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APPROXIMATE CALCULATION OF TEMPERATURE MODES IN BETATRON WINDINGS WITH LIMITED NUMBER OF HEATING AND COOLING CYCLES

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Estimation dependencies for nonstationary temperature condition calculations of betatron winding with limited number of heating and cooling cycles have been obtained.

Knowledge of temperature field of maximum strength member allows judging at first approximation about electromagnet thermal state. It permits solving the problem of further developmental work appropriateness of one of the variants of electromagnet at the design stage.

The task is reduced to temperature distribution finding in finite length cooled stem, inside of which a time-varying heat source is functioning. The intensity of the latter depends linearly on temperature. The system of equations, describing the heat conduction process, has the form

$$\frac{\partial\theta_{\text{н,о}}}{\partial \text{Fo}} = \frac{\partial^2\theta_{\text{н,о}}}{\partial X^2} - \beta^2_{\text{н,о}}\theta_{\text{н,о}} + \text{Po}_1(\text{Fo}),\ 0 < X < 1,\ \text{Fo} > 0,$$

where

$$\text{Po}_1(\text{Fo}) = \begin{cases} \text{Po}_1,\ 0 \le \text{Fo} \le \text{Fo}_{\text{н}} \\ 0,\ 0 \le \text{Fo} \le \text{Fo}_{\text{о}} \end{cases};$$

$$\frac{\partial\theta_{\text{н,о}}(0,\text{Fo})}{\partial X} - \text{Bi}\theta_{\text{н,о}}(0,\text{Fo}) = 0;$$

$$\frac{\partial\theta_{\text{н,о}}(1,\text{Fo})}{\partial X} + \text{Bi}\theta_{\text{н,о}}(1,\text{Fo}) = 0.$$

Initial conditions

$$\theta_{\text{н},1}(X,0) = \theta_0,\quad \theta_{\text{н},N}(X,0) = \theta_{\text{о},N-1}(X,\text{Fo}_{\text{о}}),$$
$$\theta_{\text{о},N}(X,0) = \theta_{\text{н},N}(X,\text{Fo}_{\text{н}}).$$

Here $\theta_{\text{н,о}}=(T_{\text{н,о}}(x,\tau)-T_{\text{ж}})/T_0$, $\theta_{\text{ж}}=(T_{\text{ж}}-T_0)/T_0$ are the dimensionless temperatures; $\text{Po}_0=q_{V0}h^2/(\lambda T_0)$ is Pomerantsev number; $\text{Po}_1=\text{Po}_0(1+k\theta_{\text{ж}})$ is Pomerantsev modify number; $\text{Fo}=\lambda\tau/(c_p\rho h^2)$ is Fourier number; $\text{Bi}=\alpha h/\lambda$ is Biot number; q_{V0} is the intensity steady component of internal heat source, Wt/m^3; $X=x/h$ is the dimensionless coordinate; h is the characteristic geometry, m; λ is the heat conductivity coefficient, Wt/(m·K); c_p is the heat capacity coefficient, J/(kg·K); ρ is the density, kg/m^3; τ is the time, s; α is the coefficient of heat exchange on cooling surface, Wt/(m^2·K); $k=\gamma T_0$ is the dimensionless temperature coefficient of an active ohmic resistance; $\gamma=1/(235+T_0)$ is the temperature coefficient of resistance, 1/K; $T_{\text{ж}}$, T_0 are the temperatures of cooling medium and active element before the first loading cycle, °C; $\beta^2_{\text{н}}=\beta^2_{\text{о}}-k\text{Po}_0$, $\beta^2_{\text{о}}=\text{Bi}\,Uh/F$ are the dimensionless coefficients, taking into account heat exchange from lateral surfaces of the active element; U, F are the perimeter and the section of the active element; N is the number of the cycle; «l» indices is the loading, «c» is the cooling pause.

Using the steady temperature profiles and the collocation method [1] the approximate solutions of the given problem are obtained. The coordinate of the peak temperature X=0,5 was used as a collocation point. Heat exchange between the winding surface and the environment exceeds Joule losses. The final temperature distribution in a fuel element for intermittent temperature conditions with the limited number of heating and cooling frequencies has the form:

In a period of current load [0, $\text{Fo}_{\text{н}}$], N≥1,

$$\theta_M(X) - \theta_{\text{н},N}(X,\text{Fo}) = B(X)T_1(\text{Fo}),$$

here $$\theta_M(X) = \frac{\text{Po}_1}{\beta^2_{\text{н}}}B(X) \ne \theta_{\text{доп}}$$

is the steady temperature component,

$$B(X) = 1 + (n^2_{\text{н,о}} - 1)\,\text{ch}[\beta_{\text{н}}(0{,}5 - X)],$$

$$n^2_{\text{н,о}} = 1 - \text{Bi}\left(\text{Bi}\,\text{ch}\frac{\beta_{\text{н,о}}}{2} + \beta_{\text{н}}\,\text{sh}\frac{\beta_{\text{н,о}}}{2}\right)^{-1},$$

$$T_1(\text{Fo}) = \frac{\text{Po}_1}{\beta^2_{\text{н}}}\exp\left(-\frac{\beta^2_{\text{н}}}{n^2_{\text{н}}}\text{Fo}\right) -$$
$$-\left\{\frac{\text{Po}_1}{\beta^2_{\text{н}}}\left[1 - \exp\left(-\frac{\beta^2_{\text{н}}}{n^2_{\text{н}}}\text{Fo}_{\text{н}}\right)\right]M_1(\text{Fo}_{\text{н}},\text{Fo}_{\text{о}}) \times\right.$$
$$\left.\times\exp\left(-\frac{\beta^2_{\text{о}}}{n^2_{\text{о}}}\text{Fo}_{\text{о}}\right) + \theta_0\exp[-(N-1)m_1]\right\}\exp\left(-\frac{\beta^2_{\text{н}}}{n^2_{\text{н}}}\text{Fo}\right),$$

$$m_1 = \frac{\beta^2_{\text{н}}}{n^2_{\text{н}}}\text{Fo}_{\text{н}} + \frac{\beta^2_{\text{о}}}{n^2_{\text{о}}}\text{Fo}_{\text{о}},$$

$$M_1(\text{Fo}_{\text{н}},\text{Fo}_{\text{о}}) = \frac{1 - \exp[-(N-1)m_1]}{1 - \exp(-m_1)}.$$

In the period of cooling pause [0, $\text{Fo}_{\text{о}}$], N≥1,

$$\theta_{\text{о},N}(X,\text{Fo}) = \theta_{\text{н},N}(X,\text{Fo}_{\text{н}})\exp\left(-\frac{\beta^2_{\text{о}}}{n^2_{\text{о}}}\text{Fo}\right).$$

Thus, the obtained formula allow estimating the concrete thermal conditions of electromagnet winding with the limited number of heating and cooling cycles, if its winding is the most thermally loaded element.

Betatron continuous work is possible if the steady temperature component is less than the acceptable temperature for the given type of electric insulation. Otherwise, it is necessary to turn to intermittent work with the period of current load $\tau_{н}$ and the pause $\tau_{о}$ alternation.

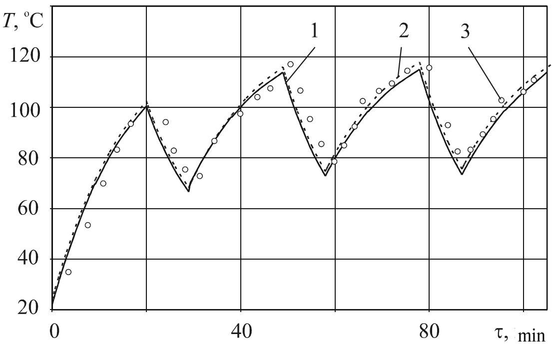

Figure. *The time change of betatron winding peak temperature in the point X=0,5: 1) exact analytical solution; 2) approximate calculation; 3) experimental data [3]*

Winding temperature conditions of PMB – 6 type betatron with a lattice pole is estimated by concrete examples [2]. The results of calculations of the betatron winding peak temperature are shown in the Figure.

The highest deviation value of the peak temperature computed by the approximate calculation relative to the exact solution achieves 10 % during the first cycle of heating and cooling. During the last cycles this value is not more than 4 %. The solution obtained in this way allows investigating the temperature conditions of this winding in the wide range of geometrical and electrophysical parameters change.

Conclusion

For the first time, the approximate dependences for calculating transient temperature in betatron winding with the limited number of heating – cooling cycles are obtained. They may be used only for estimating thermal condition of electromagnet devices which specific electric losses in magnetic circuit is significantly less than in the winding. The calculated dependences are checked-up by comparing with the experimental data from scientific literature.

REFERENCES

1. Kudinov V.A., Kartashov E.M., Kalashnikov V.V. Analytical solutions of heat-and-mass transfer and thermoelasticity problems for multilayered constructions. – Moscow: Vysshaya Shkola, 2005. – 430 p.
2. Kim M.V., Loginov V.S., Shilin G.F., Chakhlov V.L., Yarushkin Yu.P. Electromagnet of a portable betatron supplied by high frequency current // Pribory I Technika Experimenta. – 1970. – № 5. – P. 15–18.
3. Loginov V.S. The investigation of temperature conditions of betatron electromagnets: Thesis ... of the Cand. of techn. science. – Tomsk, 1973. – 251 p.

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TECHNIQUES OF ANALYSING HEAT CONDITIONS IN ELECTRON DEVICES OF SPACECRAFT

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On the bases of thermal macrolevel models of electron device and construction elements the technique of analysing heat conditions of unpressurized electron spacecraft equipment has been developed. The technique involves formation of electric loss sequence diagram for connected thermal and electric analysis, which makes possible to increase the accuracy and reliability of heat analysis for the device and its elements.

The required stage in engineering process of space craft (SC) electron devices (ED) is the analysis of heat conditions by the results of which the ED working capacity is estimated. The analysis of heat conditions of ED elements is the most urgent at its arrangement outside of pressure container and increase of SC required active life to 10 and more years.

The characteristic property of electron devices aboard SC is their operation in dynamic conditions when electron devices of power supply systems, orbit coordination and others operate by turns depending on SC orbital position. Heat release power and temperature fields in ED nodes and blocks change respectively that requires the investigation of dynamic heat conditions of ED and its elements.

This problem may be solved only using advanced manufacturing sciences of multidisciplinary calculations. In this case it is a connected electric and heat analysis allowing us to take into consideration the interference of electric and heat conditions of ED [1–6].

The available at present software (BETASoft, Ansys, Nastran, T-Flex, ABAQUS, CosmosWorks etc.) does not allow carrying out the connected electric and heat analysis in one package with the possibility to determine three-dimensional temperature fields by ED con-