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INTEGRATED MODEL OF CHANNELS OF POWER SUPPLIES OF A STATIONARY PLASMA ENGINE

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The integrated model of power supply channels of a stationary plasma engine, including models of the solar battery, the anode – cathode discharge channel and systems of power supplies is investigated. The algorithm of functioning of model and the diagrams of current and voltage of discharge for various engine work modes is shown. With the help of the obtained diagrams the greatest overregulation in system with four closed feedback is determined and on the basis of «the filter hypothesis» the conclusion about its stability is made. The proposed model allows to simulate all operating modes of power supplies system, and also to model various variants of start of the engine and work of various types of thermochokes.

Last years computer modeling of various devices draws significant attention as it allows to reduce time and to decrease essentially expenses for development of devices. It is especially important for systems which complex research is inconvenient, or demands the big material costs. The device of start and power supplies of stationary plasma engine (SPE) which primary source is solar battery (SB), and the loading is SPE, capable to work only in deep vacuum conditions.

The purpose of modeling – to obtain exact idea about the processes occurring in the circuit of the SPE device of start and power supplies in all modes of its work, to define basic features of control and to carry out the analysis of the circuit stability. Hence, the integrated model of channels of SPE power supplies should include models of SB, SPE and SPE devices of start and power supplies.

The voltaic – ampere characteristic (VAC) of a SB is described by expression [1]

$$I_{сб} = I_{к.з}\left(1-\exp\left(\begin{gathered}\left(\frac{U_{сб}}{U_{х.х}}-1\right)\times\\ \times\ln\left(1-\frac{I_{опт}}{I_{к.з}}\right)/\left(\frac{U_{опт}}{U_{х.х}}-1\right)\end{gathered}\right)\right), \qquad (1)$$

where I_{sc} is a short circuit current of s SB (at U_{sb}=0); U_{sb} is the instant value of a output voltage; $U_{x.x}$ is the maximal output voltage (at I_{sb}=0); I_{opt} and U_{opt} are the optimal current and voltage corresponding to the maximal power.

The channel of the SPE anode – cathode discharge has complex nonlinear VAC with a site of negative dynamic resistance that does not allow to describe its with one mathematical expression. In a general view of the SPE discharge VAC can be presented as follows [2]:

$$I_{р} = \begin{cases} 0, \text{ при } U_{р} < 70\text{ В}, \\ \dfrac{eI_{тд}}{\dot m}\sqrt[4]{\left(\dfrac{U_{р}-U_{з}}{U_{рi}-U_{з}}\right)}\left(1+V_{ex}\sqrt{\dfrac{M}{2e(U_{р}-{}^\wedge U_{з})}}\right), \\ \qquad \text{при } 70\text{ В} < U_{р} < U_{рi}, \\ \dfrac{eI_{тд}}{\dot m}(1+0,00065\cdot(U_{р}-U_{рi}))\times \\ \qquad \times\left(1+V_{ex}\sqrt{\dfrac{M}{2e(U_{р}-{}^\wedge U_{з})}}\right), \\ \qquad \text{при } U_{р} > U_{рi}, \end{cases} \qquad (2)$$

where e – is the electron charge (1,6·10^{-19} K); $I_{тд}$ is the thermochoke current; $\dot m$ is the minute flow rate of the working substance; U_d is the discharge pressure; U_z is the voltage at which the discharge current appears; U_{pi} is the voltage discharge corresponding to the ginning of a site of negative resistance; V_{ex} is velocity of a plasma jet on engine nozzle output (about 6000 m/s); $^\wedge U_з$ is a variable component (pulsations) of a discharge voltage.

To realize expressions (2) in model by the analytical way is sufficiently difficult, therefore the table method of function description is used. In the system of through designing of electronic devices Orcad 9.2 it is realized on the basis of block G_table presenting the model of a current source, controlled by voltage. Obtained VAC is shown on Fig. 1.

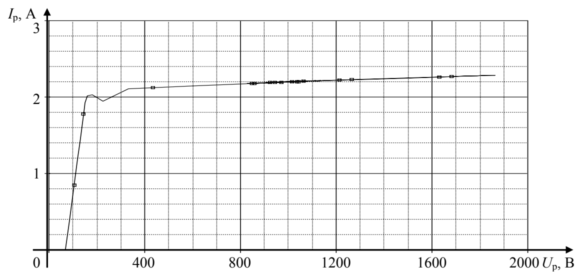

Рис. 1. *ВАХ канала анод – катод*

The model of the SPE device of start and power supplies from one side should be a link between models of SB and SPE, and from other side – to reflect adequately circuit reaction at influence on its inputs of signals changing in time. Based on this experience the integrated model of anode – cathode power supply channels, a cathode heater (CH), a fire electrode (FE) and a themochoke with the closed feedback, is developed (Fig. 2). It is made on the basis of the combined device of start and power supplies of the SPE [3]. It is realized by three pairs of functional blocks: G1-E1, G3-E2, and G4-E3. The current sources controlled by voltage G1, G3, and G4, are load for SB model (G2) therefore their problem is transformation of a anode – cathode load current into SB load current, thus their VAC is defined as

$$I_{G1} = \frac{U_{E1}+U_{E2}+U_{E3}}{3U_{сб.хх}}(I_{G6}+I_{хх}) \approx$$

$$\approx \frac{U_{E1}+U_{E2}+U_{E3}}{3U_{сб.хх}}\cdot\eta\cdot\frac{U_{IOS}}{R_{14}}\cdot\frac{U_{OS}\,(R_3+R_{26})}{R_{26}\,(U_{E1}+U_{E2}+U_{E3})},$$

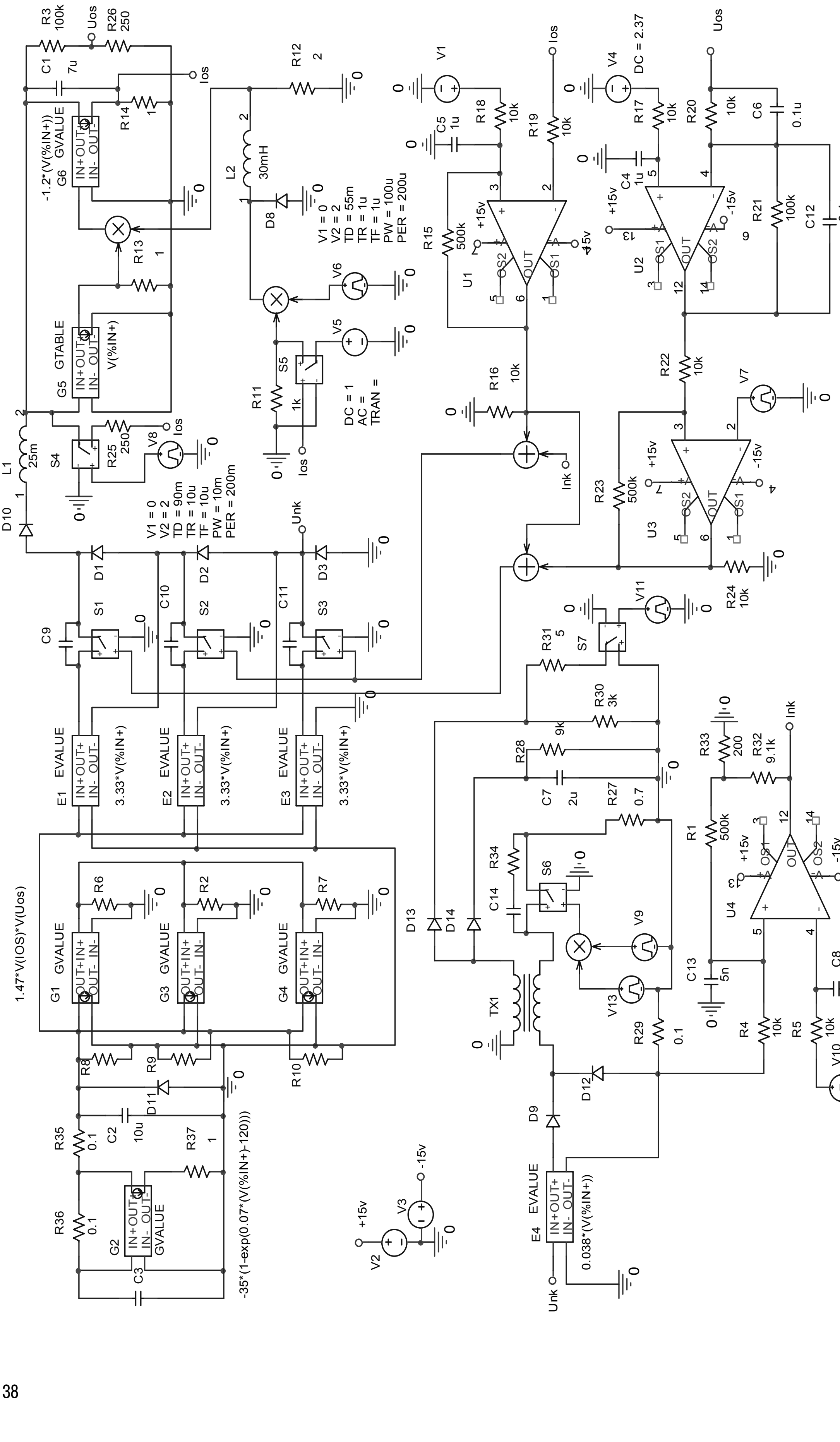

Fig. 2. *The integrated model of the SPE power supply channels*

where $I_{xx}=I_{R3}=I_{R26}$; $U_{\text{сб.xx}}$ is SB idling voltage; η is efficiency of the device of start and power supplies (0,85...0,92); U_{IOS} is the discharge current sensor signal; U_{OS} – is the anode – cathode voltage sensor signal.

Dependent sources E1-E3 play a role of constant voltage transformers with such transformation factor that the total output voltage should be not less than nominal value $U_{\text{p.nom}}$ then

$$U_{E1}=\frac{U_{\text{р.ном}}}{3U_{\text{вх.мин}}}U_{\text{сб}},$$

where $U_{\text{d.nom}}$ is the nominal voltage of the anode – cathode discharge; $U_{\text{in. min}}$ – the minimal input voltage.

Thus the discharge voltage is the sum

$$U_p=U_{E1}\gamma_{S1}+U_{E2}\gamma_{S2}+U_{E3}\gamma_{S3},$$

Where γ_{S1}, γ_{S2}, γ_{S3} are adjusting characteristics of keys S1-S3 (0...1).

The stabilization channel of a discharge voltage is made as unilateral wide – pulse – modulated regulator (U2, U3) with modulation of forward front and an inertial part (R20, C6) on the basis of dynamic models of operational amplifiers. The channel of discharge current limitation is made as a relay regulator on the basis of dynamic model of high-speed operational amplifier LT1037CS (U1). As change of HC resistance has inertial character, and the HC current channel is an electric circuit of the first order (L_{TX1}, R_{27}), its control system is made on the basis of a relay regulator (U4). The closed feedback (S5) on load resistance (the flow rate of working substance) allows to obtain more exact representation about operating modes of circuit elements in comparison with laboratory researches of physical breadboard models on active loading.

Operating modes of the start and power supplies device are caused by a principle of SPE action, on which basis the plan of research is made, which in model is realized by algorithm of work of independent sources (Fig. 3).

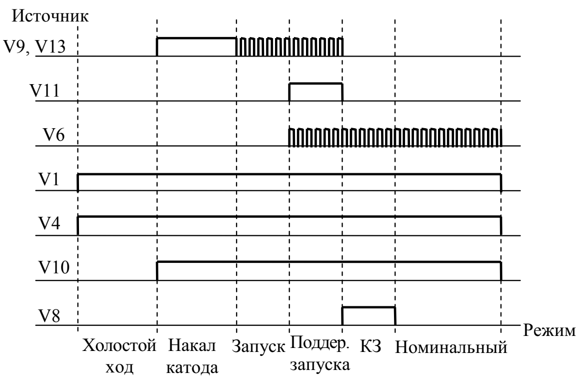

Fig. 3. *Algorithm of work of model at research of SPE work modes*

As the result of modeling diagrams of currents and voltage on all elements of the circuit are obtained. On their basis the conclusion about serviceability of the circuit and occurring processes is made. Diagrams of work of SPE power supplies channels in various modes are shown on Fig. 4.

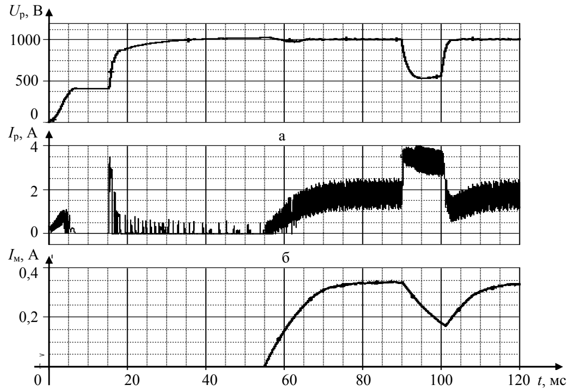

Fig. 4. *Diagrams of work of the model: a) voltage and b) a current of the channel the anode – the cathode; c) consumption of the work substance counted in current units*

On the basis of the obtained diagrams it is possible to carry out the analysis of stability of the circuit under the transitive characteristic. For this purpose it is necessary to define the greatest overregulation in system. The greatest overregulation of discharge anode – cathode voltage and oscillatory process (Fig. 4, *a*) arise at the moment of discharge current occurrence (Fig. 4, *b*) at supply of work substance in the discharge chamber (Fig. 4, *c*). Value of overregulation *?h* for this case is

$$\Delta h=\frac{U_{\text{макс}}-U_{\text{ном}}}{U_{\text{ном}}}\cdot 100\,\%=\frac{1035-1000}{1000}\cdot 100\,\%=3,5\,\%.$$

According to «the filter hypothesis» the system is considered as stable (with reserve on phase γ_c>30°), if overregulation in damping transient process Δh<30 %.

The developed model allows to simulate all operating modes of the device of start and power supplies of SPE on the basis of the combined converter, as well as to model various variants of start of the engine and work of various types of thermochokes. The model is developed taking into account nonlinearity of power supply VAKH (SB) and the site of negative dynamic resistance of loading (the channel of the anode – cathode discharge of SPD). The closed feedback on loading resistance (consumption of work substance) allows to obtain more exact representation about operating modes of circuit elements in comparison with laboratory researches of physical models at work on active loading

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