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BTVCS FUNCTIONAL CIRCUIT ON ONE CONTROL CHANNEL OF THE MID-FLIGHT SPACE ROCKET STAGE ENGINE

Annatation. The article is devoted to the development and describing the functional circuit of bifunctional thrust vector control system, consisting of an interceptor unit with fuel component injection, as the executive body of the gas dynamic thrust vector control system for trust vector direction on one regulation channel and exhaust nozzle systems, as the executive body of the additional control system channel.

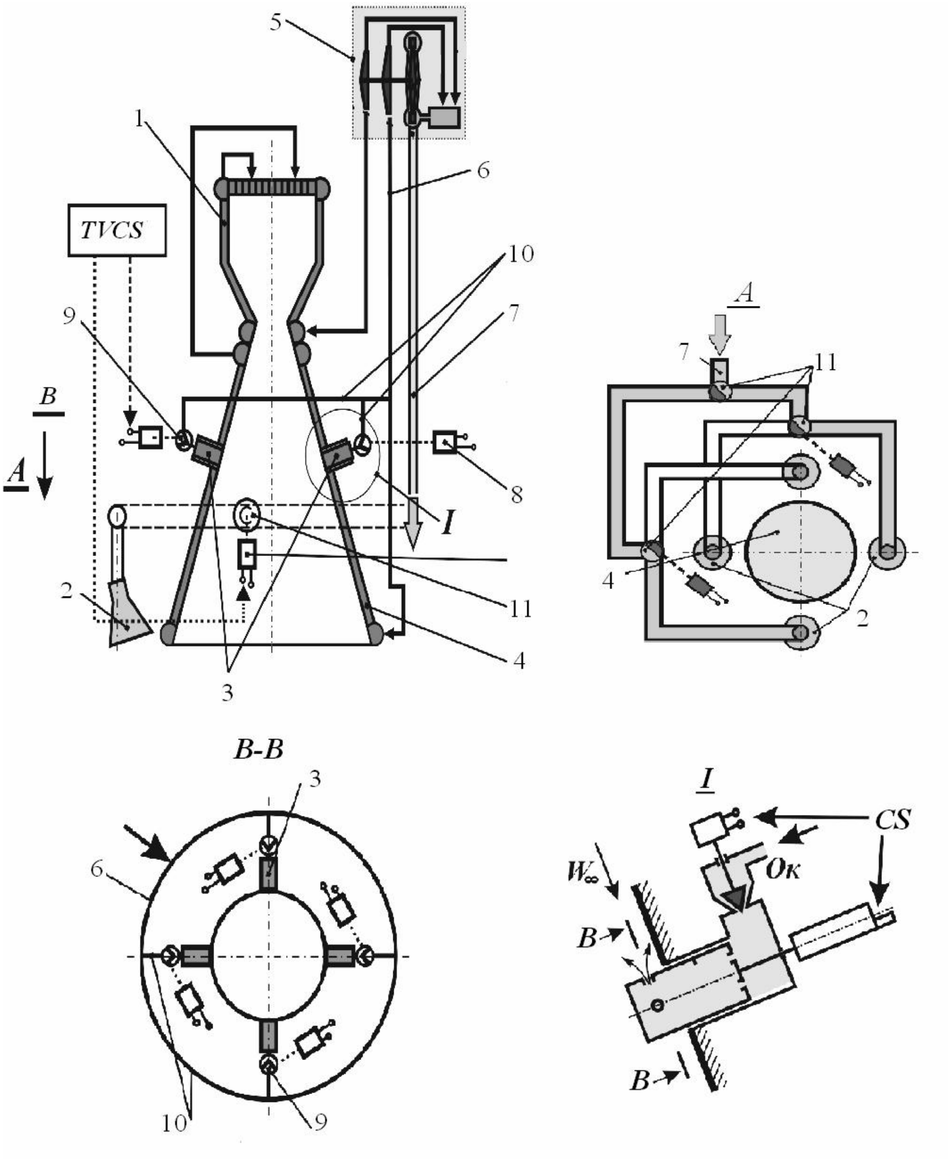
Keywords: thrust vector, control system, rocket stage, executive body, circuit.

Introduction. Due to the specifics of their mission, current and future space rocket stages (RS) operate in conditions of changing mass-centering characteristics and dynamic features. A bifunctional thrust vector control system (BTVCS) [1] of the engine, which implies the cumulative (joint) use of executive control system bodies of different functionalities with rational functional task distribution among them, can be used to control RS. The BTVCS executive bodies are selected to be able to ensure optimum thrust vector engine control for solving specific stage flight tasks without a significant reduction in the energy-mass RS characteristics. In this case, the BTVCS executive bodies must solve the problems of control and flight stabilization and be able to parry deterministic perturbing factors caused with changes in the stage mass-centering characteristics.

Analysis of publications. For advanced RS (booster blocks, space tugs), a BTVCS with a large interceptor gas-dynamic thrust vector control system (GSTVCS) and a system of control jet nozzles was proposed [1]. Control nozzles solve successfully the task of control and stabilization of the stage motion. The GDTVCS is based on the advancement into a supersonic nozzle flow (closer to the critical section) the solid large interceptors (circular or flat solid obstacles) with simultaneous injection of liquid propellant components through them [2].

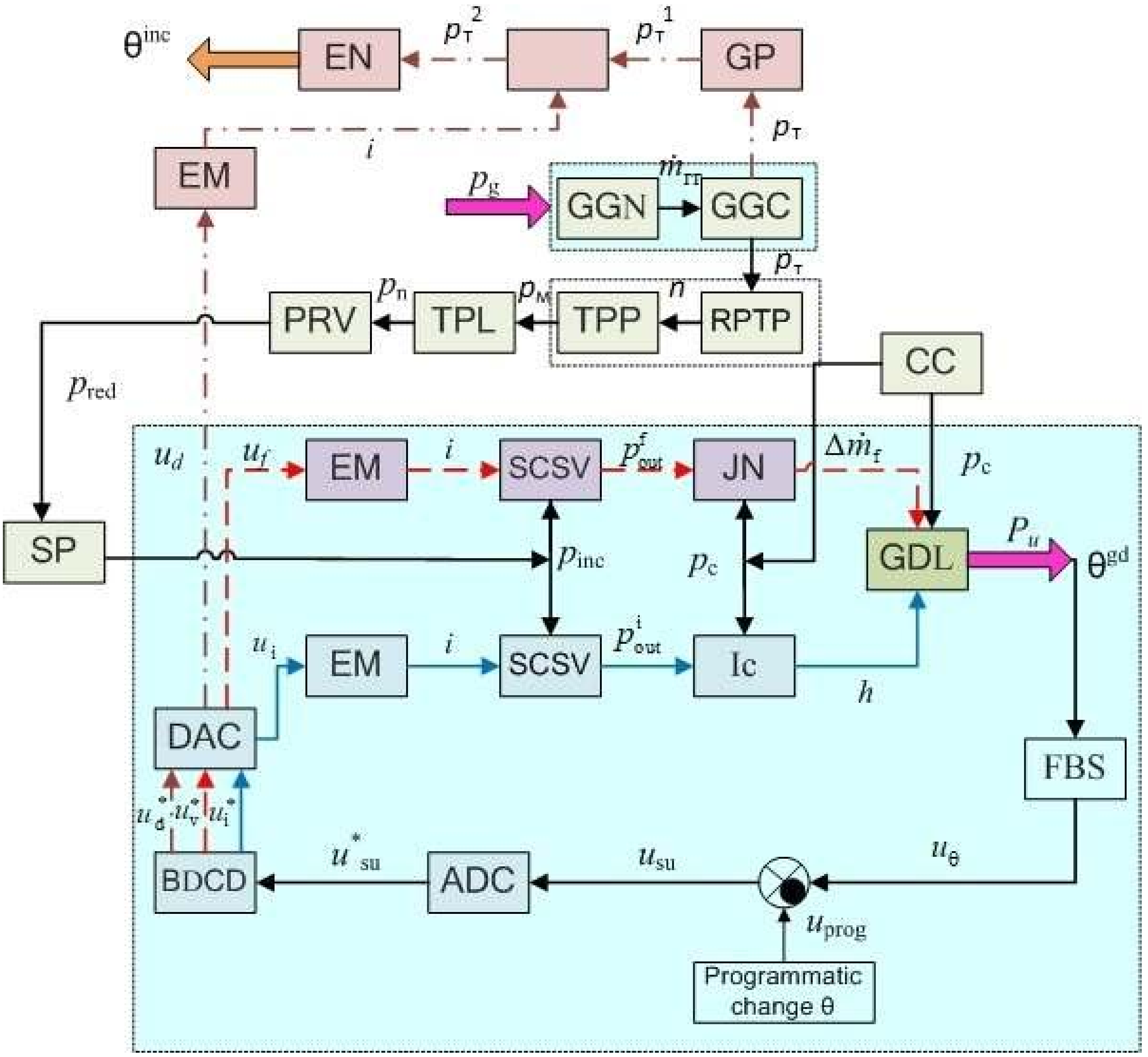
The aim of the work is to develop and substantiate the functional circuit of the bifunctional thrust vector control system on one control channel of the mid-flight RS engine.

Results and discussion. The described GDTVCS is able to parry large disturbances from changes in the mass-centering characteristics. Liquid injection solves the problem of protecting the interceptor from the effects of high-temperature and erosive supersonic flow, creates additional easily adjustable lateral forces and reduces the interceptor sizes. The conceptual circuit of the BSVT is shown in fig.1.



1 – combustion chamber; 2 – exhaust nozzles; 3 – injection units; 4 – nozzle;
5– turbopump device; 6 – high-pressure line; 7 – gas pipe; 8 – drive unit;
9 - discharge control; 10 – turbo drive; 11 – gas distributor
Figure – 1 BTVCS with interceptor system and exhaust nozzles

Functional circuit of BTVCS operation consisting of an interceptor unit with fuel component injection, as the executive body of the gas dynamic thrust vector control system with trust vector direction (one regulation channel, for example, yaw) and exhaust nozzle systems, as the executive body of the additional TVCS channel shown in fig. 2. The figure shows the internal connections between the components of the TVCS and the units, which ensure the component feeding to the executive bodies.



ADC - analog-to-digital converter; BDCD - onboard digital computing device; EN - exhaust nozzles; GP – gas pipe; GGC - gas generator chamber; GGN - gas generator nozzles; GDL - gas dynamic link; FBS- feedback sensor; SCSV- shut-off control solenoid valve; Ic- interceptor; CC - combustion chamber; PRV - pressure reducing valve; TPL -trunk pipelines; TPP- turbo pump pumps; FPL – feed pipe-line; PTHA PTNA - the rotor - turbo pump; JN - jet nozzle; RS - digital-to-analog converter; EM - Electromagnet

Figure 2 – BTVCS functional circuit on one control channel of the RS mid-flight engine

For clarity, the dynamic connection display on the circuit the executive body is divided into two dynamic links: an electromagnetic link (EM) and a shut-off control valve (SCV or SCSV), shut-off regulating organ (controlled throttle) of which is rigidly connected to the keeper of the electromagnetic converter. The component is injected through a jet nozzle (JN) inside the interceptor rod. The component consumption in the jet nozzle (forelock) is also regulated by the drive with the SCV.

When the rocket axis deviates from the position specified by the flight program, the control system records this deviation $\Delta\theta$ and generates a voltage u_{θ} proportional to the deviation. As a result of comparing this voltage with the program voltage u_{progr} , a control system signal $u_{\text{ñs}} = u_{\text{progr}} - u_{\theta}$ is generated at the summing device output. The input continuous signal $u_{\text{ñs}}(t)$ in the analog-digital converter (ADC) is converted into a discrete sequence $u^{*}_{\text{ñs}}[nT]$ of numbers (*T* is the quantization period), which fed the digital computing device input (BDCD). Here, in accordance with the algorithm embedded in signal, the input signal, is distributed between the CS channels by a synchronous sequence of numbers $u^{*}_{\text{E}}[nT]$, $u^{*}_{\text{I}}[nT]$, $u^{*}_{\text{N}}[nT]$, which is converted in a digital-to-analog converter (DAC) into a continuous signal u_{E} to the executive bodies CS drive of the stabilization channel, u_{I} - to the interceptor drive and u_{N} - to the drive of the injection . The voltage for each channel, denoted as u for short, generates an electric current *i* in the coil of an electromagnet (EM). The electromotive force moves on an amount *x* the keeper of the EMD, adjusting the parameters of the flow area of the shut off control valve throttle part (SCV) or the gas distributor for the EN. In the GDTVCS the flow rate of the component coming from the SCV regulates the force ratio acting on the interceptor and ensures the interceptor extension to the supersonic part of the engine nozzle on the value *h*. The obstacle created by the interceptor realizes a shock wave. Behind the shock wave, an area of increased pressure is formed, where the gas jet deviates (angle θ^{gd}) toward the nozzle axis, which causes the entire gas flow deflection and thereby there creates the thrust nozzle eccentricity with a direction opposite to the gas flow deviation. The injection control occurs autonomously from the interceptor motion control, expanding the control system functionality. The voltage regulates the displacement *x* of the EM keeper, which, in turn, regulates the throttle resistance in front of the jet nozzle. When the fuel component is injected through the channel in the interceptor (jet nozzle), the liquid component (consumption $\dot{m}_{\text{i}}$) enters with a pressure in the supersonic part of the nozzle. At the boundary between the supersonic flow and the vapor phase of the liquid, an additional shock wave is realized, creating an additional lateral force P_y. The dependence of the lateral force on the parameters of the interceptor and injection is the gas-dynamic link (GDL).

The feedback sensor (FBS), which is an inductive angle converter (potentiometer), monitors the deflection angle of the thrust vector. Sensor data are continuously read by the control system. These data are analyzed and the computers compares them with their given limit values. As a result, certain solutions are developed, which are also continuously transmitted in the command form to the execution to the relevant automation devices.

Studies [3] show the possibility of an optimal algorithm developing (in terms of the functional and dimensional characteristics of the rocket engine) for splitting the input signal between various executive bodies of the BTVCS.

Conclusions. A functional circuit for the BTVCS of the liquid mid-engine RS was developed. The combined control system allows to significantly expanding the range of engine thrust vector control with the help of the functional duty distribution between different executive bodies, expanding the stability area of flight stabilization modes, increasing reliability and reducing power consumption for RS flight control.

ЛИТЕРАТУРА

1 Kovalenko N.D. The new concept of thrust vector control for rocket engine / N.D. Kovalenko, Ю. Д. Sheptun, T.A. Kovalenko, G.A. Strelnikov // Системні технології. – 2016. – № 6 (107). – С. 120 – 127.

2 Коваленко Н. Д. Ракетный двигатель как исполнительный орган системы управления полетом ракет : монография / Николай Дмитриевич Коваленко. – Днепропетровск : Институт технической механики НАН и НКА Украины, 2004. – 412 с.

3 Стрельников Г.А. Разработка структурной схемы бифункциональной системы управления вектором тяги ракетного двигателя / Г. А. Стрельников, Е. Л. Токарева, Н. С. Прядко, А. Д. Игнатьев // Техническая механика. – 2018. – № 4. – 57 – 67 с.

REFERENCES

1 Kovalenko N.D. The new concept of thrust vector control for rocket engine / N.D. Kovalenko, Ю. Д. Sheptun, T.A. Kovalenko, G.A. Strelnikov // Системні технології. – 2016. – № 6 (107). – С. 120 – 127.

2 Kovalenko N. D. Raketnyiy dvigatel kak ispolnitelnyiy organ sistemyi upravleniya poletom raket : monografiya / Nikolay Dmitrievich Kovalenko. – Dnepropetrovsk : Institut tehnicheskoy mehaniki NAN i NKA Ukrainyi, 2004. – 412 s.

3 Strelnikov G. A. Razrabotka strukturnoy shemyi bifunktsionalnoy sistemyi upravleniya vektorom tyagi raketnogo dvigatelya / G. A. Strelnikov, E. L. Tokareva, N. S. Pryadko, A. D. Ignatev // Tehnicheskaya mehanika. – 2018. – # 4. – 57 – 67 s.