Calculation of Temperature Fields in Multilayer Plates and Shells with Distributed Heat Sources

Natalia Smetankina

A. Pidgorny Institute for Mechanical Engineering Problems of the National Academy of Sciences of Ukraine
Kharkiv, Ukraine
nsmetankina@ukr.net

Oleksii Postnyi

A. Pidgorny Institute for Mechanical Engineering Problems of the National Academy of Sciences of Ukraine
Kharkiv, Ukraine
alekh.po@gmail.com

Abstract—**The aircraft multilayer glazing is considered as a rectangular multilayer plate made up of isotropic layers with constant thickness. The temperature on the side surface of the plate is zero. Convective heat transfer occurs on outer surfaces of the plate; on layers' interfaces film heat sources are arranged.**

The heat conduction equation for an arbitrary plate layer is reduced to the functional equation. A solution of the functional equation we search in the form of three space functions product. We get the system of ordinary differential equations. Series expansion factors are determined from a system of linear algebraic equations. A transform of the required function is found by the second expansion theorem, and the problem solution has the form of double trigonometrical series.

The comparative analysis of the results is carried out with the results of other method. The method offered can be used for designing a safe multilayer glazing under operational and emergency thermal and force loading in different vehicles.

Keywords—safe multilayer glazing, nonstationary thermal conduction, film heat source.

I. Formulation of the problem

One of the urgent problems in modern technology is the task of reliable determination of the thermal state of structural elements. Its successful solution depends on the reliability and efficiency of the elements of different structures, which often have a heterogeneous structure.

The aircraft's modern heating glass is a complex, large, multi-layered structure. Its performance depends primarily on the strength and durability of the glass elements, the optimal parameters of adhesive layers and structural solutions that would provide the necessary heat resistance and durability of the roofing layer under cyclic loading and the action of extreme operating factors.

It should be noted that in the calculation of temperature fields in multilayer structures there are considerable mathematical difficulties. This is due to the presence of layers whose properties are significantly different, and the fulfillment of the conditions of coupling of the layers taking into account the internal heat sources.

II. Analysis of publications by research topic

Practical work on the design of protective glazing of vehicles has led to the creation of GOST R 51136-2008 [1]. This standard applies to multilayer safety glasses, which are designed to protect human life, ensure safety and reliability while storing and transporting material.

A review of the literature indicates that most publications are devoted to the calculation of structures under steady-state heating [2].

The article [3] proposes the formulation of contact problems of heat transfer and thermal elasticity in irradiated layered bodies with components of different transparency, in particular in the presence of thin intermediate layers, taking into account the effects of radiation on their surfaces, in partially transparent regions and boundaries. To describe the propagation of thermal radiation, we have used the relations of phenomenological radiation theory for partially transparent and opaque bodies. In formulating the thermal boundary and contact conditions, the fluxes that are caused by the radiation and absorption of thermal energy are considered. The conditions of ideal thermal contact were obtained taking into account the effects of radiation. As an example, the problem is solved for a two-layer plate with layers of different transparency, connected through a thin intermediate layer.

Various numerical and analytical methods of solution have been developed in [4, 5] and a number of fundamental results have been obtained. In the case of non-stationary thermal influences, one-dimensional thermal conductivity problems of unlimited multilayer plates are considered [6] or methods based on the discretization of an area or contour are used, for example, the finite element method [7]. Methods of reducing the three-dimensional problem of thermal conductivity to two-dimensional by applying various hypotheses about the temperature distribution along the thickness of the layer package are also proposed [8]. In [9], a nonstationary thermal conduction problem for layered rectangular plates at a given temperature distribution on the outer and inner surfaces is solved analytically without involving hypotheses about the temperature distribution along the plate thickness.

The unresolved problem is the development of effective methods for investigating the thermal conductivity of multilayer glazing with high parameters of thermal force loading during operational and emergency impacts.

The aim of this work is to develop a method of calculating non-stationary temperature fields in multilayer glazing of aircraft under the influence of pulsed distributed interlayer heat sources.

III. ANALYSIS OF THE RESULTS OF NUMERICAL SOLUTION

Consider heating a five-layer glazing element of the airplane with dimensions $A = 0,64$ m, $B = 0,32$ m (Fig. 1). Between the first and second layers a film heat source are placed with capacity $q^0 = 3500$ W/m^2, $q_S^1(x, y) = q^0 H(t)$, where $H(t)$ – Heaviside function, $x_1 = 0,07$ m, $x_2 = 0,57$ m, $y_1 = 0$ m, $y_2 = 0,32$ m. The layers have the following thermophysical and geometric characteristics: $\lambda_i = 1,61$ W/(m·°C), $c_i = 750$ J/(kg·°C), $\rho_i = 2500$ kg/m^3 ($i = 1, 3, 5$); $\lambda_i = 0,17$ W/(m·°C), $c_i = 1500$ J/(kg·°C), $\rho_i = 1200$ kg/m^3 ($i = 2,4$); $h_1 = 5$ mm, $h_2 = 3$ mm, $h_3 = 15$ mm, $h_4 = 2$ mm, $h_5 = 20$ mm. The coefficients of convective heat transfer on the outer and inner surfaces of the glazing element and the temperature of the external and internal environment are: $\alpha_{\text{in}} = 80$ W/(m^2·°C), $\alpha_{\text{out}} = 25$ W/(m^2·°C), $T_{\text{in}} = -20$ °C i $T_{\text{out}} = 20$ °C.

The composition of the layers and the temperature distributions along the thickness of the glazing element at a point $x = A/2$, $y = B/2$ at time $t = 10^4$ s is shown at Fig. 2. Line 1 is the result of the analytical solution of the problem by the proposed method, line 2 is the result of using development of the sought functions in a series of Legendre polynomials method [10-12]. Comparative analysis of relations allows to make a conclusion about the probability of the obtained results.

The temperature change in the bowl at a point $x = A/2$ $y = B/2$ on different surfaces of the layers is shown at Fig. 3: line 1 - $z_1 = 0$, line 2 - $z_1 = h_1$, line 3 - $z_I = h_I$.

The dashed lines in the figure indicate the values of temperatures on the surfaces of the layers, which are solutions of a stationary problem [13]. It can be seen that from the time of the temperature field becomes stationary.
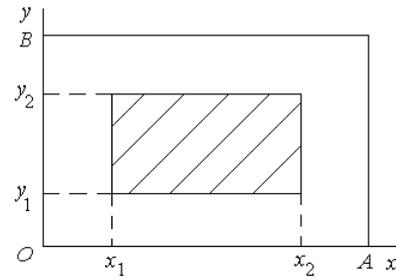
Figure 1. The design scheme of the glazing element
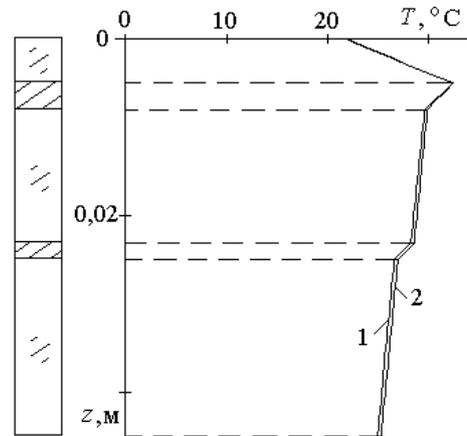
Figure 2. Temperature distribution along the thickness of the glazing element
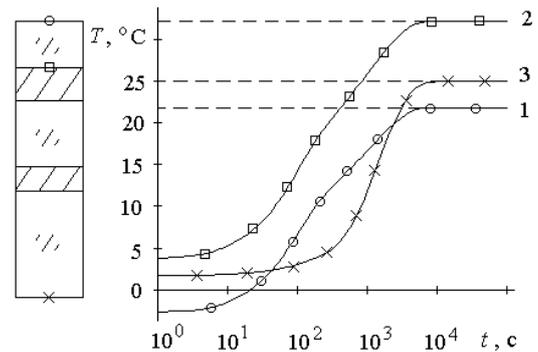
Figure 3. Temperature change over time

IV. CONCLUSIONS AND PROSPECTS FOR FURTHER RESEARCH

Thus, a method of solving the problems of non-stationary thermal conductivity in a multilayer glazing is developed. The method allows to describe the thermal state of multilayer elements that are collected from layers with different mechanical and geometric characteristics when exposed to pulsed distributed heat sources.

The proposed approach can be used in the design of a safe multilayer glazing, taking into account the assessment of patterns of damage, long-term durability and nature of the destruction of the elements of the glazing, depending on the method of mechanical, thermal and thermochemical treatment under operational or emergency thermal force.

REFERENCES

[1] GOST R 51136-2008. Stekla zashhitnye mnogoslojnye. Obshhie tehnicheskie uslovija. Prinjato i vvedeno v dejstvie Prikazom Federal'nogo agentstva po tehnicheskomu regulirovaniju i metrologii ot 29 09 2008. № 222-ст – 15 p.

[2] Heat transfer – a review of 2003 literature / R.J. Goldstein, W.E. Ibele, S.V. Patankar [et al.] // Int. J. Heat Mass Transfer.– 2006.– Vol. 49, № 3-4.– P. 451-534.

[3] Terleckij R.F. Modelirovanie termomehanicheskogo povedenija sloistyh tel s uchetom jeffektov izluchenija i pogloshhenija teplovoj jenergii / R.F. Terleckij, O.P. Turij / Teor. i prikl. meh.– 2009.– № 45.– P. 19-31.

[4] Rvachev V.L. Algebro-logicheskie i proekcionnye metody v zadachah teploobmena / V.L. Rvachev, A.P. Slesarenko.– Kiev: Nauk. dumka.– 1978.– 138 p.

[5] Podstrigach Ja.S. Termouprugost' tel neodnorodnoj struktury / Ja.S. Podstrigach, V.A. Lomakin, Ju.M. Koljano.– M.: Nauka, 1984.– 368 p.

[6] Zarubin V.S. Inzhenernye metody reshenija zadach teploprovodnosti / V.S. Zarubin. – M.: Jenergoizdat, 1983. – 326 p.

[7] Oguamanam D.C.D. Nonlinear transient response of thermally loaded laminated panels / D.C.D. Oguamanam, J.S. Hansen, G.R. Heppler // Trans. ASME. J. Appl. Mech. – 2004.– Vol. 71, № 1.– P. 49-56.

[8] Demchuk O.N. Utochnennaja teorija iteracionnogo tipa dlja reshenija zadachi teploprovodnosti sloistyh kompozitnyh obolochek i plastin / O.N. Demchuk// Dopovidi NAN Ukraïni.– 1998.– № 8.– P. 69-73.

[9] Tanigawa Y. Thermal bending of laminated composite rectangular plates and nonhomogeneous plates due to partial heating / Y. Tanigawa, Y. Ootao, R. Kawamura // J. Thermal Stresses.– 1991.– Vol. 14, №. 3.– P. 285-308.

[10] Smetankina N.V. Zadacha stacionarnoj teploprovodnosti mnogoslojnyh plastin so slozhnoj formoj / N.V. Smetankina, E.V. Svet, A.N. Shupikov // Probl. mashinostroenija.– 2004. – T. 7, № 3.– P. 25-31.

[11] Smetankina N.V., Postnyi O.V. Modeling of non-stationary heat conduction in layered medium // Вісник Національного університету водного господарства та природокористування.– 2018. – № 1 (81).– С. 33-39.

[12] Shupikov A.N. Nonstationary heat conduction in complex-shape laminated plates / A.N. Shupikov, N.V. Smetankina, Ye.V. Svet // Trans. ASME. J. Heat Transfer.– 2007. – Vol. 129, № 3. – P. 335-341.

[13] Smetankina N.V. Nestacionarnoe deformirovanie, termouprugost' i optimizacija mnogoslojnyh plastin i cilindricheskih obolochek / N.V. Smetankina. – Har'kov: Izd-vo «Mis'kdruk». – 2011. – 376 p.