various certification standards and world-wide industry agreements, demonstrate technological and intellectual advances in evaluation and logistics.

Opportunity may come knocking on the door, but somebody knowledgeable and business-savvy should be on the other side of the door, ready to open it. The strength in getting what you want from the transaction is a combined skill of understanding the nature of the deal, laying out all the main aspects that have to be included and negotiation while keeping the return on investment for both parties favorable. This is the golden key that binds the investing party and the provider of the investment.

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Стратегічна оцінка інвестиційних критеріїв очима іноземного інвестора і необхідна тактика лісової промисловості України в напрямку інвестиційної привабливості

Для покращення інвестиційної привабливості і збільшення потоку іноземного капіталу, лісова промисловість України повинна запровадити наступні кроки: впровадження приваблюючих інвесторів, законів; розроблення структури менеджменту іноземних інвестицій, яка була б зрозуміла як вдома, так і за кордоном; рекламу інвестиційних об'єктів; забезпечення екологічно-безпечного інвестиційного клімату; відповідність світовим стандартам сертифікації; заохочення бізнес-турів і розвиток нових технологій.

УДК 674.05:628.517

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STATISTICAL SIMULATION FOR INFLUENCE OF WOOD CHARACTERISTICS ON PROPAGATION SPEED OF ULTRASONIC WAVES

The statistical simulation for propagation speed of ultrasonic waves in wood is presented in the article. The regression dependences for propagation speed of ultrasonic waves on physical characteristics of wood are obtained. The rotatable second order plan is used for statistical simulation.

Keywords: ultrasound, wood, temperature, humidity, statistical simulation.

Relevance of research. The modern development of controlling over physical and mechanical properties of wood is based on utilizing the nondestructive methods. One of them, namely the acoustic control, gained rapid development in last decade. Advantage of acoustic control is using the elastic waves, which parameters are closely related to thermophysical and mechanical properties of materials. This kind of control is appropriate for all materials that are good propagators for acoustic waves. Wood is one of such materials. At this time ultrasonic method (a kind of acoustic control) is mainly considered as a defectoscopy method. The suitability of using this method for defining the physical and mechanical properties of wood is proved in this paper. Regularities of experimental data are described on the base of regression analysis.

Analysis of known research results. Analysis of regularities in relations of VUWP to and mechanical properties of wood is presented in [3-16]. But it should be admitted that only partial dependencies $c = f(T, W, \alpha)$ are considered there. Particularly in [4-6] the experimental research was conducted for obtaining relations between velocity of ultrasonic wave propagation in wood and thermophysical properties of material $c = f(T, W)$, $c = f(\alpha)$, for fixed values of T, W, where c - velocity of ultrasonic waves propagation (VUWP), m/s; T – temperature of wood, $^\circ C$; W - moisture of wood, %; α - angularity of piezoconvertors to wood fibers.

Analysis of conducted experimental research reveals following peculiarities:

- decreasing in moisture span from dry state to the limit of absorbability $W_{ГГ}$ is intensive and above change of VUWP is insignificant;
- increasing the wood temperature in range from +20 °C to +100 °C yields decreasing the VUWP in nonlinear way;
- dependence of VUWP decreasing with respect to rise of angularity between wave propagation and wood fiber also is nonlinear.

Relying upon above described features it is possible to state that curvature of response surface $c = f(T, W, \alpha)$, would be significant. It is the complexity of response surface $c = f(T, W, \alpha)$, that caused the interpretation of research results for partial cases of three variable factors (T, W, α).

Problem definition. Taking into account conducted earlier researches [4-6] we elaborate here the statistic modeling for dependence between VUWP C and temperature T, moisture W , angularity of VUWP to pine wood fiber α. It allows to obtain the dependence $c = f(T, W, \alpha)$. To research the optimum region the second order rototable plan was selected [1]. The choice of samples and materials, description of experimental device, results of ultrasonic measurements are given in [4-6]. But the significant curvature of response surface for considered dependences was obtained as that was shown by results analysis for partial cases.

That causes the substantial worsening for adequacy of statistic models. So it was proposed to divide the research region into two interlinked experiments. To calculate the statistical regression model the software package STATISTICA 6.1 was used. [2]

Obtained results and their analysis. Coding of factors to research the optimum region by means of the second order rototable plan is presented in table 1.

Table 1. Factors coding for research of the optimum region by means of the second order rototable plan

Factors level	Coded Value	Temperature, $T, ^\circ C$	Moisture, $W, \%$	Angularity, $\alpha, ^\circ$
Zero level (center of experiment)	0	60	54	45
Upper level	+1	83,78	81,35	71,75
Bottom level	-1	36,22	26,65	18,25
Positive value of star "lever" ($+d$)	+1,682	100	100	90
Negative value of star "lever" ($-d$)	-1,682	20	8	0
Range of variance		23,78	27,35	26,75

Optimum region is described by equation

$$c = b_0 + b_1 T + b_2 W + b_3 \alpha + b_{11} T^2 + b_{22} W^2 + b_{33} \alpha^2 + b_{12} TW + b_{13} T\alpha + b_{23} W\alpha \qquad (1)$$

Results of calculations for regression equation (1) coefficients in coded variables and their verification for significance by Student t-criterion are presented in table 2.

Table 2. Calculation of regression coefficients in coded variables

Regression coefficients	Values	Dispersion		Student's t-criterion	
		notation	calculated values	calculated values	table values $t_{(0,05;5)}$
b_0	1894,902	S^2_{b0}	0,321	3344,59	2,571
b_1	-101,857	S^2_{b1}	0,141	271,25	2,571
b_2	-212,899	S^2_{b2}	0,141	566,96	2,571

b_3	-823,114	S^2_{b3}	0,141	2191,99	2,571
b_{11}	12,353	S^2_{b11}	0,214	26,69	2,571
b_{22}	85,957	S^2_{b22}	0,214	185,76	2,571
b_{33}	424,253	S^2_{b33}	0,214	916,83	2,571
b_{12}	12,383	S^2_{b12}	0,177	29,43	2,571
b_{13}	40,901	S^2_{b13}	0,177	97,22	2,571
b_{23}	70,920	S^2_{b23}	0,177	168,58	2,571

Verification by direct comparison of Calculated values of Student t-criterion and its table values proved all coefficients of regression equation (1) to be significant.

Calculations for Cochrane criterion $G = 0{,}1207 < G_T = 0{,}2705$ proved that dispersion is homogeneous so the experiment can be considered as reconstructable. Results for Fisher criterion calculations yield $F = 10322{,}7 > F_T = 5{,}0503$. Thus the regression equation (1) with coefficients from table 2 does not adequately describe experimental data for VUWP dependence on temperature, moisture and angularity of sound propagation. It confirms that considerable curvature of surface response does not allow to describe adequately regression dependence (1) for pattern $c = f(T, W, \alpha)$ in a wood material. So to obtain an adequate statistic simulation for experimental data we divide the research region into two experiments:

- in the first one the range of variance for all factors would be diminished (from ±1,682 to ±1) (experiment 1);
- in the second one experimental data would be considered without upper (+1) and lower (-1) levels thus allowing to smooth the response surface (experiment 2).

In its turn smoothing the curvature would contribute to rising the adequacy of statistical simulation.

The full factor experiment (FFE) with experiments in the center of plan is presented in tables 3 and 4. To calculate coefficients within such a mixed plan the software package STATISTICA 6.1was used [2].

Table 3. Factors coding for research of optimum region by means of FFE type 2^3 with six experiments in plan center (Experiment 1)

Factors level	Coded value	Temperature, $T, ^\circ C$	Moisture, $W, \%$	Angularity, $\alpha, ^\circ$
Zero level (center of experiment)	0	60	54	45
Upper level	+1	83,78	81,35	71,75
Lower level	-1	36,22	26,65	18,25

Table 4. Factors coding for research of optimum region by means of FFE type 2^3 with six experiments in plan center (Experiment 2)

Factors level	Coded value	Temperature, $T, ^\circ C$	Moisture, $W, \%$	Angularity, $\alpha, ^\circ$
Zero level (center of experiment)	0	60	54	45
Upper level	+1	100	100	90
Lower level	-1	20	8	0

Since planning matrix (table 3) is degenerated then equation (1) looks like this

$$c = b_0 + b_1 T + b_2 W + b_3 \alpha + b_{11} T^2 + b_{12} TW + b_{13} T\alpha + b_{23} W\alpha \quad (2)$$

Values for coefficients of regression simulation are presented in table 5.

Table 5. Regression coefficients in coded variables (experiment 1, optimum range from table 3)

Regression coefficients	Values	Dispersion		Student's t-criterion	
		notation	calculated values	calculated values	table values $t_{(0,05;5)}$
b_0	1896,889	S^2_{b0}	0,064	7486,57	2,571
b_1	-111,875	S^2_{b1}	0,048	509,85	2,571
b_2	-201,375	S^2_{b2}	0,048	917,73	2,571
b_3	-797,875	S^2_{b3}	0,048	3636,18	2,571
b_{11}	532,486	S^2_{b11}	0,112	1588,66	2,571
b_{12}	12,375	S^2_{b12}	0,048	56,40	2,571
b_{13}	40,875	S^2_{b13}	0,048	186,28	2,571
b_{23}	70,875	S^2_{b23}	0,048	323,00	2,571

Verification by comparing calculated values of Student's t-criteria and their table values proved all coefficients of regression (2) to be significant.

Evaluation of model's adequacy by Fisher's criterion $F = 0.5841 \le F_T = 5.7861$ testified that regression equation (2) with coefficients from table 5 adequately describes experimental dependences $c = f(T, W, \alpha)$.

Equation (2) after appropriate mathematical transformations of coefficients from conditional (coded values) into real variables appears to be

$$c = 7778.847 - 121.608 \cdot T - 12.864 \cdot W - 38.908 \cdot \alpha + 0.942 \cdot T^2 + 0.019 \cdot TW + 0.064 \cdot T\alpha + 0.097 \cdot W\alpha \quad (3)$$

Difference between experimental and calculated values of VUWP defined according to regression equation (3) is presented on fig. 1.

Now we take up calculations for second experiment (table 4). Since in this case planning matrix is degenerated too, equation (1) transforms to

$$c = b_0 + b_1 T + b_2 W + b_3 \alpha + b_{11} T^2 + b_{22} W^2 + b_{33} \alpha^2 \quad (4)$$

Values for coefficients of regression model (4) are presented in table 6.

Verification by Student's t-criterion proved all coefficients of regression (4) to be significant. Taking into account Fisher's criterion $F = 0 \le F_T = 6.6079$ we should state that regression equation (4) with coefficients from table 6 adequately describes experimental data. Regression equation (4) after mathematical transformations of coefficients from conditional (coded values) into real variables appears to be

$$c = 5538.071 - 4.858 \cdot T - 19.793 \cdot W - 84.527 \cdot \alpha + 0.01 \cdot T^2 + 0.106 \cdot W^2 + 0.583 \cdot \alpha^2 \quad (5)$$

Difference between experimental and calculated values of VUWP defined according to regression equation (5) is presented on fig. 2.

Table 6. Regression coefficients in coded variables (experiment 2, optimum range from table 4)

Regression coefficients	Values	Dispersion		Student's t-criterion	
		notation	calculated values	calculated values	table values $t_{(0,05;5)}$
b_0	1896,889	S^2_{b0}	0,064	7486,57	2,571
b_1	-87,693	S^2_{b1}	0,068	336,10	2,571
b_2	-229,191	S^2_{b2}	0,068	878,42	2,571
b_3	-858,799	S^2_{b3}	0,068	3291,53	2,571
b_{11}	5,518	S^2_{b11}	0,032	30,81	2,571
b_{22}	79,039	S^2_{b22}	0,032	441,27	2,571
b_{33}	416,953	S^2_{b33}	0,032	2327,82	2,571

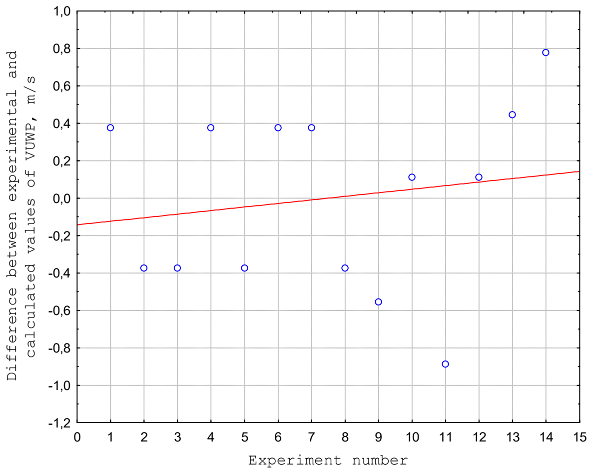

Fig. 1. Plot of residues

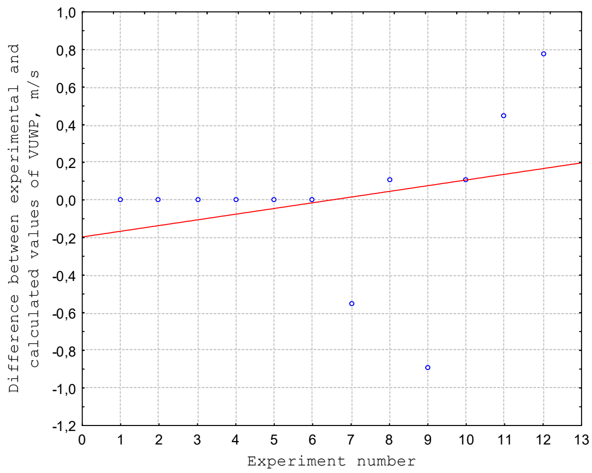

Fig. 2. Plot of residues

Having analyzed fig. 1 and fig. 2 we can draw a conclusion that difference between experimental and calculated values of VUWP does not exceed 1 m/s. This in its turn confirms the adequacy of models described by equations (3) and (5).

To obtain adequate regression model that describes experimental data from table 1 without dividing them into two experiments the multiple regression block of software package STATISTICA 6.1 was used [2]. Using this block with setting the procedure for evaluation of regression coefficients (step by step with inclusion) the fourth-order regression dependence emerged:

$$c = b_0 + b_1T + b_2W + b_3\alpha + b_{22}W^2 + b_{33}\alpha^2 + b_{12}TW + b_{13}T\alpha + b_{23}W\alpha + b_{111}T^3 + b_{222}W^3 + +b_{333}\alpha^3 + b_{1111}T^4 + b_{3333}\alpha^4 \quad (6)$$

Values for coefficients of model (6) are presented in table 7. Coefficient of multiple determination (squared R) for equation (6) with coefficients from table 7 equals $R^2 = 0{,}9999997601$. Magnitude of Student's t-criterion (table 7) proves all coefficients of regression simulation (6) to be significant. Adequacy for equation of multiple regression (6) in general is evaluated by Fisher's criterion $F = 1924119 > F_{T(0.05;13;6)} = 3{,}9764$.

Since observed value of F-criterion for $\alpha = 0.05$ exceeds the one from table, the regression simulation (6) is adequate.

Regression equation (6) after mathematical transformations of coefficients from conditional (coded values) into real variables appears to be

$$c = 5982.911 - 5.351\cdot T - 30.225\cdot W - 93.682\cdot\alpha + 0.226\cdot W^2 + 0.43\cdot\alpha^2 + 0.019\cdot TW + 0.064\cdot T\alpha + \\ + 0.097\cdot W\alpha - 0.001\cdot T^3 - 0.0007\cdot W^3 + 0.0051\cdot\alpha^3 + 0.000008\cdot T^4 - 0.000038\cdot\alpha^4 \quad (7)$$

Table 7. Regression coefficients (11) in conditional variables

Regression coefficients	Values	Dispersion		Student's t-criterion	
		notation	calculated values	calculated values	table values $t_{(0,05;5)}$
b_0	1896,889	m_{b0}	0,291	6515,94	2,447
b_1	-125,095	m_{b1}	0,423	295,74	2,447
b_2	-186,167	m_{b2}	0,423	440,13	2,447
b_3	-764,567	m_{b3}	0,423	1807,54	2,447
b_{22}	79,039	m_{b22}	0,206	384,06	2,447
b_{33}	470,382	m_{b33}	0,528	890,63	2,447
b_{12}	12,375	m_{b12}	0,252	49,09	2,447
b_{13}	40,875	m_{b13}	0,252	162,13	2,447
b_{23}	70,875	m_{b23}	0,252	281,12	2,447
b_{111}	13,220	m_{b111}	0,214	61,74	2,447
b_{222}	-15,208	m_{b222}	0,214	71,01	2,447

b_{333}	-33,308	m_{b333}	0,214	155,54	2,447
b_{1111}	1,950	m_{b1111}	0,073	26,81	2,447
b_{3333}	-18,885	m_{b3333}	0,200	94,56	2,447

Difference between experimental and calculated values of VUWP defined according to regression equation (7) is presented on fig. 3.

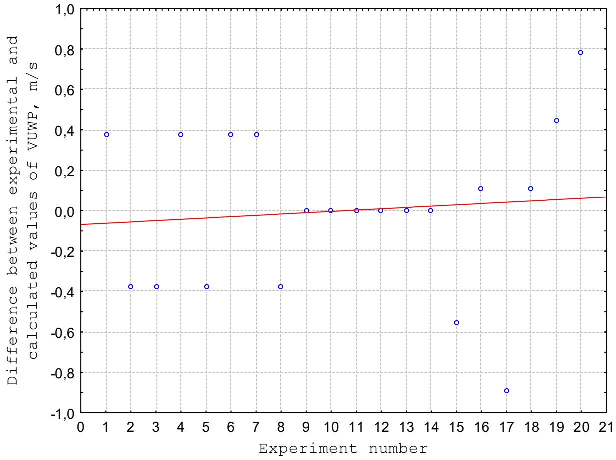

Fig. 3. Plot of residues

After the comparative analysis for figure 3 and two previous figures of residues plots the following conclusions can be drawn:

- residues obtained by calculations according to equation (7) fully coincide with residues calculated according to equations (3) and (5);
- equations (3) and (5) adequately describe the response surface in their part of optimum region, equation (7) in its turn adequately describes all the response surface from optimum region of table 1.

Plots for dependences $c = f(T, W, \alpha)$ of response surface defined by equation (7) in case when one of three variable factors is stabilized are shown on fig. 4-5.

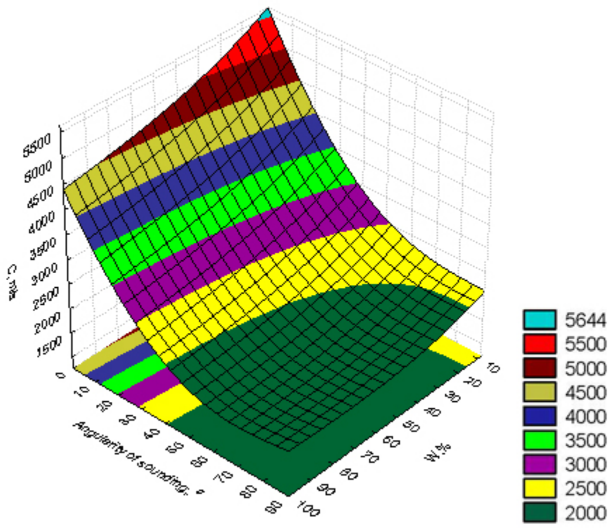

Fig. 4. Dependence of VUWP in pine wood from variations in moisture and angularity of sounding under the fixed temperature T=20 °C

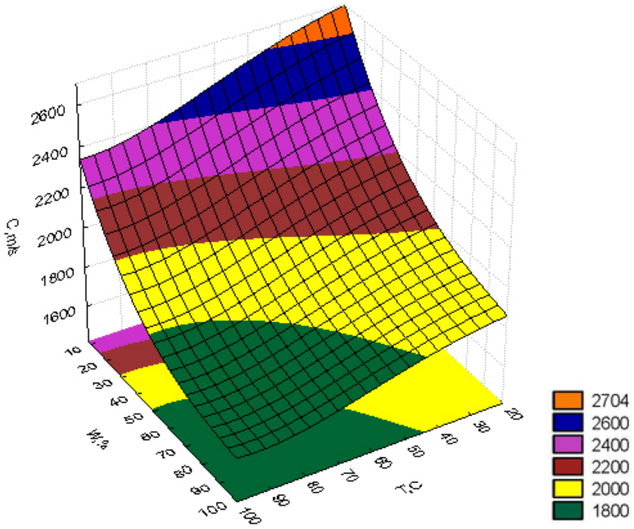

Fig. 5. Dependence of VUWP in pine wood from variations in temperature and moisture under the fixed angular of sounding to fibers 45°

Conclusions. An adequate regression model $c = f(T, W, \alpha)$ was obtained for propagation velocity C of ultrasonic waves in pine wood with respect to temperature T, moisture W and angularity of sounding α, also the procedure was proposed that allows to describe adequately the response surface $c = f(T, W, \alpha)$ taking into account its considerable curvature.

Obtained results made it possible to present visually plots of nonlinear influence (T, W, α) on propagation velocity of ultrasonic waves in pine wood.

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Статистичне моделювання впливу характеристик деревини на швидкість поширення ультразвукових хвиль

Проведено статистичне моделювання швидкості поширення ультразвукових хвиль у деревині. Отримані регресійні залежності швидкості поширення ультразвукових хвиль від фізичних характеристик деревини. Для статистичного моделювання використано рототабельний план другого порядку.

Ключові слова: ультразвук, деревина, температура, вологість, статистична обробка.