Evaporation - Type Resistor Thruster with Thermal Catalytic Decomposition of Hydrazine[1][2]

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EDB "Fakel" has offered a new method of the organization of a rocket thruster on liquid propellant operational process and the rocket thruster itself for the idea realization.//
The method is intended for application in the field of space engineering at creation of rocket thrusters on liquid propellant and gas-generators.
Application of the given way of the organization of working process of the rocket thruster on liquid propellant provides high specific characteristics at low thermal losses, a high flight and operational life-time resource, reliability and stability of the rocket thruster operation.
The method includes preliminary evaporation and submission of liquid propellant vapor in a thermal catalytic pack of the thruster, thermal catalytic decomposition of propellant and the outflowing of products of decomposition through gas-dynamic jet.
In addition, the evaporation of propellant components is carry out, increasing thermal power on evaporation under condition of following dependence being true: Tvapor < Tcr, where Tvapor - temperature of vapor, Tcr - temperature of thermal stability loss of a propellant component. Moreover, the evaporation of liquid propellant is realized with a delay equal to duration of thermal inertia of an evaporator material.
The rocket thruster on liquid propellant for realization of the proposal contains an evaporator, a chamber of thermal catalytic decomposition, a unit of propellant supply in a face part of the chamber and gas-dynamic jet. A permeable material bed or gas-dynamic decoupling with high thermal resistance may be located between the evaporator and the thermal catalytic pack.
The results of parametric researches have shown that desirable reduction of weight of stationary communication satellites to a great extent may be achieved due to improvement of characteristics of rocket thrusters on liquid propellant used in satellite stabilization system./i/

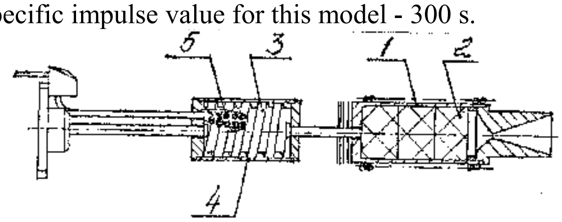
[1] Presented as Paper IEPC-01-000 at the 27th International Electric Propulsion Conference, Pasadena, CA, 15-19 October, 2001.

The analysis of results of experimental adjustment of hydrazine thermal electrocatalytic thruster (TECT) with an additional supply of vapor-type energy - K10 PG thruster./ii/

In 1989-1991 years in EDB "Fakel" had been designed, manufactured and passed firing tests engineering models of thruster working by K10PG evaporation scheme and by TK10/3000 overheating scheme.

Available technological difficulties of overheat-type thrusters (such as EDB "Fakel" produced TK10/3000 engineering models) do not arise in thrusters such as K10PG, working by evaporation scheme at heat-exchanger temperature 120-160°C. In contrast to the overheat-type TEST, additional energy is brought not to products of hydrazine decomposition, but to liquid propellant and is spent for its evaporation in a special steam generator, after that vaporous hydrazine is decomposed in the chamber of a thruster due to thermocatalysis.

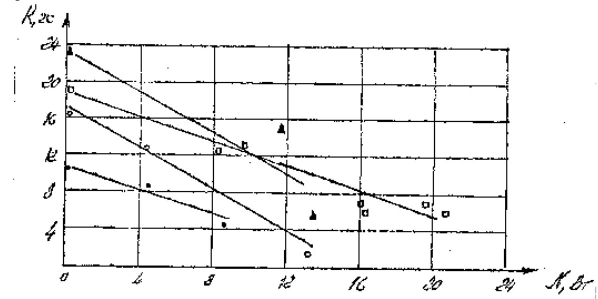
The evaporation chamber input electric power is limited practically to a heat of hydrazine evaporation Ievap=1,5 kJ/g, that defines the top limit of a specific impulse value for this model - 300 s.



Pic 1 Drawing of a thruster of modification 1. 1 - the thruster chamber, 2 - the metal catalyst, 3 - auger, 4 - the case of a steam generator, 5 – heater.

The modification 1 of K10PG thruster design (the thruster N2), which contains K10 chamber and heat-exchanger (vapor generator) installed on the hydrazine supply line is shown on pic.1. Propellant in the heat-exchanger is heated up from located inside the gas-generator auger of an electric cable, passing through the channel formed by an internal surface of a wall of the case and the auger.

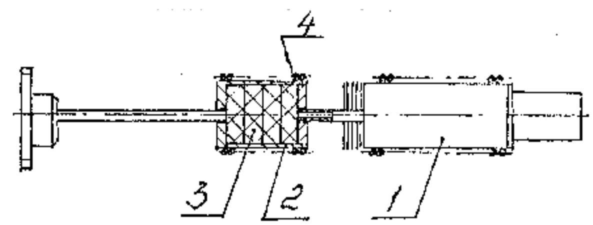
In the given design, boiling of hydrazine in the vapor-generator channel occurred, basically, due to heat acting from the chamber of decomposition, and caused increase of pressure difference on it, that resulted in sharp pressure drop in the chamber of the thruster, the thrust reduction (see fig. 2), pressure fluctuations in the chamber up to 200 %, increase of temperatures at an output from a vapor-generator up to 250-270°C.Because of it there has been no increase of a specific impulse at an input of additional power in comparison with the specific impulse received at zero power on a vapor-generator.



Pic 2 Dependence of thrust of K10PG thruster from input power. ▲ - Pin=6 kgf/sm2, - Pin=7 kgf/sm2, - Pin=4 kgf/sm2ı - Pin=3 kgf/sm2

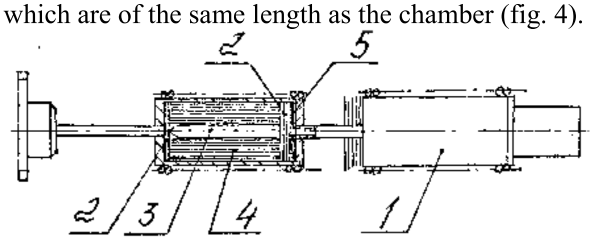
For elimination of the specified drawbacks the second and third variants of a vapor-generator were developed:

Modification 2 (the thruster N 5) - the cylindrical chamber filled with wire briquettes (fig. 3);



Pic 3. Drawing of a thruster of modification 2. 1 - the chamber of the thruster, 2 - the vapor-generator body, 3 - wire briquettes, 4 - heater.

Modification 3 (the thruster N11) - the cylindrical chamber, filled with lengthwise located needles which are of the same length as the chamber (fig. 4).



Rice 4. Drawing of a thruster of modification 3. 1 - the chamber of the thruster, 2 - a grid, 3 - a core, 4 - needles made from a wire, 5 - fibrous heat insulation linings

The changes had an objective to increase a surface of heat exchange and through passage sections for a liquid-vapor mixture.

For the thruster N5 (modification 2), the increase of a specific impulse (see fig. 5) was observed. The greatest specific power submitted on a vapor-generator, was 1,014 kJ/g (at specific heat of hydrazine evaporation Ievap=1,5 kJ/g).

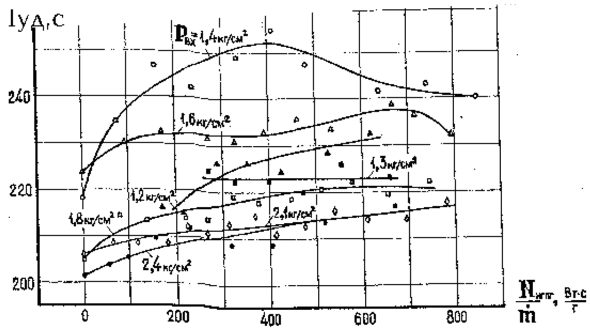
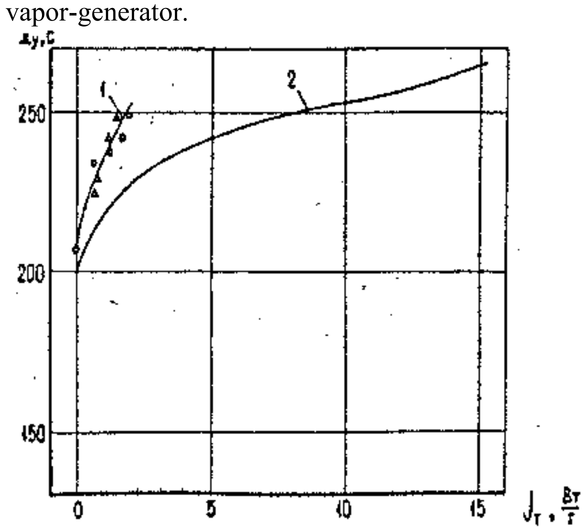


Fig 5 Dependence of a specific impulse of thrust from specific power input for K10PG N5 thruster on the established stationary modes.

For the thruster N11 (modification 3), the area of steady work of the design in a vapor-generation mode was limited to power input 8 W. (the maximal specific input power on a vapor-generator was 0,2 kJ/g). At higher power, the vapor-generator switched in a mode of propellant decomposition.

The comparative analysis of a specific impulse dependency from the price of thrust (fig.6) for over-heat and evaporation types of thrusters shows, that at the price of thrust of 2 W/g the effectiveness of K10 PG thruster is much higher, than the effectiveness of TK10/3000. It is explained by smaller thermal losses of. However, at the price of thrust of more than 2W/g the advantage of K10 PG begins to decrease, as the temperature limiting mode of the vapor-generator is being achieved, at which long operation of K10 PG thruster is impossible because of the beginning of hydrazine vapor decomposition in the vapor-generator.



Rice 6 Dependence of a specific impulse of thrust Iy from the price of thrust Jt of thrusters 1 - K10PG N05 and N11 and 2 - TK10/3000.

The further design modifications of the thruster with a power input up to the level of propellant decomposition should be carried out on a way of improvement of heat transfer process from a hot surface of heat-exchanger to propellant that will allow to avoid local rise in temperature of the walls, causing hydrazine decomposition inside the vapor generator.

With this purpose EDB "Fakel" has offered a new method of the organization of operational process of a rocket thruster on liquid propellant and the rocket thruster itself for the idea realization.

Below, the general aspects of the offered method and designs of its realization, as well as the parameters of laboratory models being manufactured in EDB "Fakel" are described.

The method of the organization of operational process of a rocket thruster on liquid propellant and the rocket thruster itself for the idea realization

According to this method of the organization of working process of the rocket thruster on liquid propellant, based on catalytic decomposition of liquid propellant, a single component liquid propellant is submitted to a reactor filled with a catalystically active material, then it is evaporated and decomposed at a contact with a catalystically active material, and finally high-temperature products of decomposition are deleted from the reactionary chamber through the nozzle. Expiring from the nozzle products of decomposition create jet thrust. The higher the speed of outcoming and quantity of products of decomposition, the higher the thrust created by the thruster. [iii]

However, the speed of outcoming at a catalytic way of decomposition of liquid propellant is limited to a level of its chemical energy.

The method of the organization of working process of the rocket thruster on liquid propellant, based on an electrothermal way of decomposition of liquid propellant [iv], consists of a preliminary heating of a catalytic pack, submission of liquid propellant into a catalytic pack, decomposition of liquid propellant, moving of products of decomposition of liquid propellant in the heat exchange chamber, supply to products of decomposition of liquid propellant of thermal energy from an electric heater and release of high-temperature products of decomposition through the nozzle.

According to the specified method, high value of a specific impulse is achieved due to summation of the chemical energy released at exothermic decomposition of propellant, for example hydrazine, and the electric energy input to high-temperature products of decomposition.

However, at the electrothermal way of decomposition of liquid propellant, the speed of outcoming is limited by a level of input electric energy, by losses of energy used for endothermal decomposition of the components making up the products of decomposition, for example ammonia, using hydrazine as single component liquid propellant, as well as by losses of heat for radiation in high-temperature heat-exchanger.

At catalytic thermal way of decomposition of liquid propellant, the catalytically active material and supplied material are preliminary warmed up in order to reduce dynamic loadings on the catalytic material. The level of dynamic loadings is proportional to a difference of temperatures a heated material and incoming liquid propellant. Here, the level of additional energy input to a working fluid is insignificantly small in comparison with evolved at propellant decomposition chemical energy and practically does not influence on the speed increase of the expiration of products of decomposition.

However, speed of the expiration at the catalytic thermal way of decomposition of liquid propellant is limited to a level of chemical energy of liquid propellant and time of stay of products of decomposition in the chamber of the thruster. Reduction of time of stay reduces the quantity of endothermally decomposed components making up ПР.

Application of known ways of additional energy supply to products of decomposition does not allow to receive high specific characteristics, to reduce thermal losses, to provide a high flight and working resource of the thruster, and also high requirements to reliability and stability of operation.

The method of the organization of working process of the rocket thruster on liquid propellant and the rocket thruster on liquid propellant itself for the idea realization [v], provides for preliminary warming up of the chamber of catalytic decomposition, submission of components of liquid propellant (LP) through unit of injection in a face part of the chamber, catalytic thermal LP decomposition on a surface of catalytic material and the expiration of products of decomposition through the gas-dynamic nozzle.

In the given thruster, return thermal and high-temperature mass eddy flows from products of decomposition transfer thermal power in the zone of evaporation, creates local overheats of propellant above the limit of loss of thermochemical stability and provides the conditions of thermal decomposition of propellant in free volume the catalytic thermal pack.

The EDB "Fakel" invention is based on the initial task of creation of a method of the organization of the operational process providing reception of high specific characteristics at low thermal losses, and the rocket thruster on liquid propellant having high flight and working resources, reliability and stability of work ..

The task in view is solved because in the known way of the organization of operational process of the rocket thruster on liquid propellant, consisting of preliminary warming up of the chamber of catalytic thermal decomposition, submission of components of liquid propellant through the unit of propellant supply in a face part of the chamber, catalytic thermal decomposition of LP and the expiration of products of decomposition through gas-dynamic nozzle, according to the invention, were realized following changes. After the injection of liquid propellant, it is preliminary evaporated at low temperature potential and, as consequence, - at small thermal losses, and then propellant vapor is submitted to the chamber of catalytic thermal decomposition.

In addition, in order to prevent decomposition of a propellant component vapor in the zone of evaporation, hence, to maintain the peak efficiency of the offered method, simultaneously with liquid propellant submission in the chamber the thermal power for propellant evaporation is increased given that the following dependence is true: Tvapor < Tcr, where Tvapor - temperature of vapor, Tcr - temperature of thermal stability loss of a propellant component.

Moreover, for the reduction of duration of the initial stage of process of evaporation from the moment of submission of liquid propellant to the zone of evaporation prior to the beginning of evaporation itself, the evaporation of liquid propellant is realized with a delay equal to duration of thermal inertia of an evaporator material. That is, firstly, the thermal electric power submitted to current contacts of the evaporator is increased, and then with the time delay determined by thermal inertia of a material, propellant is supplied to the zone of evaporation. Thus, time of the beginning of evaporation decreases by the value determined by thermal inertia of a material, and operation speed of the thruster increases.

For realization of the given method in the known thruster containing the chamber of catalytic thermal decomposition, the unit of propellant supply in the face part of the chamber and the gas-dynamic nozzle, according to the invention, the evaporator executed from permeable catalytically-inactive conducting material, provided with current contacts is installed between the unit of propellant supply and the catalytic thermal pack.

In order to prevent the return thermal flow from the decomposition products to the zone of evaporation and to increase the level of supplied thermal power, a layer of permeable material with high thermal resistance could be placed between the evaporator and the thermal catalytic pack.

A gas-dynamic decoupling could be installed between the evaporator and thermal catalytic pack with the purpose of preventing thermal transfer back into the evaporation zone by eddy mass flows of decomposition products.

In addition, for increase of efficiency of the thruster at the expense of prevention of losses of thermal energy for endothermal decomposition of ammonia, the sizes and a materials of catalytic thermal pack are chosen such that the components of decomposition products are in optimal proportion during the vapor-stage of catalytic thermal decomposition, as well as the outflow of the formed products of decomposition is carried out if expirations chemically frozen.

The condition of catalytic thermal decomposition of propellant in a vapor-phase is understood as a choice of a material of the catalyst or an inert structure, definition mass-dimensional characteristics of the catalytic thermal pack (weight, a dyne of diameter, porosity), providing full (up to 100 %) and effective (from the point of view of reception of an optimum ratio of products of decomposition) transformations of propellant.

The calculation of parameters of processes in a layer of the catalyst or inert porous structure (temperatures, structure of products of decomposition) is carried out on the basis of the known mathematical models which are taking into account physical and chemical transformations of a working fluid and hydrodynamics of its current in a layer [vi,vii].

Chemically frozen is such an expiration at which the time of chemical processes realization is less than time of a presence in characteristic volume, for example in the volume limited by an internal surface of the nozzle. It could be considered, that such an expiration takes place in the nozzle of a rocket thruster on liquid single-component propellant, since time of stay of gas is less than time necessary for the course of chemical dissociation of products of its decomposition (for example, ammonia if single-component propellant is hydrazine) [viii]. Methods of calculation of isentropic expansion in in a nozzle for the case of chemically frozen current are presented in details in [ix].

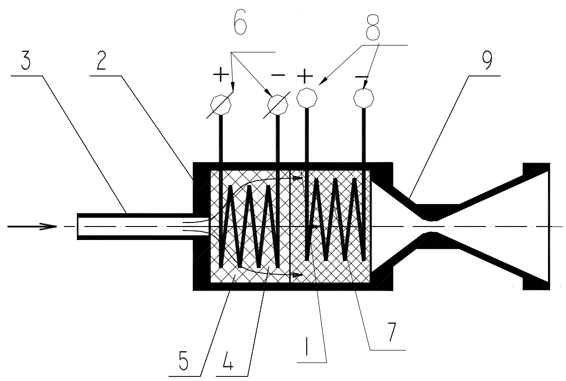
The invention is illustrated by drawings. On fig 7 the lengthwise section of the thruster, on figs 8 – the section of the thruster with a permeable layer of a high thermal resistance material, on figs 9 - section of the thruster with a high thermal resistance gas-dynamic decoupling are presented.

The rocket thruster on liquid propellant contains the chamber of decomposition of propellant 1 with the bottom 2, adjoining to the bottom of the chamber unit of a propellant supply 3, the evaporator 4 executed from permeable catalytically inactive conductive material 5, supplied with current contacts 6, the catalytic thermal pack 7 provided with current contacts 8 and the nozzle 9. In addition, a permeable layer of a material with a high thermal resistance 10 (fig 8) or a gas-dynamic decoupling with a high thermal resistance 11 (fig. 9) may be installed in the chamber 1 between the unit of propellant supply and the catalytic thermal pack.

The operation of the proposed rocket thruster on liquid propellant according to the offered method of the organization of working process is carried out as follows.

After the command of preparation, the electric power input to the current contacts 8 and 6 for preliminary warming up of the catalytic thermal pack 7 up to temperature of 400 ° and the material 5 of the evaporator 4 up to the temperature 220°C is conducted.

After the warming up of the catalytic thermal pack 7 and the evaporator 4, liquid propellant (for example hydrazine) through the unit of propellant supply 2 l adjoining to the bottom 3 goes in the evaporator 4. At the moment of propellant receipt, the voltage on the current contacts 6 of the evaporator rises. Here, a maximum level of voltage is determined from such a level of electric power supply that is sufficient for evaporation and overheating of vapor of submitted propellant up to the temperature which does not exceed the temperature of loss of thermal stability of the given component of propellant. As a result of heat exchange with a material of the evaporator, the vapor of liquid propellant is heated up and evaporates. As additional energy is brought to a propellant on a site of the chamber with the minimal difference of temperatures comparing with an environment level, thermal losses are insignificant and as an additional transformation of products of decomposition does not occur, than the time of stay of products of decomposition in the chamber is minimal. After evaporation, the propellant vapor is submitted in the catalytic thermal pack 7 through a layer of a material 10 (fig. 8) or through a gas-dynamic decoupling 11 (fig. 9). In the catalytic thermal pack 7, the propellant vapor is decomposed at an optimum ratio of the components making products of decomposition. The products of decomposition are heated up by chemical energy emerging during the process of decomposition and then high-temperature products of decomposition move in the gas-dynamic nozzle 9, expiring through which the jet of decomposition products creates jet thrust.



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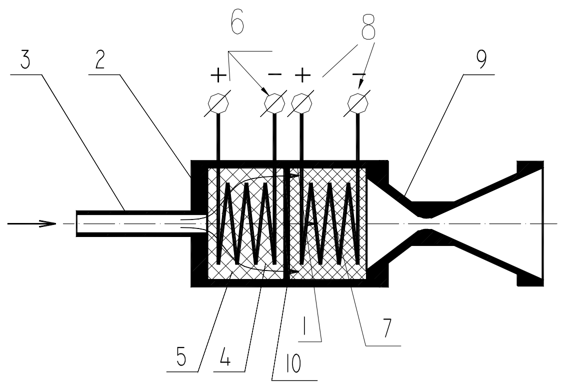

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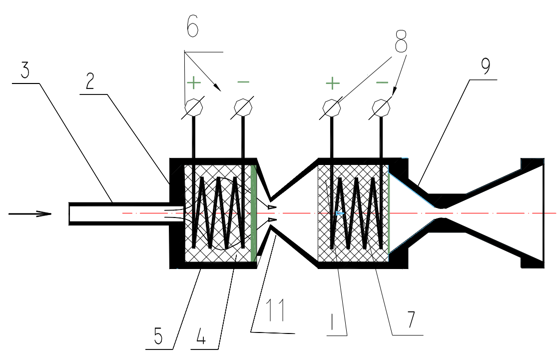

Rice 9

Parameters of laboratory models of the evaporation-type thruster being manufactured by EDB "Fakel"

On the Photo the basic elements of laboratory models are show, and on rice. 10, 11 the design drawings are presented.

EDB "Fakel" invites the interested organizations to cooperation in joint development of the given project.

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i Патент RU 2163685 C2 приоритет от 27.04.1999, опубликован 27.02.2001 Бюллетень №6.

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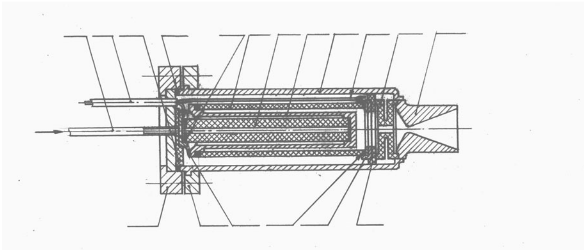

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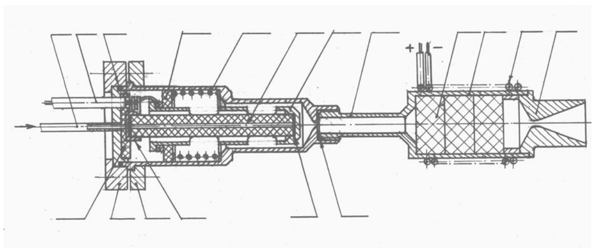

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