Heat-moisture conduction in capillary-porous substances consists of capillary heat-moisture permeability, relative thermal diffusion of liquid and vapour.

The coefficient of heat-moisture conduction is linearly proportional to temperature rise. The absolute value of the heat-moisture coefficient decreases with increased moisture diffusivity or molecular diffusion. The moisture gradient, which is produced by heat-moisture conduction, varies proportionally with the temperature gradient [5]. The water flow caused by heat-moisture conduction will also take in additional amount of heat to move in the direction of the main heat flux.

Conclusions. Based on the literature source, the analysis of the drying process of lumber has shown that moisture movement within lumber is due to the presence of three driving forces: moisture content gradient, temperature gradient, internal pressure.

References

1. **Vintoniv, I., Sopushynskyy, I., Tayshinher, A.** (2007) *Derevynoznavstvo* [Wood Science]. Lviv: Apriori (in Ukrainian).
2. **Biley, P., Sokolovskyy, I., Pavlyust, V., Kunynets, Ye.** (2010) *Kerivni tekhnichni materialy z tekhnolohiyi kamernoho sushinnya pylomaterialiv* [Guiding technical materials from lumber drying technology].Uzhgorod: Karpaty (in Ukrainian).
3. **Biley, P., Pavlyus, V.** (2008) *Sushinnya ta zakhyst derevyny* [Drying and protection of wood]. Lviv (in Ukrainian).
4. **Sergovskyy, P., Rasev, A.** (1987) *Gidrotermicheskaya obrabotka i konservirovanie drevesiny* [Hydrothermal treatment and preservation wood]. Moscow: Lesnaya promyshlennost (in Russian).
5. **Biley, P.** (2005) *Teoretychni osnovy teplovoyi obrobky i sushinnya derevyny* [Theoretical foundations heat treatment and drying of wood]. Kolomyia: Vik (in Ukrainian).

УДК 674.047

Аспір. А.М. Комбаров; проф. П.В. Білей, д-р техн. наук – НЛТУ України

Аналіз фізичних закономірностей процесу сушіння пиломатеріалів

Проведено аналіз фізичних закономірностей, які впливають на процес сушіння пиломатеріалів. Розглянуто їх вплив на швидкість на якість висушеного матеріалу. Розглянуто методи видалення вологи з деревини. Описано рівняння вологопровідності та термовологопровідності. Проведено аналіз цих рівнянь. Розглянуто принципи руху вологи в середині вологої деревини.

Ключові слова: деревина, пиломатеріал, вологість, тиск, градієнт, температура, теплопровідність, випаровування, волога, вологоперенесення, вологовміст.

UDC 674.620.168

Master's degree I.M. Lesyshyn; prof. B.P. Pobereyko − UNFU

SOFTWARE DEVELOPMENT FOR DETERMINATION OF STRESS FIELDS IN THE WOOD WITH A PARABOLIC DISTRIBUTION OF MOISTURE

The task of determination of the flat tense consisting is in-process decided of radiality-tangentiality plane of anisotropy of wood with the uneven distributing of moisture. On the basis of method of Ritca an algorithm and software is developed for the calculation of components of tensor of tensions in saw-timbers with the parabolic distributing of moisture. The algorithm of description is given in it is given in a verbal form. The program is realized in the environment C++ with the use of visual components.

Keywords: Ritz method, the stress field.

At the stage of constant rate drying saw in the plain stress state is flat , the value of the axial component of the stress tensor is almost negligible. Therefore, to determine the allowable differences in moisture drying saw limited mathematical model of stress in plain board with plane stress condition in the radial plain structural symmetry. The components of this model are:

equilibrium equation
$$\begin{cases} \dfrac{d\,\sigma_x}{dx} + \dfrac{d\,\tau_{xy}}{dy} = 0 \\ \dfrac{d\,\sigma_y}{dy} + \dfrac{d\,\tau_{xy}}{dx} = 0 \end{cases} \tag{1}$$

adjacency equation
$$\frac{d^2\varepsilon_x}{dy^2} + \frac{d^2\varepsilon_y}{dx^2} = \frac{d^2\Upsilon_{xy}}{d_x d_y} \tag{2}$$

Hooke's law for incompressible and compressible materials
$$\begin{cases} \varepsilon_x = \frac{\sigma_x}{E_x} - \frac{\mu_{yx}\sigma_y}{E_y} + \beta_x \Delta w; \\ \varepsilon_y - \frac{\sigma_y}{E_y} - \frac{\mu_{xy}\sigma_x}{E_x} + \beta_y \Delta w; \\ \Upsilon_{xy} = \frac{\tau_{xy}}{G_{xy}}, \end{cases} \tag{3}$$

boundary conditions $\sigma_x=0$ для $x=\pm R$; $\sigma_y=0$ для $y=\pm a$; $\tau_{xy}=0$ для $x=\pm R$ та $y=\pm a$ (4)

Here E_x, E_y – modulus of elasticity; G_{xy} – shear modulus; μ_{xy}, μ_{yx} – Carbon Poisson; β_x, β_y – shrinkage factor; Δw – feature changes in humidity for toschynoyu material; ε_x, ε_y – the main components of strain; σ_x, σ_y – the main components of the stress tensor; τ_{xy}, γ_{xy} – related stress and shear strain; *a* – half-plane board; R – half board thickness, x, y – the coordinates of the points of the cross-section board.

Practical implementation of a mathematical model of the Ritz method is represented as:
$$\sigma_x(x,y) = \frac{\partial^2 F(x,y)}{\partial y^2};\ \sigma_y(x,y) = \frac{\partial^2 F(xy)}{\partial x^2};\ \sigma_{xy}(x,y) = -\frac{\partial^2 F(x,y)}{\partial x dy} \tag{5}$$

Here F (x, y) - any two differentiated, which is a solution of the equation:
$$\frac{1}{E_2}\frac{\partial^4 F}{\partial x^4} + \left(\frac{1}{G_{xy}} - \frac{\mu_{yx}}{E_y} - \frac{\mu_{xy}}{E_x}\right)\frac{\partial^4 F}{\partial x^2 \partial y_2} + \frac{1}{E_y}\frac{\partial^4 F}{\partial x^4} = -\frac{\partial^2}{\partial x^2}\left(\beta_y \Delta w(x,y)\right) - \frac{\partial^2}{\partial y^2}\left(\beta_x \Delta w(x,y)\right), \tag{6}$$

obtained substituting the relations (3) into (2) and subsequent replacement σ_x, σ_y, σ_{xy} – to $\frac{\partial^2 F(x,y)}{\partial y^2}, \frac{\partial^2 F(xy)}{\partial x^2}; \sigma_{xy}(x,y) = -\frac{\partial^2 F(x,y)}{\partial x dy}$ respectively.

So, the problem of calculating the stress fields in cross-section timber uneven distribution of water equivalent to the problem of finding the solution of equation (6) which satisfies the boundary conditions (4).

Approximate solution of equation (6) look as $F = d_1\varphi_1 + d_2\varphi_2 + d_3\varphi_3$ (7)
де $\varphi = (x^2-a^2)^2(y^2-R^2)^2$; $\varphi_2 = \varphi_1 x^2$; $\varphi_3 = \varphi_1 y^2$.

The unknown coefficients d_1, d_2, d_3 – Ritz coefficients of a system of linear algebraic equations:
$$\sum_{k=1}^{3}\left(\bar{\Delta}\varphi_k, \varphi_n\right)d_k = \left(\left[-\frac{\partial^2}{\partial x^2} - \frac{\partial^2}{\partial y^2}\right]\beta_y W(x,y), \varphi_n\right), \tag{8}$$

де

$$\bar{\Delta} = \frac{1}{E^2}\frac{\partial^4}{\partial x^4} + \left(\frac{1}{G_{12}} - 2\frac{\nu_{21}}{E_2}\right)\frac{\partial^4}{\partial x^2 \partial y^2} + \frac{1}{E_1}\frac{\partial^4}{\partial x^4};$$

$\left(\bar{\Delta}\varphi_k,\ \varphi_n\right)$, $\left(\left[-\frac{\partial^2}{\partial x^2} - \frac{\partial^2}{\partial y^2}\right]\beta_y \Delta W(x,y),\ \varphi_n\right)$ – corresponding scalar product:

$$\left(\bar{\Delta}\varphi_k,\ \varphi_n\right) = \int_{-a}^{a}\int_{-R}^{R} \bar{\Delta}\varphi_k \varphi_n \, dxdy \quad ,$$

$$k = 1,2,3. \tag{9}$$

For timber with a parabolic distribution of moisture

$$\Delta W = \frac{W_{max}}{R^2} x^2 \tag{10}$$

The system of equations (8) has the form:

$$\begin{cases} A_{11}d_1 + A_{12}S_{пр}d_2 + A_{13}S_{пр}d_3 = \frac{7\varsigma}{64}\beta_y \Delta W; \\ A_{21}d_1 + A_{22}S_{пр}d_2 + A_{23}S_{пр}d_3 = \frac{13}{12}\beta_y \Delta W; \\ A_{31}d_1 + A_{32}S_{пр}d_2 + A_{33}S_{пр}d_3 = \frac{13\varsigma}{12}\beta_y \Delta W, \end{cases} \tag{11}$$

where:

$$A_{11} = \left(\frac{\varsigma^2}{E_y} + \frac{2}{7}\left(\frac{1}{G_{xy}} - \frac{2\mu_{xy}}{E_y}\right) + \frac{1}{7\varsigma^2 E_x}\right)S^3_{пр};\ A_{12} = \left(\frac{\varsigma}{7E_y} + \frac{1}{11\varsigma^3 E_x}\right)S^4_{пр};$$

$$A_{13} = \left(\frac{\varsigma^3}{11E_y} + \frac{1}{7\varsigma E_x}\right)S^4_{пр};\qquad A_{21} = \frac{16}{3}\left(\frac{13\varsigma}{7E_y} + \frac{1}{33\varsigma^3 E_x}\right)S^3_{пр};$$

$$A_{22} = \left(\frac{64}{21E_y} + \frac{1376}{2079\varsigma^2}\left(\frac{1}{G_{xy}} - \frac{2\mu_{xy}}{E_y}\right) + \frac{1647}{143\varsigma^4 E_x}\right)S^4_{пр};$$

$$A_{23} = \frac{16}{23}1\left(\frac{13\varsigma^2}{E_y} + \frac{4}{3\varsigma^2 E_x}\right)S^4_{пр};\quad A_{31} = \frac{16}{3}\left(\frac{4\varsigma^3}{33E_y} + \frac{13}{7\varsigma E_x}\right)S^3_{пр};$$

$$A_{32} = \frac{16}{3}\left(\frac{7\varsigma^2}{3E_y} + \frac{13}{\varsigma^2 E_x}\right)S^4_{пр}; \tag{12}$$

$$A_{33} = \left(-\frac{1674\varsigma^4}{143E_y} + \frac{1376}{2079}\left(\frac{1}{G_{xy}} - \frac{2\mu_{xy}}{E_y}\right) + \frac{64}{21E_x}\right)S^4_{пр};$$

$\varsigma = a/b$ – relation of width to the length of the board, $S_{пр} = aR$ – quarter of the cross-sectional area board, W_{max} – the difference of moisture content in the central layer and the surface of the board.

Coefficients d_1, d_2, d_3 –dependent on the geometrical characteristics of a material and drop of moisture on his thick. Indeed, according to (11):

$$d_1 = D_1\beta_y\Delta W;\ d_2 = D_2\beta_y\Delta W;\ d_3 = D_3\beta_y\Delta W \tag{13}$$

where $D_1 = \frac{\Delta_1}{\Delta};\quad D_2 = \frac{\Delta_2}{\Delta};\quad D_3 = \frac{\Delta_3}{\Delta};$

$$\Delta = \begin{vmatrix} A_{11} & A_{21} & A_{31} \\ A_{21} & A_{22} & A_{32} \\ A_{31} & A_{23} & A_{33} \end{vmatrix};\ \Delta_1 = \begin{vmatrix} B_1 & A_{21} & A_{31} \\ B_2 & A_{22} & A_{32} \\ B_3 & A_{23} & A_{33} \end{vmatrix};\ \Delta_2 = \begin{vmatrix} A_{11} & B_1 & A_{31} \\ A_{21} & B_2 & A_{32} \\ A_{31} & B_3 & A_{33} \end{vmatrix};\ \Delta_3 = \begin{vmatrix} A_{11} & A_{21} & B_1 \\ A_{21} & A_{22} & B_2 \\ A_{31} & A_{23} & B_3 \end{vmatrix}. \tag{14}$$

Substituting (13) and (7) and formula (5) determine the components of the stress tensor:

$$\sigma_x = \Phi_x\beta_y\Delta W;\ \sigma_y = \Phi_y\beta_y\Delta W;\ \tau_{xy} = \Phi_{xy}\beta_y\Delta W \tag{15}$$

where

$$
\begin{aligned}
\Phi_x = {} & 2\{2D_1(3y^2 - a^2) + 2D_2(3y^2 - a^2)x^2 \\
& + D_3(15y^4 - 12a^2y^2 + a^4)\}(x^2 - R^2)^2; \\
\Phi_y = {} & 2\{2D_1(3x^2 - R^2) + D_2(15x^2 - 6R^2x^2 + R^4) \\
& + 2D_3(3x^2 - R^2)y^2\}(y^2 - a^2)^2; \\
\Phi_{xy} = {} & 16D_1(x^3 - R^2)(y^3 - a^2y) \quad + 8(y^3 - a^2y)(3x^5 - 4R^2x^3 + R^4x)D_2 \\
& + 8D_3(x^3 - R^2x)(3y^5 - 4a^2y^3 + a^4y).
\end{aligned}
\tag{16}
$$

In this work in C + + Builder it is developed software that allows modeling distributions of stress fields in the component timber parabolic distribution of moisture. The result of practical testing of the software on the plain pine boards are shown in Fig. 1.

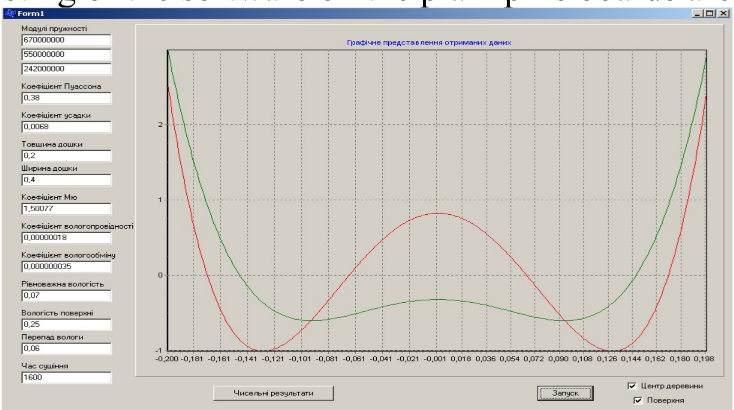

Fig. 1. Software for determining the stress fields in the wood

So in the work it is done the mathematical formulation of the problem of determining the stress state of the wood. The developed automated system for calculating the stress state of timber with non-uniform distribution of moisture fields can be used in modern systems of early detection and control of hazardous on forming and fracture in drying boards stresses.

Conclusions. An algorithm and the respective software for constructing the curves of strength of biaxially stressed wood have been developed. Based on the analysis of the software application results, it has been shown that the strength of pine wood is adequately described by Goldenblatt-Kopnov's criterion.

References

1. **Pobereyko, B.** (2006) *Vyznachennya korotkochasnoyi mitsnosti derevyny* [Determination of short-term strength of the timber]. *Scientific Bulletin of the UNFU, 16.2,* 73–77 (in Ukrainian).

УДК 674.620.168

Магістр І.М. Лесишин, проф. Б.П. Поберейко, д-р техн. наук – НЛТУ України

Розробка програмного забезпечення для визначення полів напружень у деревині з параболічним розподілом вологи

Вирішено задачу визначення плоского напруженого стану у радіально-тангентальній площині анізотропії деревини з нерівномірним розподілом вологи. На основі методу Рітца розроблено алгоритм та програмне забезпечення для розрахунку компонентів тензора напружень у пиломатеріалах з параболічним розподілом вологи. Програма реалізована у середовищі Builder C++ з використанням візуальних компонентів.

Ключові слова: метод Рітца, поля напружень.