OPTIMIZATION OF THE PARAMETERS BY PROGRAM FOR (SSTC) OF EPS AND EPT

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ABSTRACT

The mathematical model of the complex heat-exchange in the elements in construction with internal and external thermal loads in the time variable and the orientation dependence of the last one has been developed in the frames of the isothermal elements method. Method of the parameters optimization of the system elements to provide the system secure temperature condition (SSTC) is submitted. The general description of the functional mission of the developed programs is submitted herein after.

INTRODUCTION

Normal operating of the elecrojet propulsion set (EPS) for the correction, orientation and the spacecraft's (SC) stationkeeping and the accomplishment of the flight program are defined by providing the temperatures conditions for the construction elements of propulsion set's units, which undergo variable spatial-time external and internal thermal loads. SSTC of PS is being developed to keep the temperature of the construction elements in the fixed range, to distribute the heat between the elements and to remove its excess. The efficiency of its operating is defined by the parameters of the passive (system passive temperature condition - SPTC) and the active (system temperature condition - STC) elements, which are the radiators and the heaters.

MATHEMATICS MODEL OF THE COMPLEX HEAT- EXCHANGE.

Method of SSTC parameters optimization - radiators' square (SPTC) and the nominal power of the heaters (STC) is based upon the mathematics model of the complex heat-exchange in the elements in the construction being the system (N<100) of the balance equations as the follow:

$$\int_t^{t+\tau}\Big\{(1-K_i-M_i)\Big(\sum_{j=1}^{N}[\sigma_o\varepsilon_i\varepsilon_j F_i(T_j^4(t)-T_i^4(t))\Phi_{ij}+\sigma_{ij}(T_j(t)-T_i(t)+\sum_{i=1}^{N}\delta_{ij}(1-\delta_{ij})P_{ij}(t)]+P_i^k(t)+P_i^s(t)+P_i^r(t)+$$

$$C\dot{T}(t)\Big)+P_i(t)-(K_i+M_i)T_i(0)\Big\}dt=0; \qquad (1.1)$$

$$K_i=\{^1_0;\ M_i=\{^1_0;\ K_i+M_i=\{^1_0;$$

$$i,j=1,2,\ldots,N\le 100 \qquad (1.2)$$

Here is: 1-st member to be under the "plus" describes the radiation links between the i-th and j-th elements; $\Phi = f(\varphi_{ij})$ - middle permitting corner coefficient, which is the function of the middle geometric corner coefficients of radiation of the closed surfaces system (for the cylinder and coaxial non-isothermal chambers with the ring butts we got its expressions in analytic view [1,2]); 2-nd member provides conductive component of the heat-exchange; 3-rd member is the external flow coming to i-th element to be located under the j-th heat-insulating element, $\sigma_{ij}\neq 0$ is for these.

Magnitudes of the coming energy flows are defined as per following formulas:

a) $P_{ij}(t)=[\sigma_o\varepsilon_i T_i(t)-P_j(t)-P_k(t)]\{1+n(\varepsilon_i/\varepsilon_{np})\}^{-1}$; **(1.3)**

b) convective [3]:

$$P_i^k(t)=D_i(t)[T_i(t)-T_1^{BX}-\sum_{j=1}^{i-1}P_j/c_jG_j(t)]; \qquad (1.4)$$

$D_i(t) = \{1/\alpha_i F_i + 1/2c_iG_i(t)\}^{-1}$, $G_i(t)$ - mass flow rate, α_i - coefficient of the convective heat-exchange, C_i - specific thermo-capacity of the heat-carrier

c) external

$$F_i^s(t) = \alpha_i^s q^s F_i \mathrm{Cos}\beta_i^s(t) \qquad (1.5)$$

α_i^s - coefficient of adsorption, q^s - power of external flow, $\mathrm{Cos}\beta(t) = [r_k][A(t,(\alpha_k)_j)][n_k(\Delta t_j)]_k^{T\,max}$ - angle cosine between the direction of the external flow $R=[r_k]$ and the normal to the surface $N = [n_k]_k$ (k=1,2,3) while the system moving around the axis $A_j=[a_{kj}]$ within the time Δt_j;

d) reflected by f-th surface on i-th external flow, adsorbed by it:

$$F_{ik}^r(t) = \alpha_i^s q^s F_i \sum(1-\alpha_f^s)\mathrm{Cos}\beta_{ik}^r(t), \qquad (1.6)$$

$\mathrm{Cos}\beta_{ik}^r(t) = [r_k^r][A(t,(\alpha_k)_j)][n_k(\Delta t_j)]_k^{T\,max}$ - angle cosine between the direction of the reflected from f-th surface $R^r=[r_k^r]$ flow and the normal to the surface;

e) $P_i(t)$ - magnitude of the internal thermo-load.

$K_i = 1$ is the coefficient for the thermo-static (T_i=Const=$T_i(0)$) elements (for example, settle place) and equaled to zero for the rest. $M_i = 1$ coefficient is for the ЭВТИ elements, temperature of whose is calculated according to one of the formulas (to reduce the calculation time).

$$T_i(t) = \left\{[P_i^s(t) + P_k^T(t)]/\sigma_o \varepsilon_i F_i\right\}^{1/4}, \qquad (1.7)$$

$$T_i(t) \approx 110 - 260\,[\mathrm{Cos}\beta_i^s(t) + \mathrm{Cos}\beta_k^T(t)]^{0.376} \qquad (1.8)$$

When M_i=0, the temperature of ЭВТИ can be defined as per (1.1)

MATHEMATICS MODEL OF SSTC

According to functional purpose, the elements are devided into the following groups:

1) thermo-perceiving radiator (SPTC);
2) thermo-allocating - operating or heater (STC);
3) thermo-insulating - (SPTC)
4) controlling (managing) - the temperature of this (these) element should be in the needed temperature range;
5) convective - it is used for forced or natural convective heat-exchange;
6) reflecting - element(s), reflecting external flow for the other elements;
7) settle place - thermo-static element (K_i=1), its temperature is fixed as per cyclogram;
8) the environment of the fixed temperature is the separated element.

The system can be an aggregate of the not obligatory identical sub-systems (units) and the calculation of SSTC parameters is made considering mutual influence through the linking elements.

The mathematics model of SSTC is based upon the results of the solving of the equations system (1.1) and the temperature uncorrespondence of the control elements allows to define, when the developing stage, optimal parameters of the means which provide thermal mode of the thrusters, thrusters' units and the secondary subsystems for the working body storage and flow, the transformation of the power and managing. Optimization is made in accordance with 24-hours power-consumption of EPS and EPT in the real cyclogram condition of the internal heat of the construction, as well as external and reflected thermal flows taking into account their orientation dependence.

Optimal parameters of SPTC units - radiators' area,- are located on the all radiators of the construction simultaneously, as far as temperature field of the unit elements is the square function of each one:

$(T_i)_b = f(s1, s\ ,\ldots,s)$, n- the quantity of the radiators.

The changing of the temperature field in the units, while the changing radiators' square, could be put together with the equations' system

$$[(dT_i)_b]^T = [(\delta T_i)_b/\delta S_j]_R [dS_j]^T, \qquad i=1,2,\ldots,n \qquad (2.1)$$

Matrix in (2.1) is called the reaction matrix of $[C]_R$, its elements could be found as per procedure

$$C_{b,j} = \frac{(T_k^{max}(S_j))_b - (T_k^{max}(mS_j))_b}{(m-1)S_j}, \qquad S_j = \sum_1^r (S_j)_r.$$

Here: T_k - maximum temperature of the control elements of the unit b;
m=1.1-1.2 - coefficient of radiators' square changing;
r- quantity of the unit radiators.

Uncorrespondence is defined while the calculation of the dynamic mode for the each τ_k-th iteration step

$(D_1 T_b)_b^{max} = (T_b)_b^{max} - (T_{g1} + T_{g2})_b/2$

(T_{g1} and T_{g2} - upper and lower limit of the range).

When the accomplishment of any condition

$(D_1 T_b)_b^{max} > 1/2\Delta T_{g1,2}$ (a)

or $(D_1 T_b)_b^{max} < -1/2\Delta T_{g1,2}$ (b)

the correction of the radiators square is made as per the procedure

$$[C]_R [\Delta S_b]^T = (n(T_k^{max})_b)^{-1} [D_1 T_b]_b^{max}, \qquad (2.3)$$

$$n(T_k^{max})_b = (T_k^{max})_b/A; \qquad A \sim 150$$

(in (2.3) plus "+", if (2.2a), and "-" if (2.2.b)).

The total amendment of the unit's radiators squares found as per (2.3) is distributed proportionally to the radiator area

the entering to the dynamic mode is made. Optimal parameters of SPTC are defined only according to upper limit of the range; lower limit when the calculating per the 1-st scheme (positive balance) is provided with the aid the heaters (STC elements), if it is necessary.

The definition of the nominal heaters power in the unit while the operating as per 2-nd scheme (negative balance) and the cyclogram of its operating is made taking into account the elements' cyclogram of the internal thermal allocation (of discharge chamber elements - operatings).

The lack of coordination is being controlled at each τ_k-th step

$$(d_3T_k)_l = (T_k^{min})_l - (T_{g3})_l, \qquad (d_4T_k^{min}) = (T_k^{min})_l - (T_{g4})_l,$$

and if in any l-th unit the condition of $(d_3T)_l$>JK0 will be carried out and the heaters were switched on, thus, the order to switch it off will be passed.

If it turned out that

$$(d_4T_k)_l \le g_4\Delta T_{g3,4}, \tag{2.5}$$

(g_4 - preemptive coefficient $0< g \le 1/2\Delta T_{g3,4}$), thus, the heater power at τ_{k+1} -th step can be found as per formulas:

$$P_i^H(\tau_{k+1})_l = P_i^H(\tau_k)_l\left[1+\Delta P^H(\tau_k,\tau_{k+1})/\sum_i^m(P_i^H(\tau_k))_l\right],$$

where for the l—th unit

$$\Delta P^H(\tau_k,\tau_{k+1}) = \sum_{i=1}^m P_i^{раб}(\tau_k) - \sum_{i=1}^m P_i^{раб}(\tau_{k+1}) +$$
$$+ \frac{C_i}{\tau_{бл}}\left\{(1-g_3-g_4)\Delta T_{g3,4} + \frac{\tau_k}{\tau_{бл}}\left[T_k(\tau_{k-1}) - T_{g4} - g_4\Delta T_{g3,4}\right]\right\}$$

These formulas are summarized, i.e. these consider all possible versions of the operating thermal allocation, including the zero one as well, and presuppose the power of the all haters of the unit coming to the zero at τ_{k+1} -th step when ΔP^H<0, in this case the operating thermal allocation will be sufficient to compensate the all thermal losses.

If the heaters should not be switched off during the calculated time t_p, so the nominal power of these should be found according to the procedure

$$(P_i^H)_l = t_p^{-1}\sum_k\left[\tau_k P_i^H(\tau_k)_l\right]. \tag{2.6}$$

When the nominal power of the heaters have been defined, the calculation per the 2-nd scheme is made again with nominal power heaters to be switched on constantly. There is another version - unit heaters of nominal power (2.6) to be switched on in case of the accomplishment of the controlled non-coordination (2.5).

While making the design of EPS and EPT, it is reasonable to simulate the temperature field of the construction with internal thermal allocation planned. To do so, it is enough to use the equation (1.1) modernized :

$$(1-K_i-L_i)F_{ij} - K_iT_i + L_iP_i = -(1-L_i)P_i + L_iF_{ij}, \tag{2.7}$$

where $F_{ij} = \sum_j^N[\sigma_0\sigma_i\sigma_jS_i(T_j^4 - T_i^4)\Phi_{ij} + \sigma_{ij}(T_j - T_i)]$,

$$K_i+L_i = \left\{{}^1_0\right.;\ K_i=1,0;\ L_i=0,1.$$

Usage of (2.7) allows to provide the temperature distribution required (K_i=1) in the construction by dint of the defining of magnitude needed to this power Pi upon the some elements. The power distribution with temperature distribution to be set upon the elements defining the mode allows to find conductive and radiation links between the elements, which provide the connection to the element of the power needed. Formula (2.7) is one of the possible (simplified) approaches to solve the back task of the heat conduction.

The shown mathematics models of complex heat exchange and SSTC were used while the developing of the complex of logic analytical programs to provide the calculation part of the thermal treatment of EPS and EPT within the all stages of design, manufacturing and testing. The programs are different in summarized level of temperature field calculation method and SSTC parameters, external thermal loads as well as the number of the system freedom degree and the quantity of heat exchange components to be considered. Programs permit to make the calculation for the all three schemes to provide the thermal mode, doing so, these could be both connected and disconnected with each other, to make the user free. Data input and output in the program are standardized.

The method of isothermal elements is not irreproachable physically. Therefore, when the tasks of complex heat exchange is being solved, the method of finite elements in the Galerkin formulation is more desirable.
While the working [4], we have got summarized expression for the input of the elements

$$I^e=\int_{V^e}\sum_{i=1}^{3} l_{ji}\Big[\partial N/\partial l_i - \frac{k-1}{h_i}\,\frac{(1-\delta_{i,2})(2\delta_{i,1}+\delta_{i,3}-\delta_{k,2})}{1+\delta_{k,3}}\,\cdot$$

$$\begin{pmatrix} Ctg\xi_{s_3} \\ -tg\xi_{s_3}\end{pmatrix}^{\delta_{k,3}} N\Big]^T \frac{\partial N}{\partial l_i}\,TdV + \oint_S \alpha(N^TN)_s TdS + \int_{V^e}\eta N^TNTdV -$$

$$-\int_{V^e}\omega N^TdV + \oint_S D_s(N^T)_s dS \qquad (2.8)$$

(where k=1,2,3 - the order of the system symmetry), it lets to formulate the program algorithm to calculate the complex heat exchange in the construction of any configuration with thermal loads locally distributed (internal and external). Classification of the elements as per symmetry order and the dimensions with the calculation formulas based on (2.8) lets to develop universal program, which physically describes thermal processes to be in the investigated construction more adequately.

CONCLUSION

The programs complex developed allows to do the followings:
-to summarize the thermal properties of SPT's staff ranks;
- to investigate the possibilities to force prior to "divisible by two" level of discharge power with minimum changes in the construction;
-to detect the special features of the units' thermal protection of the modules to be switched on simultaneously;
-to make the calculated simulation in the full volume of autonomous factory and complicated finishing tests in composition with thermal mock-ups of SC;
-to confirm the workability of the construction in the limited by time extreme situations, it lets to really decrease the requirements to thermal properties of EPS.

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