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EDGE FIXING EFFECT ON THE LIFE OF A VACUUM CHAMBER THIN SPHERICAL COVER SUBJECTED TO CREEP DAMAGE

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Within framework of the numerical studies of creep resource of a thin spherical cover of a vacuum chamber, we present mathematical formulation and the calculation method for the solution of the initial boundary value problems of the creep theory of thin shells with account of the damage accumulation process of the material. The effect of edge fixing along the normal and tangential lines to the median surface, as well as angular edge fixings, on the cover life in creep are studied under atmospheric pressure creep conditions. The calculation data obtained made it possible to determine the dependence between the cover life in creep and its edge fixing conditions: this effect is strong by the latent fracture time and weak by the allowable deflection values.

Keywords: life, creep, damageability, fracture time, cover of a vacuum chamber, spherical shell, the Bubnov–Galerkin method.

Introduction. Vacuum systems are used for a variety of processes and scientific development purposes. Due to a specific nature of the latter applications, system components can operate under creep conditions. The life prediction for structural elements in-service is governed by ensuring their safe operation and therefore presents an urgent scientific and technical problem.

The required life of vacuum system elements at the given levels of temperatures and intensities of mechanical loads is traditionally achieved by selecting materials, geometry and certain sizes. The limited nature of the choice in materials and sizes of structures is due to the known objective reasons. The fixing of structural elements influences their life and is an additional factor in its ensuring.

The goal of the present work is to perform a computational study of the effect of edge fastening of a spherical cover of the vacuum chamber on its life in creep. The investigation technique is the mathematical simulation of the processes of deformation and damaging due to creep and the generalization of the accumulated results of numerical experiments.

Mathematical Formulation of the Problem. We consider the spherical cover of vacuum chamber that separates the vacuum enclosure from the atmosphere as a thin shell, namely, a spherical dome of constant thickness h, radius R, and with the apex angle 2θ (see Fig. 1) loaded by the pressure p. To model the high-temperature creep and damage of the cover material, we adopt the creep law, such as the Bailey–Norton creep law, and a continuum version of the damage theory proposed by Rabotnov [1, 2]. Under the axisymmetric deformation of thin shells [2, 3], the Lame parameters of the median surface of a spherical shell are dependent only on the coordinate x_1, whereas the parameters of the stress-strain state and damaging due to creep vary with the time t and are dependent on the coordinates x_1 and x_3.

The resolving differential equations in the mixed form with respect to the unknown internal forces, moments, displacements, and rotation angle of the spherical shell median surface normal are of the following form [2, 3]:

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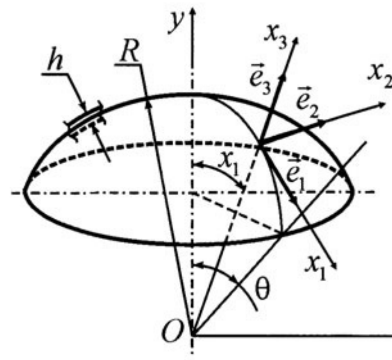

Fig. 1. Design model for vacuum chamber cover.

$$\begin{cases} -\dfrac{N_1^0}{Eh} + \dfrac{\nu N_2^0}{Eh} + \dfrac{1}{A_1}\dfrac{\partial u_1^0}{\partial x_1} + k_1 u_3^0 = \dfrac{1}{h}\displaystyle\int_{-h/2}^{h/2} c_{11}\,dx_3, \\ -\dfrac{N_2^0}{Eh} + \dfrac{\nu N_1^0}{Eh} + \dfrac{1}{A_1 A_2}\dfrac{\partial A_2}{\partial x_1} u_1^0 + k_2 u_3^0 = \dfrac{1}{h}\displaystyle\int_{-h/2}^{h/2} c_{22}\,dx_3, \\ -\dfrac{M_1^0}{Eh} + \dfrac{\nu M_2^0}{Eh} - \dfrac{1}{A_1}\dfrac{\partial \vartheta_1^0}{\partial x_1} = \dfrac{12}{h^3}\displaystyle\int_{-h/2}^{h/2} c_{11} x_3\,dx_3, \\ -\dfrac{M_2^0}{Eh} + \dfrac{\nu M_1^0}{Eh} - \dfrac{1}{A_1 A_2}\dfrac{\partial A_2}{\partial x_1}\vartheta_1^0 = \dfrac{12}{h^3}\displaystyle\int_{-h/2}^{h/2} c_{22} x_3\,dx_3, \\ -k_1 u_1^0 + \dfrac{1}{A_1}\dfrac{\partial u_3^0}{\partial x_1} - \vartheta_1^0 = 0, \\ \left(\dfrac{\partial A_2}{\partial x_1} + A_2\dfrac{\partial}{\partial x_1}\right) N_1^0 - \dfrac{\partial A_2}{\partial x_1} N_2^0 + k_1 A_1 A_2 Q_1^0 = 0, \\ k_1 N_1^0 + k_2 N_2^0 - \dfrac{1}{A_1 A_2}\left(\dfrac{\partial A_2}{\partial x_1} + A_2\dfrac{\partial}{\partial x_1}\right) Q_1^0 = -p, \\ \left(\dfrac{\partial A_2}{\partial x_1} + A_2\dfrac{\partial}{\partial x_1}\right) M_1^0 - \dfrac{\partial A_2}{\partial x_1} M_2^0 - A_1 A_2 Q_1^0 = 0, \end{cases} \tag{1}$$

where $A_1 = R$ and $A_2 = R\sin x_1$ are Lame's parameters, $k_1 = k_2 = 1/R$ are the principal curvatures, u_1^0 and u_3^0 are the displacements of the median surface point, ϑ_1^0 is the rotation angle of the normal, N_1^0, N_2^0, and Q_1^0 are the membrane and shearing forces, respectively, M_1^0 and M_2^0 are the bending moments, c_{11} and c_{22} are the creep strain tensor components, and E and ν are the elasticity modulus and Poisson's ratio of the material, respectively.

The creep damage constitutive equations are written in the following way:

$$\dot{c}_{11} = \frac{3}{2}\frac{B\sigma_i^{n-1}}{(1-\omega^r)^n}\left(\frac{2}{3}\sigma_{11} - \frac{1}{3}\sigma_{22}\right), \qquad \dot{c}_{22} = \frac{3}{2}\frac{B\sigma_i^{n-1}}{(1-\omega^r)^n}\left(\frac{2}{3}\sigma_{22} - \frac{1}{3}\sigma_{11}\right), \qquad \dot{\omega} = \frac{A\sigma_i^k}{(1-\omega^r)^k}, \tag{2}$$

where B, A, n, k, and r are the material constants determined at the preset temperature from the creep and long-term strength curves up to fracture, ω is the damageability parameter, σ_i is the stress intensity, and σ_{11} and σ_{22} are the stress tensor components,

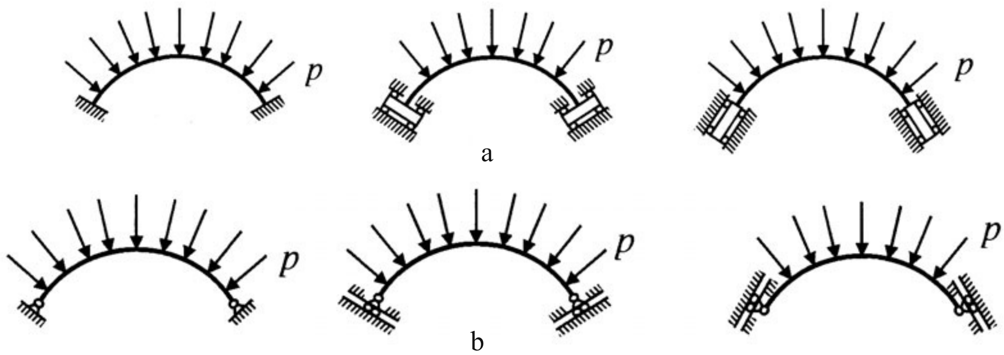

Fig. 2. Versions of fixing for a cover of vacuum chamber.

$$\sigma_i = \frac{1}{\sqrt{2}}\sqrt{\sigma_{11}^2 + \sigma_{22}^2 + (\sigma_{22} - \sigma_{11})^2},$$

$$\sigma_{11} = \frac{1}{h}N_1^0 + \frac{12x_3}{h^3}M_1^0 + \frac{E}{h(1-\nu^2)}\int_{-h/2}^{h/2}(c_{11} + \nu c_{22})dx_3 + \frac{12Ex_3}{h^3(1-\nu^2)}\int_{-h/2}^{h/2}(c_{11} + \nu c_{22})x_3\,dx_3 - \frac{E}{1-\nu^2}(c_{11} + \nu c_{22}),$$

$$\sigma_{22} = \frac{1}{h}N_2^0 + \frac{12x_3}{h^3}M_2^0 + \frac{E}{h(1-\nu^2)}\int_{-h/2}^{h/2}(c_{22} + \nu c_{11})dx_3 + \frac{12Ex_3}{h^3(1-\nu^2)}\int_{-h/2}^{h/2}(c_{22} + \nu c_{11})x_3\,dx_3 - \frac{E}{1-\nu^2}(c_{22} + \nu c_{11}).$$

A complete set of resolving equations (1) and (2) satisfies the initial boundary-value problem of the theory of creep of thin shells whose solution governs the time-varying fields of stress-strain state, median surface displacements, creep strains, and the damageability parameter for a spherical vacuum chamber cover. These equations are supplemented by the symmetry conditions at the cover apex $x_1 = 0$, the boundary conditions of edge fixing $x_1 = \theta$ and the initial conditions.

The symmetry conditions at the cover apex are of the form

$$u_1^0(t,\,0) = 0, \qquad Q_1^0(t,\,0) = 0, \qquad \vartheta_1^0(t,\,0) = 0. \tag{3}$$

Next, we consider six versions of combinations of the cover edge fixings, three of which correspond to the rigid angular fixing that eliminates the rotation of the cross-section $x_1 = \theta$ (Fig. 2a), and three to the hinged fixture which is a support with zero angular stiffness (Fig. 2b).

The boundary conditions that correspond to the rigid angular fixing of the cover edge (Fig. 2a from left to right) are of the form:

$$u_1^0(t,\,\theta) = 0, \qquad u_3^0(t,\,\theta) = 0, \qquad \vartheta_1^0(t,\,\theta) = 0, \tag{4}$$

$$u_1^0(t,\,\theta) = 0, \qquad Q_1^0(t,\,\theta) = 0, \qquad \vartheta_1^0(t,\,\theta) = 0, \tag{5}$$

$$N_1^0(t,\,\theta) = 0, \qquad u_3^0(t,\,\theta) = 0, \qquad \vartheta_1^0(t,\,\theta) = 0. \tag{6}$$

The boundary conditions that correspond to the hinged fixings of the cover edge (Fig. 2b from left to right) are written in the following way:

$$u_1^0(t,\,\theta) = 0, \qquad u_3^0(t,\,\theta) = 0, \qquad M_1^0(t,\,\theta) = 0, \tag{7}$$

$$u_1^0(t,\theta)=0, \qquad Q_1^0(t,\theta)=0, \qquad M_1^0(t,\theta)=0, \tag{8}$$

$$N_1^0(t,\theta)=0, \qquad u_3^0(t,\theta)=0, \qquad M_1^0(t,\theta)=0. \tag{9}$$

The initial conditions are assumed to correspond to the elastic deformation:

$$c_{11}(0,x_1,x_3)=0, \qquad c_{22}(0,x_1,x_3)=0, \qquad \omega(0,x_1,x_3)=0. \tag{10}$$

In determining the cover life, both the end of the hidden fracture and the abnormal operation due to intolerably large deflection are considered independently as the ultimate state [4].

The time of the end of the cover hidden fracture t_ω is determined from the condition

$$\omega(t_\omega,x_1,x_3)=\omega_*, \tag{11}$$

where ω_* is the critical value of the damage parameter which is practically equal to unity.

A significant increase in the creep strain rate and the damage parameter at $\omega \approx 1$ makes it difficult the integration of equations (1) and (2) and insignificantly specifies the time of the end of the hidden fracture. Therefore, when making calculations, it is reasonable to determine the time of the end of the hidden fracture from the value of $0.5 \le \omega_* \le 0.9$; then, after the damage parameter reaches this value, the problem solving is stopped, and in what follows it is assumed that $\omega_* = 0.6$.

The time of the abnormal operation due to a strong change in the shape of the cover, t_u, is determined from the deflection at its apex:

$$u_3^0(t_u,0) \le u_*, \tag{12}$$

where u_* is the admissible value of deflection of the cover at its apex.

Problem Solution Method. Consider the application of the Bubnov–Galerkin method to the solution of the initial boundary-value problem of creep (1) and (2) with initial and boundary conditions. The sought unknowns are represented by global analytic approximations with respect to the prescribed trial function systems of the spatial coordinates with unknown coefficients which are the functions of time [5, 6]. All the boundary conditions are satisfied by choosing the trial functions. The approximation coefficients are determined from the Cauchy problem obtained using the orthogonality conditions in (1) and (2) for the trial functions.

In view of the initial conditions in (10), the approximations of the creep strain and the damage parameter are taken as

$$\begin{cases} c_{11}(t,x_1,x_3)=\sum\limits_{k=1}^{m}\sum\limits_{j=1}^{m} a_{kj}^{(c1)}(t)\psi_k(x_1)\psi_j(x_3), \qquad a_{kj}^{(\nu 1)}\Big|_{t=0}=0, \\ c_{22}(t,x_1,x_3)=\sum\limits_{k=1}^{m}\sum\limits_{j=1}^{m} a_{kj}^{(c2)}(t)\psi_k(x_1)\psi_j(x_3), \qquad a_{kj}^{(\nu 2)}\Big|_{t=0}=0, \\ \omega(t,x_1,x_3)=\sum\limits_{k=1}^{m}\sum\limits_{j=1}^{m} a_{kj}^{(\omega)}(t)\psi_k(x_1)\psi_j(x_3), \qquad a_{kj}^{(\nu 3)}\Big|_{t=0}=0, \end{cases} \tag{13}$$

where m is the number of trial functions, ψ_k are the Chebyshev polynomials, and $a_{kj}^{(c1)}$, $a_{kj}^{(c2)}$, and $a_{kj}^{(\omega)}$ are the sought approximation coefficients.

We represent the sought functions governing the stress-strain state of the shell by the approximations that satisfy identically the symmetry conditions at the cover apex (3) and boundary conditions in (4)–(9). The construction of such approximations in the problems considered is simplified by that the domain under study has a canonical form, its boundary coincides with the coordinate line $x_1 = \theta$ and boundary conditions contain no derivatives of the sought unknowns. For the domains of complex shapes, the construction of the approximations satisfying identically the boundary conditions can be made by using the methods of the theory of *R*-functions [7]. We give the approximations satisfying the conditions in (3) and those in (4) which correspond to the rigid edge fixing of the dome (Fig. 2a):

$$\begin{cases} u_1^0(t, x_1) = \dfrac{x_1}{\theta}\left(1 - \dfrac{x_1}{\theta}\right)\sum\limits_{k=1}^{n} a_k^{(u1)}(t)\psi_k(x_1), \\ u_3^0(t, x_1) = \left(1 - \dfrac{x_1}{\theta}\right)\sum\limits_{k=1}^{n} a_k^{(u2)}(t)\psi_k(x_1), \\ \vartheta_1^0(t, x_1) = \dfrac{x_1}{\theta}\left(1 - \dfrac{x_1}{\theta}\right)\sum\limits_{k=1}^{n} a_k^{(u3)}(t)\psi_k(x_1), \\ N_1^0(t, x_1) = \sum\limits_{k=1}^{n} a_k^{(u4)}(t)\psi_k(x_1), \quad N_2^0(t, x_1) = \sum\limits_{k=1}^{n} a_k^{(u5)}(t)\psi_k(x_1), \\ M_1^0(t, x_1) = \sum\limits_{k=1}^{n} a_k^{(u6)}(t)\psi_k(x_1), \quad M_2^0(t, x_1) = \sum\limits_{k=1}^{n} a_k^{(u7)}(t)\psi_k(x_1), \\ Q_1^0 = \sum\limits_{k=1}^{n} a_k^{(u8)}(t)\psi_k(x_1). \end{cases} \tag{14}$$

The approximations satisfying the conditions in (3) and (5)–(9) are similar to those in (13) and (14).

Consider the application of the Bubnov–Galerkin method to the construction of the Cauchy problem, which after being solved results in the determination of the approximation coefficients [6]. First, we represent equations (1) and (2) in the operator form:

$$\mathbf{Au} = \mathbf{f} + \mathbf{Cv}, \tag{15}$$

$$\dot{\mathbf{v}} = \mathbf{w}(\mathbf{v};\ \mathbf{u}), \tag{16}$$

where the vector $\mathbf{u}^T = (N_1^0 \quad N_2^0 \quad M_1^0 \quad M_2^0 \quad Q_1^0 \quad u_1^0 \quad u_3^0 \quad \vartheta_1^0)$, the vector $\mathbf{v}^T = (c_{11} \quad c_{22} \quad \omega)$, **A**, **C**, and **w** are the operators, and **f** is the vector whose view is determined in an obvious way from the vectors **u** and **v** and equations (1) and (2).

We represent the approximations of the sought unknowns in the matrix-vector form:

$$\mathbf{u}(t,\ \mathbf{x}) \approx \mathbf{u}^{(n)}(t,\ \mathbf{x}) = \mathbf{u}_{\upsilon}(\mathbf{x}) + \Phi_{\mathbf{u}}^{(n)}(\mathbf{x})\mathbf{a}_{\mathbf{u}}^{(n)}(t), \tag{17}$$

$$\mathbf{v}(t,\ \mathbf{x}) \approx \mathbf{v}^{(m)}(t,\ \mathbf{x}) = \Phi_{\mathbf{v}}^{(m)}(\mathbf{x})\mathbf{a}_{\mathbf{v}}^{(m)}(t), \qquad \mathbf{a}_{\mathbf{v}}^{(m)}(0) = \mathbf{0}, \tag{18}$$

where the vector $\mathbf{x}^T = (x_1,\ x_3)$, n is the number of trial functions, $\mathbf{u}_{\upsilon}$ is the vector that continues the boundary values inside the domain, $\Phi_{\mathbf{u}}^{(n)}$ and $\Phi_{\mathbf{v}}^{(m)}$ are the matrices composed of $8n$ and $3m^2$ columns of trial functions, and $\mathbf{a}_{\mathbf{u}}^{(n)}$ and $\mathbf{a}_{\mathbf{v}}^{(m)}$ are the vectors composed of the approximation coefficients (to be determined) which are the functions of time.

By substituting approximations (17) and (18) into equations (15) and (16) and by writing the orthogonality conditions for trial functions, we obtain

$$\int\limits_{\Gamma^0} (\Phi_{\mathbf{u}}^{(n)})^T (\mathbf{A}(\mathbf{u}_{\upsilon} + \Phi_{\mathbf{u}}^{(n)}\mathbf{a}_{\mathbf{u}}^{(n)}) - \mathbf{f} - \mathbf{C}(\Phi_{\mathbf{v}}^{(m)}\mathbf{a}_{\mathbf{v}}^{(m)}))d\Gamma^0 = 0, \tag{19}$$

$$\int_{\Gamma} (\Phi_{\mathbf{v}}^{(m)})^T (\Phi_{\mathbf{v}}^{(m)} \dot{\mathbf{a}}_{\mathbf{v}}^{(m)} - \mathbf{w}(\Phi_{\mathbf{v}}^{(m)} \mathbf{a}_{\mathbf{v}}^{(m)};\ \mathbf{u}_{\upsilon} + \Phi_{\mathbf{u}}^{(n)} \mathbf{a}_{\mathbf{u}}^{(n)})) d\Gamma = 0, \tag{20}$$

where Γ^0 is the median surface and Γ is the volume of the shell under study.

The linearity of the operators $\mathbf{A}$ and $\mathbf{C}$ makes it possible to represent the orthogonality conditions (19) and (20) in the form:

$$\begin{gathered} \mathbf{A}^{(n)} \mathbf{a}_{\mathbf{u}}^{(n)} = \mathbf{f}^{(n)} + \mathbf{C}^{(nm)} \mathbf{a}_{\mathbf{v}}^{(m)}, \\ \dot{\mathbf{a}}_{\mathbf{v}}^{(m)} = (\mathbf{K}^{(m)})^{-1} \mathbf{w}^{(m)} (\mathbf{a}_{\mathbf{v}}^{(m)};\ \mathbf{a}_{\mathbf{u}}^{(n)}), \end{gathered} \tag{21}$$

where

$$\mathbf{A}^{(n)} = \int_{\Gamma^0} (\Phi_{\mathbf{u}}^{(n)})^T (\mathbf{A} \Phi_{\mathbf{u}}^{(n)}) d\Gamma^0, \qquad \mathbf{C}^{(nm)} = \int_{\Gamma^0} (\Phi_{\mathbf{u}}^{(n)})^T (\mathbf{C} \Phi_{\mathbf{v}}^{(m)}) d\Gamma^0,$$

$$\mathbf{f}^{(n)} = \int_{\Gamma^0} (\Phi_{\mathbf{u}}^{(n)})^T (\mathbf{f} - \mathbf{A}\, \mathbf{u}_{\upsilon}) d\Gamma^0, \qquad \mathbf{K}^{(m)} = \int_{\Gamma} (\Phi_{\mathbf{v}}^{(m)})^T \Phi_{\mathbf{v}}^{(m)} d\Gamma,$$

$$\mathbf{w}^{(m)} (\mathbf{a}_{\mathbf{v}}^{(m)};\ \mathbf{a}_{\mathbf{u}}^{(n)}) = \int_{\Gamma} (\Phi_{\mathbf{v}}^{(m)})^T\ \mathbf{w}(\Phi_{\mathbf{v}}^{(m)} \mathbf{a}_{\mathbf{v}}^{(m)};\ \mathbf{u}_{\upsilon} + \Phi_{\mathbf{u}}^{(n)} \mathbf{a}_{\mathbf{u}}^{(n)}) d\Gamma.$$

By using the first equation in (21), we eliminate the vector $\mathbf{a}_{\mathbf{u}}^{(n)}$ from the second one thus obtaining the Cauchy problem with respect to the vector $\mathbf{a}_{\mathbf{v}}^{(m)}$:

$$\begin{gathered} \dot{\mathbf{a}}_{\mathbf{v}}^{(m)} = (\mathbf{K}^{(m)})^{-1} \mathbf{w}^{(m)} (\mathbf{a}_{\mathbf{v}}^{(m)}), \\ \mathbf{a}_{\mathbf{v}}^{(m)} (0) = \mathbf{0}, \end{gathered} \tag{22}$$

where

$$\mathbf{w}^{(m)} (\mathbf{a}_{\mathbf{v}}^{(m)}) = (\mathbf{K}^{(m)})^{-1} \mathbf{w}^{(m)} (\mathbf{a}_{\mathbf{v}}^{(m)};\ \mathbf{a}_{\mathbf{u}}^{(n)}),$$

$$\mathbf{a}_{\mathbf{u}}^{(n)} = (\mathbf{A}^{(n)})^{-1} (\mathbf{f}^{(n)} + \mathbf{C}^{(nm)} \mathbf{a}_{\mathbf{v}}^{(m)}).$$

The solution of the Cauchy problem (22) using any approximate step-by-step method, such as the Runge-Kutta method modified by Merson [8], makes it possible to find, at the integration step, the approximation coefficients $\mathbf{a}_{\mathbf{u}}^{(n)}$ and $\mathbf{a}_{\mathbf{v}}^{(m)}$, and from their values, the sought functions from which the stress-strain state, creep strains and damage parameter are determined at each point of the shell.

Calculation Studies. Consider the calculation results for the cover of vacuum chamber of alloy D16AT with rigid angular and hinge fixings (Fig. 2) that is loaded by the pressure $p = 0.1$ MPa. The cover dimensions are as follows: $R = 0.35$ m, $h = 0.003$ m, and $\theta = 60°$; the physico-mechanical characteristics of the material are taken from the data in [9]: $E = 72$ GPa, $\nu = 0.35$, $n = k = 2.93$, $B = 3.4 \cdot 10^{-8}$ MPa^{-n}, $A = 1.9 \cdot 10^{-7}$ MPa^{-k}, and $r = 1.38$.

The calculations show that fixings of the cover getting damaged due to creep significantly influence its life governed by the condition of (11) for the end of the hidden fracture. In the cover with tangential fixing of the type corresponding to (5) and (8), the momentless state is realized at which the stresses while varying in time remain uniformly distributed by thickness, and the calculated time obtained t_{ω} for the end of the hidden fracture is about 9977 h. With fixings of the type corresponding to (6) and (9) that are installed along the normal, the stresses are distributed nonuniformly and are redistributed significantly in thickness due to creep; with t_{ω} being approximately equal to 12 and 10 h, respectively. In the case of the rigid (4) and fixed hinge (7) fixings of the cover edge, the stresses are distributed nonuniformly and are significantly redistributed in thickness due to creep (Fig. 3). For the

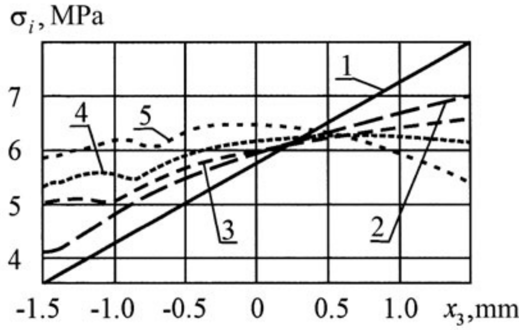

Fig. 3

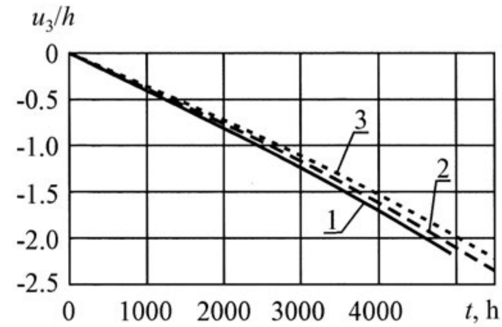

Fig. 4

Fig. 3. Stress intensity redistribution in thickness over the critical cross section of the hinged cover: (*1*) $t = 0$; (*2*) $t = 13$ h; (*3*) $t = 1007$ h; (*4*) $t = 6005$ h; (5) $t = 7281$ h.

Fig. 4. Displacement due to creep of the apex of the cover with a rigid fixing (*1*) corresponding to Eq. (4), with a fixed hinge fixing (*2*) corresponding to Eq. (7), and with tangential fixings (*3*) corresponding to Eqs. (5) and (8).

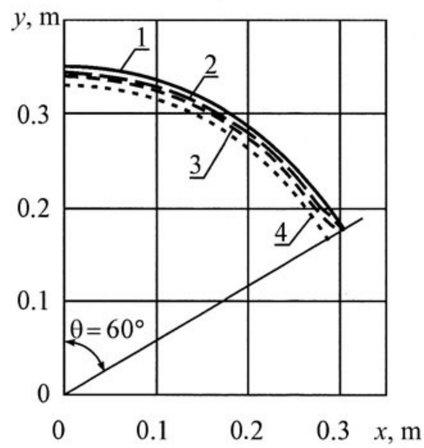

Fig. 5. Change in the shape of the median surface of the nondeformed cover (*1*), with a rigid fixing (*2*) corresponding to Eq. (4), with a fixed hinge fixing (*3*) corresponding to Eq. (7), and with tangential fixings (*4*) corresponding to Eqs. (5) and (8).

cover with a rigidly fixed edge $t_\omega = 4938$ h, the critical cross section is located in the fixing, whereas for the cover with a fixed hinge fastening of the edge $t_\omega \cong 7281$ h, it is at some distance from the fixed edge and has the coordinate $x_1 \cong 1.006$ rad, which is equivalent to about $\cong 57.6°$.

The calculation results were obtained by retaining the terms of the series in the approximations of the solutions of equations (13) and (14) with $m = n = 16$ when the discrepancy in the time before fracture for $m = n = 15$ was from 0.2 to 0.4%. For the fixings of the type corresponding to (5) and (8) with the momentless deformation of the spherical shell, the numerical solutions coincide with the analytical ones.

Fixings influence the life defined by the condition of (12) for the allowable in-service deflection of the cover (Fig. 4). The largest displacement of the cover apex was obtained at some fixed instant of time for the rigid fixing of the edge, while the smallest one – for the tangential one.

Figure 5 presents the data on the change in the shape of the median surface of the cover of vacuum chamber with different types of edge fixing due to creep in the initial state and at the instant of the end of the hidden fracture. It is seen that the shape of the median surface varies rather significantly with time. In all cases, in the initial instant of time, under the elastic deformation of the shell, the deflections are much smaller than the thickness, which agrees with the geometric linearity of the problem. A significant increase in deflections $(0 < |u_3/h| < 2.5)$, up to the point of the exhaustion of the shell life, is caused only by spontaneous irreversible creep strains.

CONCLUSIONS

1. The edge fixings have an influence on the life of a cover of vacuum chamber getting damaged due to creep at atmospheric pressure, with a significant effect on the time of the end of the hidden fracture and insignificant one on the time of the ultimate shape change.

2. The maximum life with respect to the time of the end of the hidden fracture is achieved by tangential fixing, and the minimum one – by fixings along the normal to the median surface of the cover. The minimum life with respect to the shape change is achieved by rigid fixings and the maximum one by tangential fixings.

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