

Alexey Morozov – leader of the SPT development in the USSR

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Abstract: Professor Alexey I. Morozov has passed away in Moscow on May 6 2009. He was a chief scientist at the Russian Research Center “Kurchatov Institute” and an outstanding researcher in the field of plasma dynamics and plasma accelerators. A.I. Morozov was a State (USSR) Prize winner for his development of physical bases of electric propulsion and received several international awards including a medal from the Electric Propulsion Society for his pioneering work in Electric Propulsion and a Silver medal from the French Aeronautics and Space Academy. He had made significant contribution to several branches of plasma dynamics including invention of the Stationary Plasma Thruster (SPT). Of no doubts that was a brilliant result of his activity. Some notable moments of his achievements are given below.



Professor Alexey I. Morozov.

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I. Prehistory

ALEXEY Ivanovich Morozov was born on March 30, 1928 in Kashira (USSR). In 1947 he had finished secondary school with a gold medal in Pyatigorsk city and entered the Physics Faculty at the Moscow State University (MSU). He graduated from MSU in 1951 with diploma of excellence, but was obliged to teach physics in the technical school in a provincial town of Lyudinovo (Fig. 1).

Being in Lyudinovo he had started investigation of possibility to accelerate air flow using Ampere force and had made the 1st experiments on this topic, confirming such possibility (Fig.2, Ref. 1).

In 1954 he was back to Moscow and became a PhD student at the MSU. Three years later he successfully defended his PhD work. His first paper "On Plasma acceleration by magnetic field" appeared in 1957² and it was focused on the electrons and ions movement specifics in the ExB fields on the linear plasma conductor acceleration.

In 1957 he was employed as a researcher by the Institute of Atomic Energy (IAE). During late 50th – 60th he made theoretical analysis of plasma dynamics in several plasma accelerators available at several Institutes. The main field of his interests at that time was the powerful coaxial plasma accelerator and his idea was to organize magnetic nozzle for the plasma acceleration similar to general gasdynamic nozzle (Fig. 3, Ref. 1,3). Development of this plasma accelerator took into account the requirements of the Mars manned mission. At that time these requirements were formulated as follows:

- Electric propulsion system power 10MW
- Thrust 100N
- Specific impulse 10000s
- Life time 10000hours



Figure 1. Alexey Morozov in mid 50th.

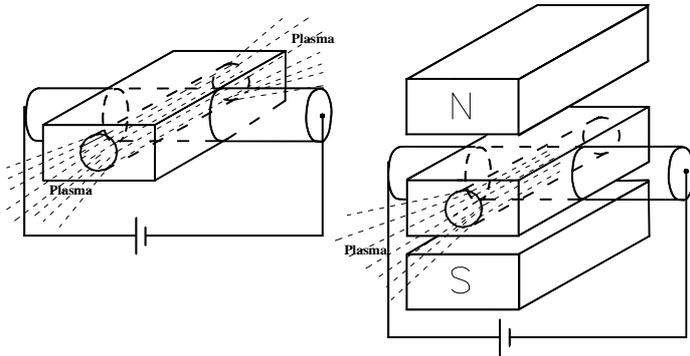


Figure 2. Scheme of the 1st Morozov's experiments made in Lyudinovo¹.

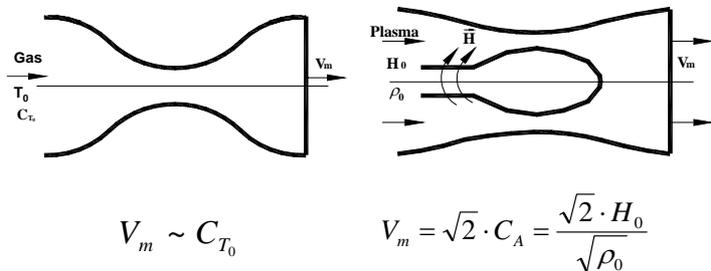


Figure 3. Scheme of the coaxial plasma accelerator which was under Morozov's studies during late 1950th - early 1960th¹.

During these years he was also theoretically analyzing the other types of plasma accelerators. Base on this analysis in 1965 he prepared and in 1966 successfully defended his Doctor of Science thesis "Investigation of the stationary electrodynamic plasma acceleration"³. Thus, in the mid of 1960th he became one of the leading theoreticians on plasma acceleration in the USSR. It is necessary to note his active position in science and great organizational

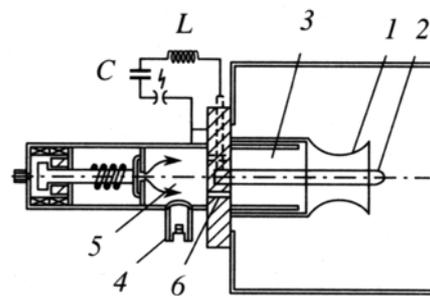


Figure 4. Experimental model of the coaxial plasma accelerator studied by Morozov with some other scientists at IAE¹. 1 – outer electrode, 2 – inner electrode, 3 – buffer volume, 4 – AT-cut probe, 5 – for-volume, 6 – holes in the diaphragm.

potential. In the middle of 1960th he had organized regular seminar at IAE where results of plasma accelerator studies performed in different Institutes of the Soviet Union were regularly discussed. Due to his wide interests and high scientific potential this seminars became an All-Union scientific school for the researches and engineers from all scientific centers of the USSR dealing with plasma accelerators.

II. Alexey Morozov – farther of the SPT

The Stationary Plasma Thruster (SPT) development and studies were initiated by Alexey Morozov and his group of scientists and engineers in the laboratory headed by Dr. German Shepkin at the Institute of Atomic Energy (IAE) in 1962^{3,4}. At that time, the laboratory was a part of IAE Department of Plasma Research, headed by the outstanding physicist academician Lev Artsimovich, who was actively supporting the advanced plasma accelerator developments. By that time, the concept of thruster with anode layer (TAL) with “plasma acceleration by Hall current” in the narrow ExB sheath was already formulated and experimentally demonstrated by another IAE scientist Askold Zharinov⁵. In opposite to this concept Morozov proposed to create an electric field with a help of magnetic field within the plasma volume and to focus ions during their acceleration by creating the “focusing” configuration of the magnetic field lines³. This idea was supported by his theoretical analysis of the magnetic field lines and electric field equipotential lines connection in plasma reduced later on to the so-called “thermalized potential” formula that is now widely used by many researchers. The 1st paper by Morozov on this topic was published in 1965⁶. In fact, proposed idea served as bases for the further development of plasma optics theory. As far as SPT is concern, the concept by itself led to creation and studies of the so-called E-type plasma accelerators in the mentioned IAE laboratory. Specific features of the E-accelerator were as follows:

1. Extended enough circular accelerating channel made in the dielectric discharge chamber.
2. Specific configuration of the magnetic field lines inside the accelerating channel to create topology of the electric field equipotential lines focusing ions (Fig. 5).

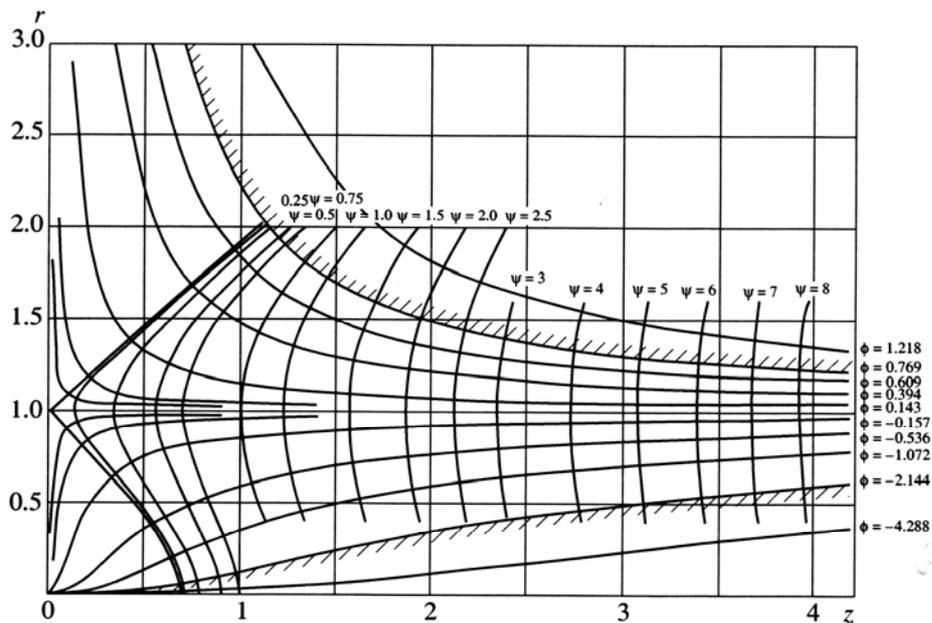


Figure 5. The magnetic field topology calculated and considered by A.I. Morozov as prospective one for SPT³.

From the mentioned Morozov’s analysis it follows, that to reduce deviation of the electric field equipotential lines from the magnetic field lines it is necessary to have low electron temperature in the acceleration zone³. To reduce this temperature it was proposed to use in E-accelerator the discharge chamber made of ceramics having high secondary electron-electron emission yield. So, in 1964 the 1st E-1 accelerator with the mentioned features was created and it was able to operate long enough time with noble gases, having thrust efficiency till 0.4, specific impulse till 1800 s and power level till 5 kW (Fig. 6, Ref. 3). Further on, a series of the theoretical and experimental studies of E-accelerator physics were fulfilled by Morozov’s team and by the end of 1968 the design of accelerator was significantly improved allowing its steady state operation during several hundred hours⁵.

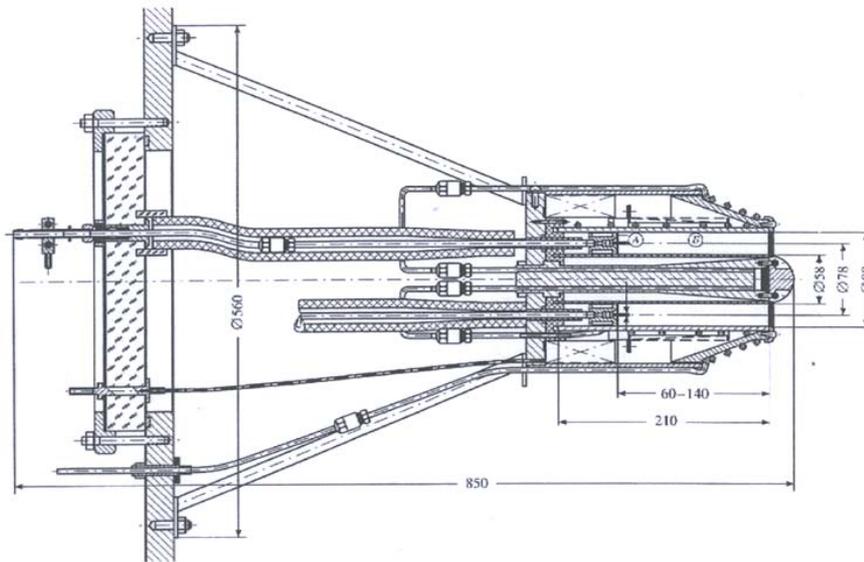


Figure 6. Design of the 1st E-1 plasma accelerator laboratory model developed and tested by Morozov and collaborators.

It is noteworthy mentioning, that by those times the E-type accelerators had competitive performance level within the range of specific impulses (1000-2000 s) and powers of ~1 kW. Therefore in 1968 due to initiative of Morozov and support from Lev Artsimovich, Anatoly Alexandrov the IAE President, and Andronic Iosiphian, the president of the All-Union Electromechanics Institute (VNIIEM) and a chief designer of Meteor satellites it was decided to realize SPT test on board of the mentioned above satellite. Under A.I. Morozov 's supervision the scientists and engineers from IAE, Design bureau (DB) "Zarya", DB "Fakel" and VNIIEM were engaged in that preparation^{7,8}. In 1971 the mentioned above tests were successfully fulfilled and in December 1971 the "Meteor" satellite with SPT had been launched into orbit (Fig. 7).

In fact, during that particular period, the prototype of the 1st flown SPT (Fig. 8), as well as of the Xe storing and feeding subsystem, were designed and tested under leadership of the IAE engineer and scientist Youri Sharov. Later on, engineers from DB Fakel managed by Fakel chief designer Roald Snarsky jointly with IAE and DB "Zarya" teams had developed and tested the 1st flown SPT (see Fig. 8), power processing unit (PPU) and the 1st experimental propulsion system on the base of SPT (Fig. 9, Ref. 7,8). Tests performed in 1972 were very successful and the main results of this test were as follows⁸:

- the SPT thrust was estimated using data on the satellite orbit parameter change due to SPT operation during several hours and it was shown that thrust magnitude is close to that one obtained during ground tests;
- the height of the 1st class satellite orbit was changed by ~17 km due to SPT operation with thrust around 20 mN during ~170 hours and satellite was positioned into the geostationary orbit for the Earth observation, and that was the first real task was solved by SPT;
- compatibility of SPT with other satellite subsystems was demonstrated.

Thus, this test could be considered as a birth of SPT as a space technology unit and Morozov could be called as a "farther of SPT".

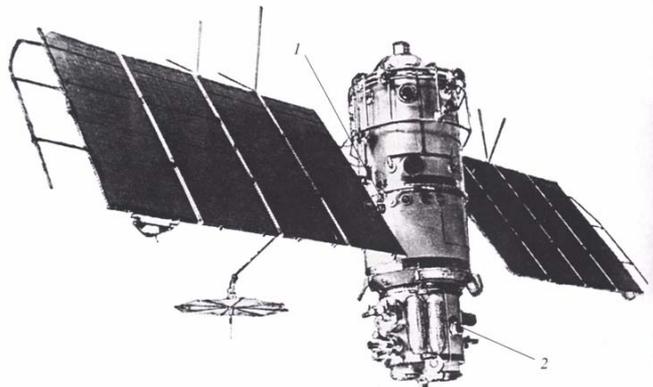


Figure 7. General appearance of the Meteor satellite.

1 – position of SPT, 2 – Xe tanks.

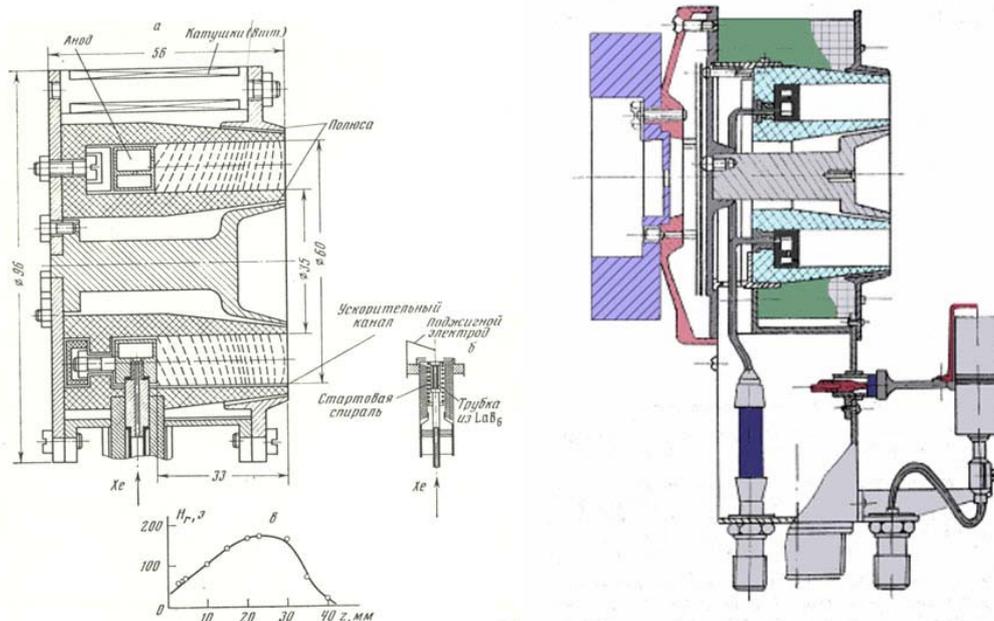


Figure 8. SPT prototype developed at IAE by Yu. Sharov (left) and of the 1st flown SPT developed at DB Fakel (right).



Figure 9. Parts of the 1st experimental propulsion system on base of SPT tested in 1972 on board of the Meteor satellite.

Success of the 1st test busted further development of SPT and associated technologies. Besides the IAE, DB Fakel and the VNIIEM, several other institutes and enterprises were involved into this activity including Moscow Aviation Institute (MAI), Central Institute of Aviation Motor Building (TsIAM), Kharkov Aviation Institute (KhAI), Moscow Institute of Radioelectronics (MIREA) and others ⁷. Till mid the of 70th the leading

role in these studies plaid Morozov's team which had fulfilled series of the basic researches⁹⁻¹⁵. During 1970th A. I. Morozov was coordinating activity of the above mentioned Institutes on SPT researches and development. Results of this activity are well known – SPT had become effective and reliable electric propulsion effectively used in space technology^{5,7,8} (Fig. 10).

Besides the results obtained by researchers during this period,⁵ one should note, that Morozov proposed the mechanism of the near wall conductivity to explain large electron current transverse to magnetic field in the SPT discharge¹⁶, made theoretical analysis of the ion flow movement stability in the acceleration zone with positive gradient of the magnetic field induction¹⁷ which was one of the bases for the new generation SPT development. Together with I. Melikov he performed analysis of the ionization similarity conditions under SPT operation with different propellants¹⁸ and together with S.Yakunin and others had made the 1st kinetic 1D simulation of the ion and neutral flows in the SPT discharge¹⁹. So, he was actively engaged in scientific research.

Alexey Morozov was also demonstrated remarkable organization skills being a Chairman of the Plasma Accelerator Section of the Plasma Physics Council of the USSR Academy of Sciences. During the 1970th – 1980th he and his collaborators organized several All-Union Conferences on plasma accelerators and ion injectors, and that was the main scientific forum in the USSR on plasma dynamics and acceleration.

These years he was also the member of several All-Union Electric Propulsion Conferences. In the late 1980th – early 1990th he was also co-chair of the Coordination Council on electric propulsion development and application of the Ministry of the General Machine Building of the USSR.

During 1980th Morozov was dealing with development of the quasistationary powerful plasma accelerators (QPPA) and again he was organizer and supervisor of this development. About 10 research Institutes were engaged in this consortium and as a consequence several valuable results were obtained (Ref. 19). During the 1990th – early 2000th he was taken by the project “Galatea” – a magnetic plasma traps²⁰ and in addition he continued the SPT development supervising a group in MIREA. As a result of that activity several new and advanced SPT schemes were developed and tested³.

Besides the achievements mentioned above, he wrote two books on plasma dynamics^{21,22} and published nearly 300 articles in scientific journals. His publications and reviews (see, for example, Ref. 23,24) are used by generations of scientists and engineers in electric propulsion and plasma dynamics and a high citation rate of his principal publications proves it. He is also co-author of several international patents related to SPT (see, for example, Ref. 25-27). So, Morozov had left behind numerous followers and remarkable scientific legacy.

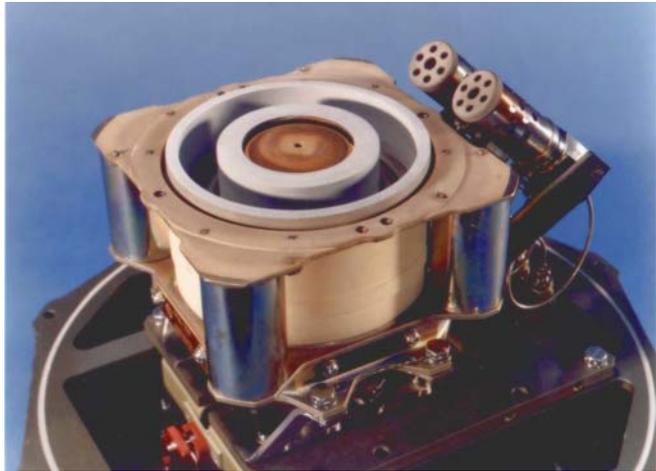


Figure 10. Well known SPT-100 thruster which is now a serial production at DB “Fakel”.



Figure 11. A.I. Morozov among the members of Organizing Committee of the 1st All-Union conference on plasma accelerators in 1972.



Figure 12. A.I. Morozov, H.R. Kaufman and a group of EP experts during the coordination meeting at the DB Fakel in Svetlogorsk (near Kaliningrad) in 1991.



Figure 13. Professor A.I. Morozov with a picture of QPPA and Professor A.I. Bougrova at the seminar on the International co-operation held in Svetlogorsk in 2003.

III. Some additional notes

It deserved mentioning that actually, the term “SPT” is not precise. Many experts in Russia don’t appreciate the term “Hall thruster” taking into account the following reasons. As a matter of fact, the so-called Hall current in SPT is mainly electron current induced by drift of electrons in the crossed electric and magnetic fields. So, using electromagnetic interpretation of plasma acceleration we have to explain how this movement is transferred to forces accelerating ions. In the classic explanation of the Ampere force electrons which are moved in conductor are shifted by magnetic field due to the Hall effect and this shift creates an electric field moving ions in the same direction as direction of the electron shift. Thus, electrons are shifted and draw ions in the same direction and conductor as a whole is shifted. But in the acceleration zone of SPT (and TAL) electrons are moved in one direction and ions - in another direction. Moreover we already had assumed that electric field moving electrons exists in plasma. Therefore, it is more precise and clear to explain ion acceleration by direct impact of electric field on its movement. That was the reason why the first SPT type accelerators were called as E-accelerators². And one of the main Morozov’s ideas to create in plasma over thermal electric field able to accelerate ions was realized in SPT and other plasma optics systems he proposed³. Thus, taking all mentioned above into account, it is reasonable to call SPT as “Morozov’s thruster”. At the same time we can distinguish thrusters designed by different authors or designers. So, it is possible to name them as Morozov’s thruster designed by Youri Sharov or Fakel or other company designer.

IV. Conclusion

Thus, Professor Alexey Ivanovich Morozov an outstanding scientist, a pioneer of Electric Propulsion and inventor of the SPT (a big success in space technology), will be remembered by his colleagues and generations of scientists and engineers in the field of plasma dynamics, plasma accelerators and electric propulsion.

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