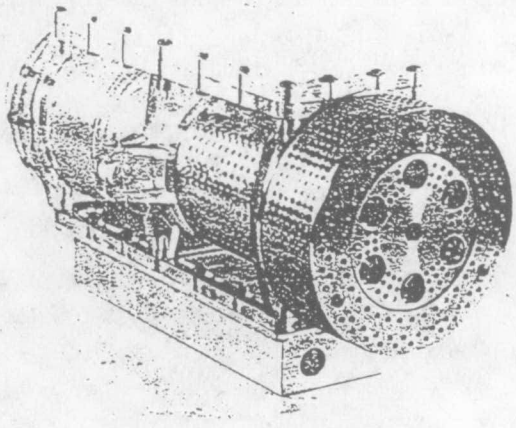


Fig. 3. Monoblock structure of the colloid thruster
F=10⁻³ N; Fт=10⁴ N·s

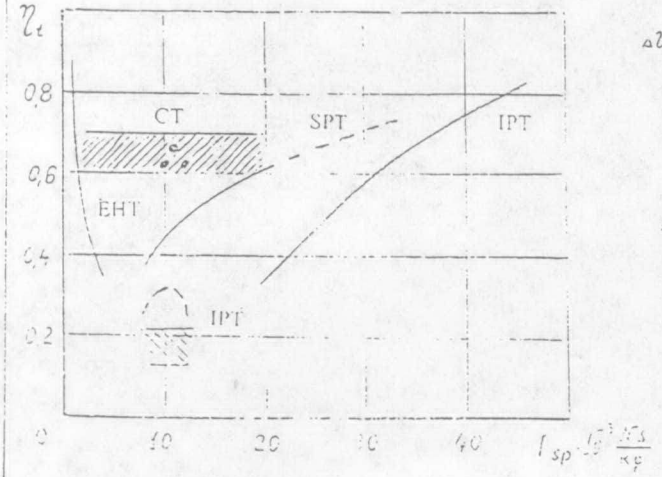


Fig. 2. Electro-rocket thruster efficiency

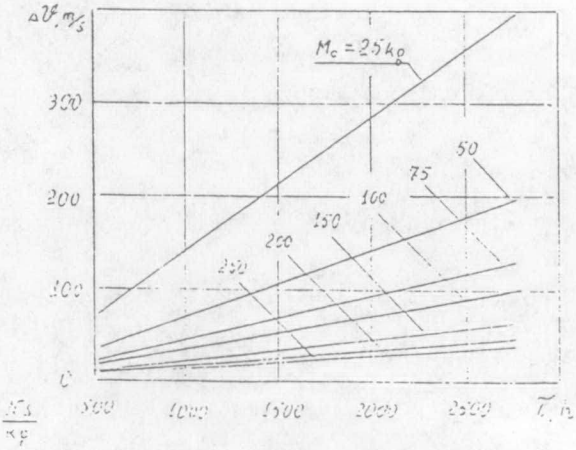


Fig. 4. Small satellites characteristical velocity from the monoblock thruster operation time

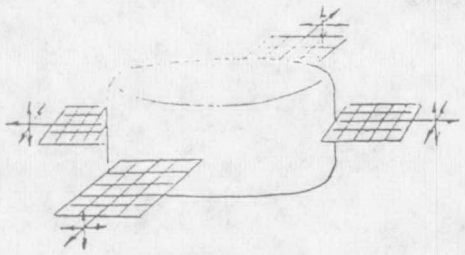


Fig. 5. Thrusters dislocation scheme at small sattelites for microacceleration compensation

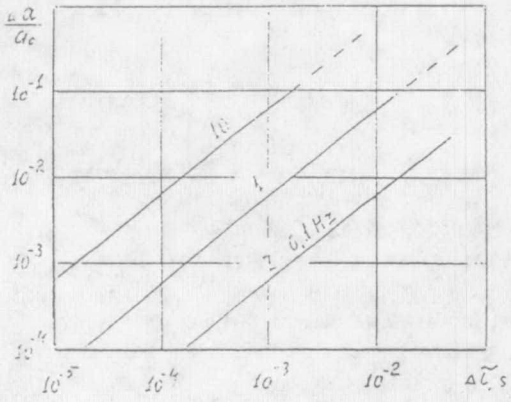


Fig. 6. Relative shore of the remaining acceleration under active compensation with the help of ERT.

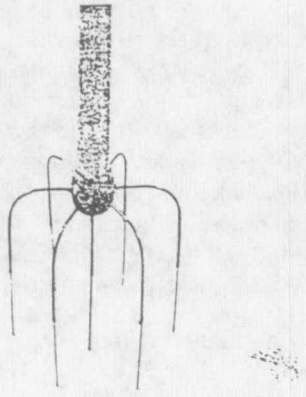


Fig. 7. Experimental technological atomizer with 7 needles

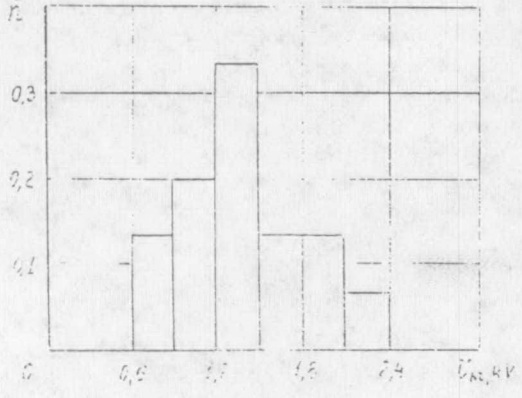


Fig. 8. Polyimide resin film breakdown potential histogram

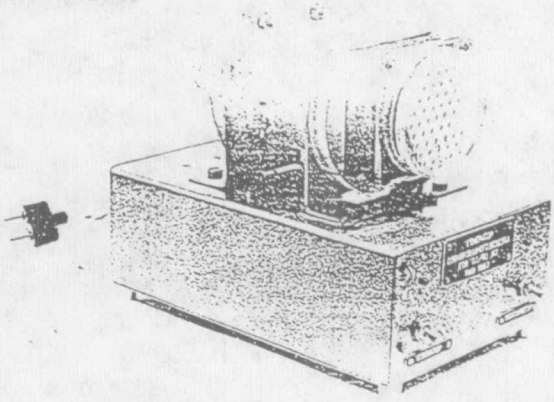


Fig. 9. Generator of ozonized air ГОВ - 0.1/40

ρ_{O_3}=5...30 mg/m^3 N=25 W

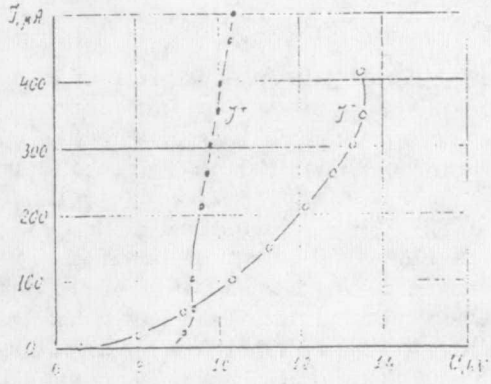
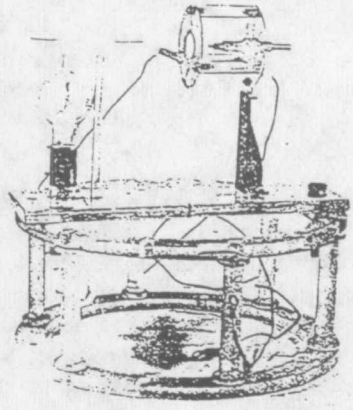


Fig. 10. Discharge chamber current-potential performance



11. Single mesh forEGD air accelerating

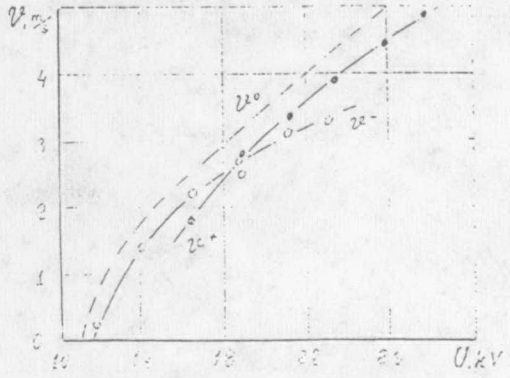


Fig. 12. EGD air acceleration parameters