PROJECT OF MULTIFUNCTION ELECTRIC PROPULSION PLANT
FOR TRANSFERRING SPACE VEHICLES TO GEOSTATIONARY ORBIT

V. F. PRISHNIKOV, S. N. KONYUKHOV*, A. I. KONDRATYEV*, S. F. LYAGUSHIN*, I. N. STATSENKO*

Abstract

An electric propulsion plant (EPP) included in the combined accelerating unit of "Zenit" launcher is considered, the plant being intended for space vehicle transfer to the geostationary orbit. The EPP feeding is provided by solar arrays of two power versions: 20 KW and 30 KW.

A space vehicle with a power-propulsion unit is supposed to be put into an intermediate orbit with using liquid propulsion, the further elevation is exercised by EPP which carries out the tasks of damping, orientation and stabilization at all the flight stages, interorbital transfer, orbit parameter maintenance, and movement to a higher orbit after the service life completion.

Anode layer thrusters are used as rocket motors. The EPP composition includes 4 units of cruise engines, 2 units of thrusters for orientation in respect to list, service and control systems.

The principal EPP parameters are analyzed in dependence upon the duration of putting into orbit and the mass of apparatus for mission purpose.

Introduction

Nowadays the intensive settling of high orbits including the geostationary orbit (GSO) is carried on. Up to now "heavy" launch vehicles (LV), such as "Proton" in Russia and "Ariane-5" in France, are used as launching means for putting space vehicles (SV) into high orbits.

SV with masses of about 2.5 tons are put into GSO with using accelerating units (AU) based on nitrogen tetroxide (NO₂) and non-symmetric dimethyl hydrazine (NDMH). The mass of space vehicles which are put into GSO is supposed to be raised to 3.5-4.5 tons to using AU on oxygen and hydrogen components.

Application of a combined AU consisting of a liquid propulsion plant and a power-propulsion unit (PPU) based on solar arrays and electric thrusters is of great interest for fulfilling the above mentioned tasks. Incidentally, a rather long time of putting into orbit is not already a restricting factor due to the tendency to increasing active operation time to 8-10 years. A powerful solar electric station is placed into operation orbit, the power station being capable of satisfying ever increasing demands to the power of a space vehicle power supply system.

Using a combined AU with PPU on a middle-class launcher "Zenit" is of special interest because of its ecological cleanliness. We shall consider the problem of PPU application in reference to "Zenit" launcher.

* Dniepropetrovsk State University
13 Prov. Naukovi, Dniepropetrovsk, 320625, Ukraine
** Design Enterprise "Plivdenne"
3 Kryvorizka Str., Dniepropetrovsk, 320059, Ukraine
LV "Zenit" is a two-stage rocket. But the Design Enterprise "Pivdenne" has developed the version of a three-stage launcher with the 3rd stage 14C851 based on AU with a liquid propulsion plant (LPP) operating with high-boiling fuel components in an ampule performance. At present the work on equipping the launching complex with the 3rd stage 14C41 based on AU with LPP using the oxygen-hydrogen components is carried on.

1. Design characteristics of the power-propulsion unit

The solar power plant (SPP) in PPU composition consists of a solar array, power storage, complex of control devices and cable network. Silicon solar cells are the only applicable ones for solar arrays with taking into account the raw material base, technology of manufacturing and cost. We estimate the really attainable specific mass of a solar array as 2.5 Kg/m² considering the necessary service life and the reached level of specific power of silicon solar cells (the initial power equals to 150 W/m², the degradation rate is up to 6% per year).

Two variants of SPP power have been worked out, i.e. 20 and 30 kW. Corresponding SPP masses were 1090 and 1440 Kg. Their specific mass was 50 Kg/KW. Therefore this specific mass value of SPP has been accepted for ballistic calculations.

An anode layer thruster (ALT) has been chosen as an electric rocket motor for the further analysis. The Experimental Designers' Office "Foton" of Dniepropetrovsk State University had certain achievements in ALT elaboration. The great angular accuracy of a thrust vector orientation, great performance stability in time, minimum power consumption, and low wearability of units are its important advantage in comparison with other electric thruster types.

The electric propulsion plant (EPP) consists of:
- 4 cruise motor blocks;
- 2 list orientation motor blocks;
- a system for propellant storage and supply;
- a block for voltage transformation and control.
Electric thruster specific pulse changes in the range 1400-6000 s have been accepted for ballistic analysis. Incidentally the thrust cost changes in the corresponding range from 140 to 426 W/gf. According to the problem examination by the EDO "Foton" and the Design Enterprise "Pivdenne", the specific mass of the system for propellant storage and supply is supposed to equal to 0.5 Kg per 1 Kg of propellant. The noble gas xenon is admitted as propellant.

A space vehicle mass including the mass of the EPP structure with the propellant storage for operation in orbit is accepted as a criterion of PPU application efficiency, this mass in named conditionally a payload mass. Conditionally the power plant mass is not included in the mass determining the efficiency criterion though the SPP provides power supply for a SV (including EPP) in an operation orbit.

2. Putting-into-GSO scheme

The analysis of PPU application efficiency was carried out for the following scheme of putting SV into GSO [1]. The 3rd stage of a launcher with SV and PPU is put into non-closed elliptic orbit with the lack of velocity to the orbital value by the continuous operation of the first two stages. After the 3rd stage separation from the 2nd
one and passive flight which is necessary for the stabilization after
the separation, the cruise motor of the 3rd stage is switched on, it
fulfils putting the 3rd stage with SV and PPU into the reference cir-
cle orbit. The orbit height depends upon the variant of putting into
orbit and the 3rd stage start mass and makes from 200 to 350 Km.

After the passive flight of the 3rd stage in the circle orbit the
second switching on of the cruise motor provides putting the 3rd stage
into the transfer orbit with the apogee height equaling to that of an
intermediate orbit. After the passive flight the third switching on of
the cruise motor carries out putting the 3rd stage with SV and PPU in-
to the intermediate circle orbit where the SV and PPU separation from
the 3rd stage occurs. The 3rd stage transfer from the reference circle
orbit to the intermediate one may be complanar or with the turn of the
orbit plane (partial or full). The remaining part of the orbit plane
turn is fulfilled at the PPU operation sector. Putting SV from the in-
termediate orbit to the GSO is carried out by the PPU work. We suppose
that the EPP is switched off while SV flying in the Earth shadow.

The range of intermediate orbit heights (i.e. initial heights of
the autonomous flight of SV with PPU) for two versions of AU with liq-
uid propulsion plants was considered in calculations:
- from 1000 to 6000 Km for AU 11C851;
- from 6000 to 20000 Km for AU 14C41.

Ballistic calculations were conducted in the Design Enterprise
"Pivdunie" on the basis of methods developed there. The value of the
EPP thrust was assigned for three variants of the duration of putting
SV into GSO: 200, 400 and 600 days.

3. Results of PPU efficiency analysis

The analysis of PPU application efficiency has been carried out
for the different values of the specific pulse of electric thrusters,
intermediate orbit height and putting-into-GSO time.

As expected, there is a payload mass optimum at specific pulse
variations, and it is expressed more distinctly for lesser putting-
into-GSO times. For the small duration of putting SV into GSO (200
days) the maximum payload mass slightly depends on an intermediate or-
bit height and corresponds to the specific pulse from 2000 to 3000 s.
For greater values of putting-into-GSO time (400-600 days) the optimum
payload mass corresponds to the specific pulse from 3000 to 4000 s.

The maximum values of payload mass are reached at small heights
of an intermediate orbit. This can be explained by the decrease of the
total mass of the stage put into an intermediate orbit by AU while the
intermediate orbit height increasing.

If the PPU operation time increases, the payload mass also grows,
and this is accounted for by the decrease of the necessary thrust and
hence the SPP power and mass. Incidentally at small times of putting
into GSO the influence of an intermediate orbit height vanishes.

The results of the work done show that a qualitatively new system
for putting space vehicles into high orbit (GSO included) can be de-
designed on the basis of an ecologically clean launcher "Zenit".

The performance of the power and propulsion plants for two versi-
ons of SV ("light" and "heavy" classes) is given in the table. Space
vehicles with the mass of apparatus for mission purpose of 500-600 Kg
are classified as SV of "light class" and those with the corresponding
mass of 1200-1300 Kg are classified as SV of "heavy class".
<table>
<thead>
<tr>
<th>Parameters of systems</th>
<th>SV of light class</th>
<th>SV of light class</th>
<th>SV of heavy class</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Solar array power. KW</td>
<td>30</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>2. Putting-into-GSO time, days</td>
<td>322</td>
<td>251</td>
<td>367</td>
</tr>
<tr>
<td>3. SV mass, Kg</td>
<td>4930</td>
<td>4330</td>
<td>5320</td>
</tr>
<tr>
<td>4. Total EPP thrust, gf</td>
<td>139</td>
<td>123</td>
<td>119</td>
</tr>
<tr>
<td>5. Specific pulse of thrust, s</td>
<td>3000</td>
<td>2000</td>
<td>2080</td>
</tr>
<tr>
<td>6. EPP mass, Kg. including propellant mass, Kg.</td>
<td>2130</td>
<td>2195</td>
<td>2900</td>
</tr>
<tr>
<td>7. SPP mass, Kg. including photovoltaic solar array mass, Kg</td>
<td>1440</td>
<td>1090</td>
<td>1090</td>
</tr>
</tbody>
</table>

- EPP specific pulse has been determined depending on the putting-into-GSO time.

In the proposed transportation system high-efficiency EPP and power supply system are delivered into GSO together with the apparatus for mission purpose, they providing orbit corrections, manoeuvres, and feeding SV with electric energy during its normal operation in orbit and taking it off from the orbit after the end of service life or in the case of the fault of special devices.

Reference