

# Vernier Propulsion System for Small Earth Remote Sensing Satellite “Canopus-V”.

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**Abstract: The satellite constellation of perspective Space Complex (SC) of operative monitoring of technogenic and natural emergency situations “Canopus-V” comprises two “Canopus-V” satellites located in one plane with phase difference of 180° and on 510km altitude orbit. The “Canopus-V” SC includes a Vernier Propulsion System (VPS) based on SPT-50 Stationary Plasma Thruster. The paper describes a structure, main characteristics of VPS, its block diagram, detailed conversion and control system PPU-CV providing power supply and operation logic for VPS.**

## I Introduction

The future-oriented Space Complex of operative monitoring of technogenic and natural emergency situations “Canopus-V” is designed to fulfill the following main tasks:

- monitoring of technogenic and natural emergency situations including hydrometeorological acts of nature
- detection of forest fires, major release of polluting matters into natural environment
- monitoring of agricultural activities, natural resources (including aquatic and nearshore resources monitoring)
- land utilization
- operating supervision of designated areas of earth's surface in the interest of different sectors of the national economy.

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The space complex “Canopus-V” includes a constellation consisting of two “Canopus-V” SC on one plane at 180° phase position.

The constellation operating on sun-synchronous orbit of 510km altitude requires total expenditures of reference speed  $\Delta V_{\Sigma} = 80.1 \frac{m}{s}$  for seven years operation life of SC.

The Vernier Propulsion System (VPS) of “Canopus-V” is designed for:

- initial error correction during the satellite injection into orbit
- generation of a satellite constellation with phase difference  $\varphi=180^\circ$
- orbit correction to compensate for atmospheric braking
- orbit correction to maintain the satellite angular location based on the argument of latitude.

## II Necessary thrust characteristics of SC orbit correction.

According to estimates the necessary total impulse to carry out the respective kinds of corrections of SC orbital parameters are 30.59 kNs (33.65 kNs taking into account 10% for spread propulsive effort as for absolute magnitude). The values of correction parameters and necessary thrust characteristics of SC orbit correction are shown in Table 1.

Table 1. Correction parameters and thrust characteristics for “Canopus-V” SC for orbit correction of 7 years.

Parameters correction	Parameters correction value	Necessary thrust pulse, kNs
Initial period of revolution, $\Delta T$	4 s	0.82
Initial inclination, $\Delta i$ $\Delta i$	2°	2.16
Initial eccentricity, $\Delta e$ $\Delta e$	0.0008	1.48
Initial perigee argument, $\omega$	40°	2.09
Moving apart in phase $\varphi=180^\circ$	5 s	1.04x2
Period support, $\Delta T$ $\Delta T$	48.2 s	9.88
Inclination support, $\Delta i$ $\Delta i$	7°	7.35
Orbital plane position correction	4.8°	4.73
Total impulse, kNs	30.59 (33.65 inclusive 10% propulsive effort spread)	

## III Comparing various types of VPS

Various types of VPS models (both foreign and Russians) were considered on the assumption of total impulse  $I_{\Sigma} = 40 \text{ kNs}$   $I_{\Sigma} = 40 \text{ kNs}$

Table 2 represents characteristics of various types of VPS with respect to “Canopus-V” SC.

Table 2. VPS characteristics

VPS parameters	VPS type					
	SSTL Xenon VPS	SSTL Water VPS	NIIEM Ammonical VPS	NIIPME Ftoroplast VPS with Ablative Pulsed Plasma Thruster (APPT)	Experimental Design Bureau “Fakel” Hydrazine VPS with Thermocatalytic Thruster (TCT)	Experimental Design Bureau “Fakel” Xenon VPS with Stationary Plasma Thruster (SPT)
Total impulse, kNs	40	40	40	40	40	40
Specific impulse, s	60	152	164	1700	208	900
Thrust, G (mN)	1.0 ... 4.0 (10 - 40)	4.5 (45)	4.0 (40)	0.25 ... 0.35 (2.5 - 3.5)	10 (100)	1.5 (15)
Power consumption,	80	100	100	100	~ 30	~ 300

W						
Propellant mass per thrust, kg	67	27	24.4	2.5	19.2	4.4
Total mass, kg	90	40	36,5	17.5	45	25

#### IV “Canopus-V” SC Vernier Propulsion System

The VPS based on Stationary Plasma Thrusters SPT-50<sup>1,2,3</sup> developed by OKB “Fakel” (Kaliningrad, Russia) was chosen for “Canopus-V” SC taking into account the achieved characteristics and grade of experience in natural conditions.

#### Main characteristics of VPS

Parameter	Value
Power consumption, W	317
Nominal thrust, G (mN)	1.4 (14)
Nominal thrust specific impulse, s	850
Operating life, hour	800
Number of firings	2000
VPS dry mass, kg	19.2
Loaded xenon mass, kg	5.2
Total warranty period, years	10
Lifetime, years	7

The VPS of “Canopus-V” SC contains the following units:

- Two Thrusters SPT-50 (Fig. 1), one of which is a backup, providing a corrective pulse thrust
- Two Xenon Flow Controller XFC-50 (Fig. 2) to supply xenon to main and redundant thrusters SPT-50 respectively
- Flow Control Unit – FCU (the same Xenon Feed Unit) (Fig. 3) containing the main and backup branches to conduct xenon to XFC-50
- Xenon Storage System (unit) XSS (Fig. 4) providing storage and supply of stock-pile into FCU
- Power Processing Unit PPU-CV designed for power supply and control of VPS units.

Two SPT-50 thrusters, two gas control units, xenon feed unit, interunit pipes with receiver are structurally united in SC Orbit Correction Unit (Fig. 6).



Fig.1. Stationary Plasma Thruster (SPT-50).



Fig.2. Xenon Flow Controller (XFC-50).



Fig.3. Flow Control Unit - FCU (Xenon Feed Unit)



Fig.4. Xenon Storage System (XSS).

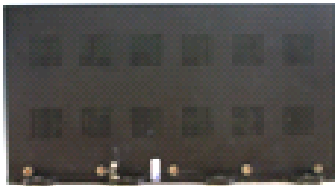


Fig.5. Power Processing Unit (PPU-CV)

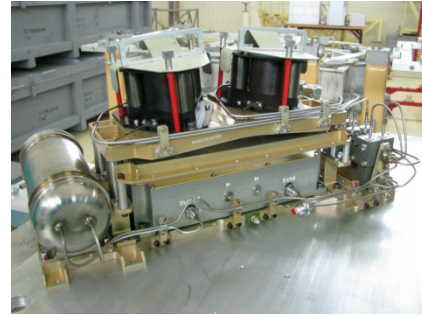


Fig.6. Orbit Correction Unit (OCU).

Figure 7 represents the VPS block diagram. It should be noted, that PPU-CV has only electrical connections to the sells shown in the scheme and as an individual unit is not shown.

XSS contains two xenon tanks (Tnk1 and Tnk2), two pyrotechnic valves (PV1 and PV2) installed in parallel in the xenon supply tract, heat sensor (HS) and Filler Neck (FN). The xenon is supplied from XSS to FCU after PV1 and PV2 pyrotechnic valves blowing up along interunit piping of high pressure (HPP1) including the Test Neck (TN1).

FCU contains two independent xenon feed lines and herewith only one of them is operating, the second line is a redundant. Each FCU branch has an Electric xenon supply Valve EV1 (EV3) fulfilling a cut-off function, mechanical Pressure Regulator PR1 (PR2) and a supply valve EV2 (EV4). The mechanical pressure regulator is to lower xenon pressure from changeable high at input (~110kg/cm<sup>2</sup>) to low constant at output (1 – 6 kg/cm<sup>2</sup>). Each pressure regulator PR1 (PR2) has a heater EV providing a necessary thermal mode and a telemetric heat sensor HS1 (HS2). A high pressure telemetric sensor HPTS1 (HPTS3) is mounted in each xenon feed line behind the cut-off valve at pressure regulator PR1 (PR2) input.

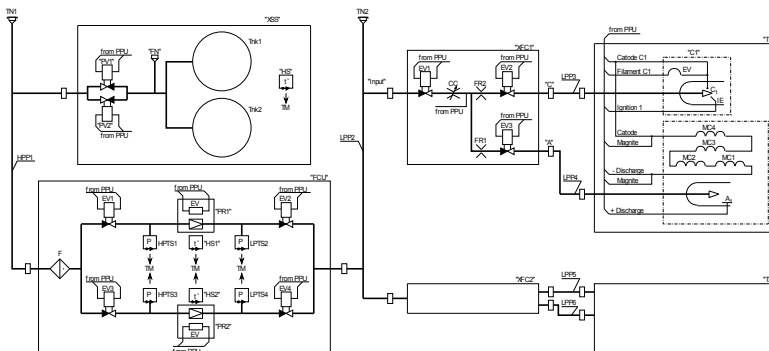


Fig.7. “Canopus-V” SC VPS block diagram.

A Low Pressure Telemetry Sensor LPTS2 (LPTS4) is mounted at Pressure Regulator output PR1 (PR2). The xenon is supplied from FCU to XFC-50 (XFC1, XFC2) via low pressure InterUnit Piping (LPP2) including the Test Neck (TN2).

The xenon flow controller XFC-50 (XFC1, XFC2) supplies xenon to anode (A) and cathode tracts of SPT-50 thruster (T1, T2) with required value of xenon consumption via interunit pipes LPP3 and LPP4 (LPP5 and LPP6). Each XFC -50 xenon supply tract has a supply valve EV1 at input and cutoff valves EV2 and EV3 at output.

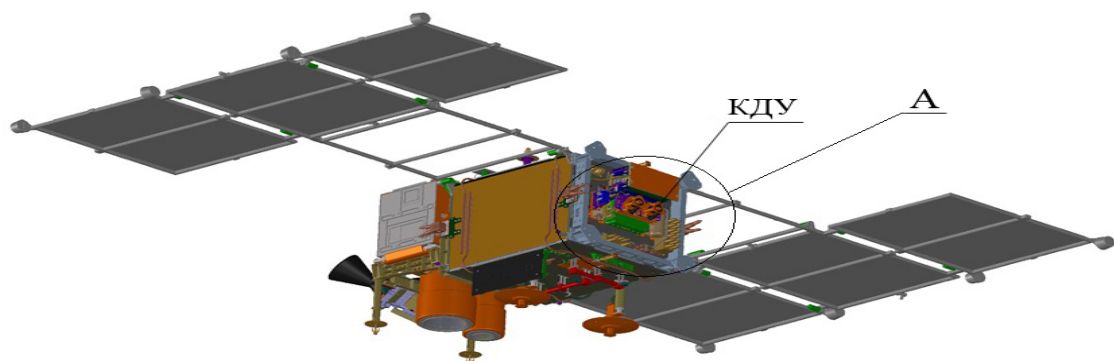
The Consumption Controller (CC) and Flow Restrictors (FR1 and FR2) of XFC-50 provide a necessary

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consumption level of xenon to Anode (A) and Cathode (C) of the SPT-50 thruster in dependence of discharge current value. The SPT-50 thruster (T1, T2) provides creation of corrective burst of power by means of interaction of plasma charged particles with mutually perpendicular lengthwise electrical and radial magnetic fields created in coaxial channel of discharge chamber of the thruster. Each SPT-50 contains cathode (C) and anode (A) packs. The cathode pack has a proper cathode  $C_t$ , heater (H) and igniting electrode (IE). The anode pack has a

proper anode and magnet system coils (MC1 ... MC4).

Figure 8 represents a general view of “Canopus-V” SC with VPS mounted on it.



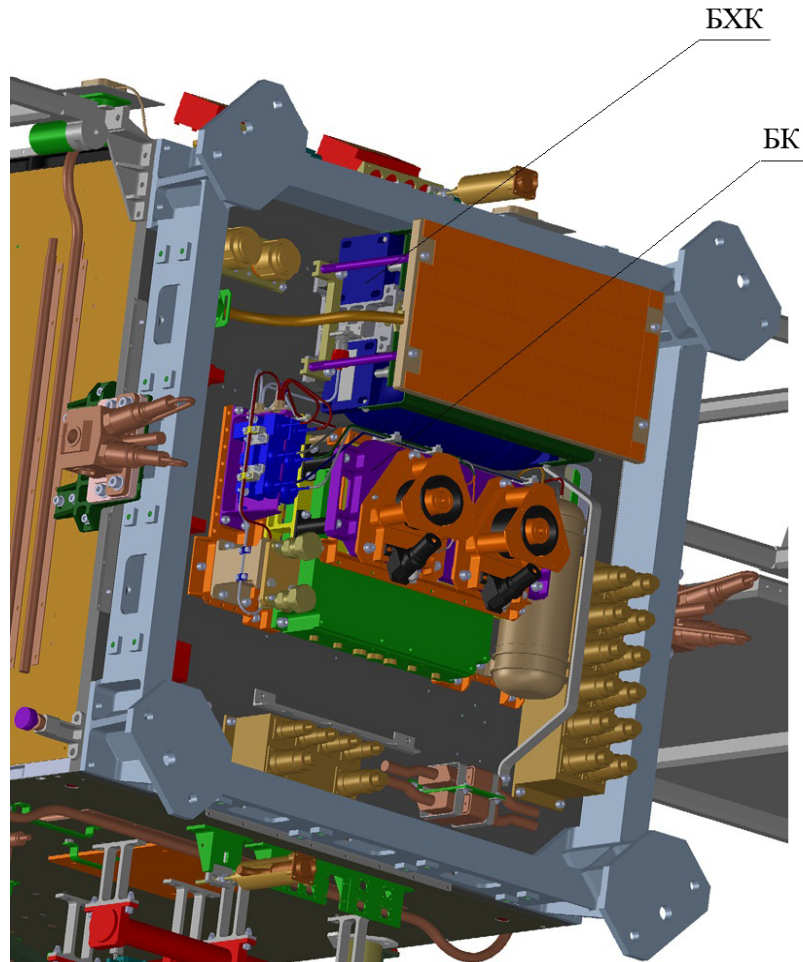


Fig.8. “Canopus-V” with VPS

It should be noted, that PPU-CV is an important element of VPS supplying power and logic of operation and is worth to be described in more details.

The PPU-CV is manufactured in accordance with electro-pneumatic principal scheme of VPS and consists of functional modular constructs (Fig. 9).

Fig.9. PPU-CV block diagram.

Switcher Power Supply Modules (SPSM), Conversion Modules (CM) and xenon supply control modules (XSCM) are general and function when Thrusters T1 and T2 operate. A discharge supply module (DSM), Thruster Igniting Module (TIM), and XFC Control Unit (XFCCU) with number 1 serve only for thruster T1 operation, with number 2 – only for thruster T2.

The PPU-CV is based on a launch system and power supply with a multiplex voltage converter and general control circuit on base of Pulse Duration Modulation Controller<sup>4</sup> (PDMC). The PDMC provides stabilization for each channel:

- cathode heater current  $I_{ch} = \varphi(U_{fessd}, R_{ch})$ ;

– discharge voltage  $U_d = \varphi(U_{fessd})$  at stabilized consumption of working agent;

– magnetic coils additional current  $I_{mc ac} = \varphi(U_{fessd})$ .

Via the discharge channel the same PDM controller limits the discharge current  $I_{lim dc}$  in anomalous conductivity of discharge channel mode  $G_{acd}$  at the preset level as per functional dependence:

As far as the cathode heating and operation discharge mode operate in different time, the stabilization  $I_{ch}$ ,  $U_d$  and  $I_{d lim}$  is provided by change of durability of inverter ac voltage pulses generated by general PDM controller according to relations:

where  $t_U^* = 2ft_U$  is a relative durability of inverter voltage pulses  
f – voltage frequency conversion

$$U_{fessd}^* = \frac{U_{fessd}(t)}{U_{fessd min}} - \text{VPS power supply relative voltage}$$

$$R_{ch}^* = \frac{R_{ch}(t)}{R_{ch max}} - \text{cathode heater relative resistance}$$

$$G_{acd}^* = \frac{G_{acd}(t)}{G_{acd min}} - \text{relative conductivity of discharge channel in anomalous mode.}$$

The minimal conductivity of the discharge channel in anomalous mode is determined by ratios:

$$G_{acd min} = \frac{I_{d lim}}{U_d}$$

At anomalous mode of conductivity, the requirements to  $U_d$  stability are not presented.

The stabilization of additional current of magnetic coils in function from  $U_{fessd}$  is provided at  $U_d$  stabilization, but in dependence of change of summarized resistance of magnetic coils  $R_{mc}$  by uninterruptable current stabilizer. Thanks to the mentioned additional current the pulses of magnetic coils are minimal.

The power supply of the heater, cathode discharge and magnetic coils of each thruster is performed from separate voltage converter (VC) with three channel output produced as per pseudo two-cycle scheme from single-cycle converters. The set output power of consumers in transient mode of thruster igniting is:

where 0.65 is a discharge current index  $I_d$  corresponding to thruster operation mode starting.

The summarized output power of the converter in operation mode of the thruster:

In PPU-CV the nominal values of output power of three channel converter in the start-up mode as well as in operational one are respectively 250W and 242W.

It should be noted that the usage of multichannel voltage conversion in PPU-CV with common PDM controller combining stabilization functions of power supply parameters of each output of the converter enabled to provide acceptable mass and dimensions for PPU-CV.

The pressure regulators heaters of xenon storage and supply system of XSSS and electric valves of VPS in holding mode are supplied with electric power from an auxiliary power source made according to the self-oscillator scheme with multichannel output. The current for thermal throttle of standby and operation modes is generated by individual converters - current controllers.

Along with the concordance of VPS power consumers the PPU-CV receives and executes 22 commands, generates and transmits analog (10) and signal telemetric data (6).

### References

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