The paper discusses anode layer thruster (ALT) suitable for orbit correction and recession of worthless satellite from geocentric orbit as well. In doing so, thrust system transition out of transfer regime into regime of task 1, apparently will come to alternations of thrust block parameters. In this case those thrusters are preferable which capable of thrust parameters variation in wide range.

For third task the thruster with high specific impulse is to be developed. The ion thruster entirely would be suitable. But because of low thrust density which is inherent to it, the dimensions and weight of such thruster is unacceptable large.

In comparison the data of Table 1 the attention is paid on the very wide range variation of thrust and power parameters provided the fulfillment of the above-mentioned tasks. Range of parameters variance within each task is fairly wide as well that at the analysis space program it may be indicated three perspective directions at which electric propulsion application can give substantial profit into project costs, or provide opportunity its realization in principle.

Table I.

<table>
<thead>
<tr>
<th>Task</th>
<th>I_p (s)</th>
<th>W (kW)</th>
<th>I_sum (Ts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Geocentric orbit correction</td>
<td>1500–1900</td>
<td>0.5–2</td>
<td>60–200</td>
</tr>
<tr>
<td>3. Mission to Moon and Mars</td>
<td>4000–7000</td>
<td>5 \times 10^{-3}–10^{-4}</td>
<td>5 \times 10^{-3}–10^{-4}</td>
</tr>
</tbody>
</table>

Each out these tasks has its peculiarity, which must be taken into account at the choice of the type of thruster most suitable for its realization.

The manufacturing thrust systems for orbit correction - it's task of present day, its practical realization by means of electric propulsion was tested on soviet satellites. Next step is the elaborating thrusters capable to provide summary impulse in a few times larger at rather low thrust unit. Another words, the problem of long life time becomes most important one at thruster elaboration for this task.

The second of the above-mentioned tasks was discussed repeatedly in literature and appreciable profit, which gives electric propulsion for this task is quite real. It is necessary to add here, that much more profit will be provided if in addition to transfer task, the joint power system provide also orbit correction and recession of worthless satellite from geocentric orbit as well.
ALT PECULIARITIES

ALT uses principle of ion acceleration into gas discharge with crossed electric and magnetic fields. Its general scheme, Fig. 1, shows its discharge chamber which is formed of electrodes under applied voltages and pole pieces, with cathode potential applied, is bounded with conductive walls. Under these conditions applied voltage is concentrated into thin layer, of about electron cyclotron radius in dimension.

The ion acceleration into thin layer takes a number of advantages. First of them, the short way of acceleration gives less opportunity for ion collisions with particles and walls and minimize energy losses as a result. Second, the ion path in magnetic field is small because of its angular divergence is small too. Except of that, conductive walls reveal possibility to create multistage acceleration where cathode walls of one discharge chamber work as anode for next one. This regime of acceleration takes significant advantages in high ion velocities must be achieved.

There are two stages may be defined in ALT investigations. On the first stage there was performed investigation of physical peculiarities which control gas discharge with anode layer. The physical principles anode layer accelerator and main results are expounded in Fig. 1. We mark these or them which are significant for thruster elaboration.

It was defined that anode layer is excellent ion generator which effectively fulfills ionization any particles.

It was shown that ion acceleration take place into electric field of double layer which structure don't depend on value of ion current. This attribute defines capability of thrust unit parameters change in wide range varying by voltage or flow rate which are tied in feeble manner and may be varied independently.

The significant property this accelerator is linear dependence thrust on flow rate, which keeps at flow rate variation in ten times.

At the same time two-stage accelerators were studied most completely and their main parameters were defined. Fig. 1 just shows two-stage accelerator scheme. The first stage operates as ion generator which supplies ions to second stage where they to be accelerated by applied voltage V_a. Discharge characteristics of two stage accelerator are shown in Fig. 2.

Each of them contains two typical parts. There is horizontal part where discharge current value in a high precision equal to mass flow current. This part corresponds to normal regime of acceleration with high efficiency (about 0.7-0.9). On the second part current increases rapidly with voltage decrease. At voltage variation here and there, there are different current values are obtained. This part of discharge characteristic corresponds to unstable, anomalous regime with low efficiency. This regime is the main obstacle limited voltage declination below 1.5-2 kV bound.

The aspiration to achieve effective ion acceleration under low voltages was the main goal of investigations next step. This purpose was achieved with hollow anode creation. Research show that single-stage accelerator is rather efficient for low power level. Fig. 3 shows scheme of single-stage accelerator with hollow anode. Its performances are shown in Fig. 4. Such accelerator operates at substantially low magnetic field densities and provides high efficiency at low voltages. It proved to be very interesting engine with unexpected properties which are realized at magnetic field variation.

There was stated existence of critical magnetic field H_c in going through which discharge structure changes and its performances change in radical way. Externally it is visible that discharge filled anode hollow H=H_c since anode layer shape itself does not change. The current to probe to be placed near back wall of hollow, increases in 10-15 times. Except of that, specific impulse grows, exceeding admissible value at applied voltage and spectrograms show presence of multicharged ions. The effect of varying the magnetic field strength is indicated in Fig. 5 for a fixed voltage. Critical magnetic field corresponds to axial value specific impulse which exceeds admissible
value at 1.5 times. That means that multicharged ions share may be significant.

Critical field value depends on external parameters so as applied voltage, gas flow, shape pole pieces and electrodes. If RH* the obvious analogy discloses between performances hollow anode thruster and SPT: specific impulse and efficiency become maximal for definite values applied voltage and mass flow, to differ at deferent H. Instead of, if RH* these parameters don't depend on H, current slightly depends on voltage and efficiency rises. There are definite features two-stage accelerator.

As a result the main processes and relationships gas discharge with anode layer had been defined, the methods of control its parameters had been found and basis of engineering design ALT engines had been created. There had been accumulated experimental data about methods of optimization ALT and its performances in a wide range of operation: from 0.5 to 1.00 kilowatts by power, from 1000 to 10 000 seconds by specific impulse. There had been found too that ALT efficiency tends to increase with power increasing and power to be some 5 kW, efficiency attains 0.8 and more value. At the low power and specific impulse levels there had been attained efficiency not less then 0.5. At the basis of 1000 hour life time tests of two-stage accelerator ALT engines time operation spun was estimated to be not less than 4000 hours.

In parallel with single-stage accelerators physical research the evaluation of thrust units was carried, which, in distinction of research engines had to satisfy to definite package of technical requirements. The problem consisted in choice their optimal combination and search the way for their joint improvement.

THrust UNITS PARAMETERS

In Table 2 parameters of experimental ALT thrust units worked out and tested in TSNIIMASH are shown. It is evident that they practically supercede whole-range of specific impulse variation (see table 1). The range

<table>
<thead>
<tr>
<th>Type</th>
<th>F(kW)</th>
<th>( F_{\text{g}}(\text{g}) )</th>
<th>( I_{\text{rpm}}(\text{s}) )</th>
<th>( \eta )</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5-5</td>
<td>0.8-2.5</td>
<td>4-12</td>
<td>1250-2700</td>
<td>0.5-0.6</td>
<td>1 step</td>
</tr>
<tr>
<td>0-100</td>
<td>3.5-15</td>
<td>6-65</td>
<td>2000-4200</td>
<td>0.6-0.7</td>
<td>1+2 step</td>
</tr>
<tr>
<td>0-250</td>
<td>20-50</td>
<td>250-300</td>
<td>500-2500</td>
<td>0.7-0.8</td>
<td>2 step</td>
</tr>
</tbody>
</table>

Works under two-stage thrusters were directed to elaboration powerful engines with radiative cooling. Disclosed methods of anomalous regime overcoming were used at their designed. As a result, universal engine was created, with high efficiency at low powers too. To make transfer from high Isp regime to regime at low Isp it is enough to short out first stage so that it turns to single-stage thruster. The possibility to simplify electric circuit two-stage thruster was studied. It was shown that one power supply is enough. For example it can be used divider.

There are not given data about life time in Table 2. The estimation of life time was given in previous section. We will discuss here some aspects cause this parameter. Firstly notice that life time is not entirely exact definition for engine to operate as thrust apparatus because at space mission analysis the summary impulse is defined as one of significant mission parameters, which quite definitely describes thrust unit life ability too.
the contemporary level of fulfillment because account of and parameters. with fulfillment account at general analysis conditions provided issuance promised. decrease. the, defined). within not depend directly neither plasma flow. It was adopted too that erosion seed thruster parts which cause thruster power, i.e. is a value which remains steady within thruster operation range (if ion velocity is defined). It shows too that it is possible to increase \( I_{\text{max}} \) by ion average velocity or specific impulse decrease. This circumstance have to be taken into account at general analysis conditions provided mission fulfillment and at initial choice thrust system parameters.

Notice, that the essential \( I_{\text{max}} \) variation for account of and \( \eta \) and \( L \) increase is improbable yet because modern thrusters are on that stage of fulfillment at which optimization these parameters at the contemporary level of knowledge about the physics of operation and of methods engineering and design are achieved already. Therefore it is necessary above all to pay attention to the possibility of ion flow to the walls decrease. For this purpose the exploration of possibilities to optimize physical process into wall regions and the seeking of progressive technical solutions, preventing interaction rapid ions flow with discharge chamber walls have to be stimulated.

As for ALT, such technical solution has been found. Its practical value have to be scrutinized yet. Nevertheless preliminary examinations are very promising. So, we speak about creation the engine with external layer, where accelerated ions don't interact with walls. The results of elaboration and the practical realization of this technical principle is discussed in 5. We only note here that check measurements walls sputtering velocity indicate on possibility its diminution in several times.

We also note that a small number of thrust units is enough for all named transfer tasks to be performed. Such situation is proved to be feasible owing to abilities ALT to effective operation under the wide range variation propellant flow and voltage. The limitation of power of thrust units from above is connected with its ability to heat radiation.

Data given in Table 2 illustrate one general trend which is peculiar to ALT nature, namely, it is growth of thrust efficiency as power increase. This trend comes out of overall theory of discharge in crossed E, H-fields. So, evaluation of probability of ionization is evident or it to rise as gas flow density increase. As a result the ignition zone becomes smaller, attached to anode. That comes to diminution of ions energy incoherence. The results of calculation the parameters of ion flow fulfilled in one-dimensional approach testify this situation. Ion energy distribution measurements affirm that trend too. Fig.6 indicates that average ion energy rises as gas flow increase.

In Figure 7 the thrust efficiency D-55, and D-100 thrust units as a function of propellant flow density are presented. The bold curves represent thrust.
efficiency variation for each unit for its steady state regime where it's capable to operate for a long time. The upper border of such regime is defined by most power which the unit is able to radiate without magnetic system overheating and efficiency deterioration as a result.

In addition to separate points there are presented the results of D-55 operation for short-time on power exceeding the utmost steady state one, where the unit don't get to steady state regime and its efficiency decreases monotonously after some time. That regime may be described with a time while the efficiency retains within acceptable limits.

So, the possible way to rise thrust units efficiency is to heat removal improvement from most hot parts of thruster. There are anode walls and its edges to undergo to most influence of discharge. And heat removal must be realized if that heat is not to come to parts of magnetic system as the most sensitive ones to heating. That's significant for technical decision of this problem that anode is fabricated of conductive material. In modern thrusters which are designed for large operational power there are used copper screens to prevent heat transfer to magnetic system and direct it to back wall of engine. But there are only the first steps on the way of solution the heat removal problem.

The main processes and laws of closed drift discharge with anode layer have been studied and methods control parameters of accelerators used this discharge have been defined. Performances anode layer accelerator have been studied in wide range variation power and specific impulse. These data have found base for creation thrusters useful for any space task.

The engineering methods of elaboration and manufacturing ALT thrusters have been developed. ALT units elaborated on the base of these methods can be taken as a base for creation of thrusters for prospective mission tasks providing overall range of thrust and power parameters by changing of their regimes. The promised directions of life time problems overcoming and efficiency improvement are found. To put this directions into practice it's necessary to conduct long-term life time tests ALT module with external layer and to entertain wide-range engineering developments of efficient heat transfer for next generation thrusters.

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6. S.O.Tverdokhlebov "Study of Double-Stage Anode Layer Thruster Using Inert Gas" rep. at present conference