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CONTENTS

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THE STUDY OF THE INFLUENCE OF COMPENSATION SLOT PARAMETERS ON THE NOISE LEVEL OF CIRCULAR WOOD-CUTTING SAWS

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Abstract:

One of the disadvantages of using circular saws as a cutting tool is the aerodynamic and mechanical noise generated by circular saws during rotation. Aerodynamic noise includes two components: vortex noise (from the formation of vortices in the area of the toothed edge) and from the heterogeneity of the air flow (when the teeth pass at the edges of the workpiece, and the edges of the slots in the machine table etc.). Mechanical noise (mainly vibration) arises from transverse vibrations of the blade due to disruption of the stability of the blade - centrifugal inertia forces, as well as a result of the transmission of vibrations along the saw shaft and the dynamic imbalance of the blade and clamping washers.

In modern scientific and industrial practice, a number of methods have been developed and applied to reduce the noise of circular saws such as the use of damping materials and new saw designs. In addition, the method of creating compensation slots, which is considered in this paper, is highlighted as the most efficient and which does not require significant material costs. To determine the influence of the parameters of saws with compensators of the the noise of the saw during operation, the method of mathematical designing of the experiment was used. Two variable factors are chosen – X_1 – the area of the compensation slot S, the second factor X_2 – the angular orientation of the compensation slot α. Output parameter L – noise level, in dB.

In addition, a plan for designing the study and the number of repetitions for each selected test was substantiated. A preliminary series of tests having been conducted, a set of statistical coefficients was determined, such as the mean value of the tensile strength, variance, standard deviation, index of variation, and experimental accuracy. The results of the study tests performed in accordance with the design of the mathematical experiment are presented. An application computer program has been developed to process the above-mentioned research results. In addition, coefficients were established for the regression equations of the incomplete quadratic equation, both in normalized and explicit forms. The normality of the tensile strength distribution was checked using the asymmetry and excess criteria. Fisher's coefficient test proved the adequacy of the obtained regression equations. The influence of the main factors on the noise level is analyzed.

Key words*: circular saw; compensation slots; noise; influential factors; regression equation.*

INTRODUCTION

Circular saws for lengthwise and crosswise sawing of wood and wood-based materials have found application in all sectors of the national economy.

The peculiarity of sawing with circular saws is closely related to the specific shape and size of the cutting tool (small thickness compared to the outer diameter), the participation in of a large number of cutters (teeth) in cutting chips, the formation and movement of chips in a narrow space closed on three sides (cut), the variability of chip thickness along the cutting path. At the same time, the noise is also created by the destruction of chips into separate parts (sawdust) of varying sizes, the high speed of the process (40, 60, 80, 100 m/s), the frequency of impact of cutters on the wood and, finally, a large number of interrelated factors and the variability of physical mechanical properties of the workpiece being machined (including its anisotropy).

One of the disadvantages of working with circular saws as a cutting tool is the noise created by the saw shaft. The rotation of the saw is accompanied by the formation of noise of aerodynamic and mechanical origin (Szymani et al. 1984).

Aerodynamic noise includes two components: vortex noise (from the formation of vortices in the area of the toothed edge) and from the heterogeneity of the air flow (when the teeth pass at the edges of the workpiece, the edges of the slots in the machine table etc.) (Stakhyev 1989).

Mechanical noise (mainly vibrations) arises from the transverse vibrations of the blade due to disruption of the stability of the blade - centrifugal inertia forces, as well as a result of the transmission of vibrations along the saw shaft and the dynamic imbalance of the blade and clamping washers (Rebezniuk et al. 2019).

In modern scientific and industrial practice, a number of methods to reduce the noise of circular saws have been developed and applied, such as the use of damping materials and new saw designs. In addition, the method of creating compensation slots stands out as the most efficient and which does not require significant material costs.

The companies producing circular saws have developed and use various designs of compensation slots. However, their design is chosen tentatively and the validity of one or another form of sections, as a rule, is proved by experimental methods. It should be noted that the criterion for assessing the effectiveness of slots itself is not sufficiently substantiated. Therefore, in some cases, estimates are used that are not directly related to the noise generated during the operation of the saw. The lack of knowledge complicates the choice of optimal parameters of the slots which would provide not only noise reduction, but also do not reduce the strength characteristics of the saw blade (Cheremnykh 2013).

PRESENTATION OF BASIC MATERIAL

This paper considers the results of experimental studies on the influence of the size and location of compensation slots, which are made on the blades of circular saws, on the noise generated during the rotation of the circular saw at operating speed.

It is proposed to make slots in the form of segments of Archimedes' spirals, which ensures a smooth transition from the slotted area to the intact section, and this allows decreasing the stress in the disk and reducing the noise level of the saw during the cutting process to the normative sanitary standards. We have received a patent of Ukraine for an invention for the use of saws with slots in the form of Archimedes's spirals (Circular saw: patent for utility model No. 150258, 2021).

One of the additional justifications for the effectiveness of using slots in the form of Archimedes' spirals in circular saw blades can be the widespread use of this curve for back surface relieving of shaped milling tools. The compensation slots are made with a laser slot 0.5mm wide, they have the shape of Archimedes spirals and are located evenly on the base circle with a radius of 0.65 *R*, where *R* is the radius of the saw. The area of one slot, which was calculated using a 3D model of a circular saw built in the SolidWorks program, is equal to $S = 124 mm^2$. The saws have an outer diameter of 400mm, a mounting bore of 50mm, the number of teeth – 72 pcs, the disk thickness – 2.8mm.

Figure 1.*a* shows a specimen of a saw with four slots, each of which has an area *S* and rotates on the base circle at an angle α. In Fig. 1.*b* the slots are located so that the angle $\alpha = 0$ and their number is eight.

External compensators are not taken for comparison, as they are not in the body of the saw, but are located on the outer diameter and are designed to absorb stresses that occur when heating the saw during soldering. To determine the influence of the parameters of saws with compensators for the noise of the saw during operation, the method of mathematical planning of the experiment was used. We choose two variable factors – X_1 – the area of the compensation slot *S*, the second factor X_2 – the angular orientation of the compensation slot α. Output parameter *L* – noise level, in dB.

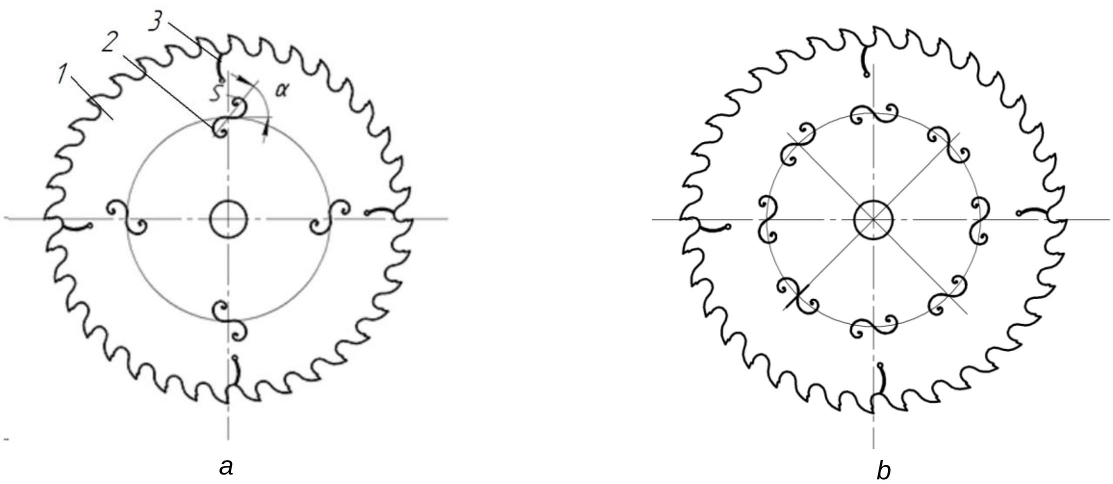

Fig. 1.
Types of saw specimens: a – with four slots; b – with eight slots;
1 – saw disks; 2 – compensation slots; 3 – external compensators.

All the factors are quantitative, controllable and manageable. It is expected that each factor will change at two levels. See the values of the levels in Table 1.

Table 1

Coding levels of factors affecting circular saw noise

Factors	Marking	Level of variation			Interval
		top code «+1»	middle code «0»	bottom code «-1»	
1. The area of the compensation slot, mm^2	S	124	186	248	62
2. Angular orientation of the compensation slot, degrees	α	0	22.5	45	22.5

We choose the regression equation for two variables in the form of an incomplete quadratic equation:

$$y = b_o + b_1 X_1 + b_2 X_2 + b_{12} X_1 X_2 .$$

The coefficients b_o, b_1, b_2, b_{12} are coefficients of the regression equation.

The measurement of the noise level of circular saws was performed on a format circular saw machine during idle rotation of the saws.

For designing, we choose a complete factorial design (CFD) in which we implement all possible combinations of two levels of factors – upper and lower. The number of experiments in this case $N = 2^2 = 4$.

To construct a design-matrix, we turn to dimensionless normalized notations of variable factors. The detailed design-matrix of designing in the code values of the factors in their natural values is given in Table 2.

Table 2

Detailed CFD design-matrix 2^2

Experiment No.	Code values factors		Natural values of factors	
	X_1	X_2	*S, мм²*	*α, degrees*
1	-1	-1	124	0
2	+1	-1	124	45
3	-1	+1	248	0
4	+1	+1	248	45

The number of repeated experiments was determined by the method (Pilipchuk et al. 2007) on the basis of preliminary experiments taking into account the required reliability coefficient p = 0.95, the confidence interval of accuracy assessment ε = 0.05 dB and the variance of preliminary measurement results in previous experiments S^2 = 0.0786. As a result of calculations, the number n = 2.38 was obtained. That is, at each point of the plan, it is necessary to conduct at least three experiments.

The data on the results of measurements of the tensile strength of the specimens are given in Table 3.

The coefficients of the regression equation were found by processing the design-matrix of the experiment and are of the following values:

b_0 = 78.33; b_1 = –2.67; b_2 = –4.83; b_{12} = 0.17.

Regression equation in normalized form

$$y = 78.33 - 2.67X_1 - 4.83X_2 + 0.17X_1 X_2.$$

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pp. 36-41

Table 3

Data on the noise level measurement results, *L*

Test No.	The results of repeated measurements of noise level, dB			The average noise level, dB	Dis-per-sion, S^2	Mean quadratic deviation, σ, dB	Deviation coefficient, υ, %	Average error, m	Accuracy of testing, *p*, %
	L_1	L_2	L_3						
1	87	85	86	86	1.0	1.0	0.15	0.5	0.07
2	80	81	80	80	0.33	2.0	0.40	1.0	0.10
3	76	75	77	76	1.0	1.0	0.12	0.5	0.06
4	71	72	70	71	1.0	1.0	0.08	0.5	0.04

The significance of the coefficients of the regression equation was tested using the Kochran criterion. First, the homogeneity of the variances was identified by determining the actual value of the criterion – $G_f = 0.221$, the tabular value of the Cochran test $G_t = 0.39$ for the number of specimens $N = 3$ and the number of degrees of freedom $f = n–1 = 5–1 = 4$ for the significance level $q = 0.05$. Therefore, $G_f < G_t$ and the hypothesis of homogeneity of variances is accepted.

To determine the significance of the regression coefficients, we find the average variance of the experiment and compare it with the variances of the estimation of the regression coefficients. All the coefficients are significant.

The adequacy of the regression equation was assessed using Fisher's test. The estimated value of Fisher's test $F = 0.0017$. The tabular value of Fisher's test at $f_1 = 3, f_2 = 8$ $F_t = 4.07$.

$$F_t = 4.07 > F = 0.0017$$

This confirms the adequacy of the model.

The regression equation is explicit

$$L = 96 - 0.14S - 0.08\alpha + 0.0002\,S\alpha$$

RESULTS AND DISCUSSIONS

Normalized and explicit regression equations make it possible to construct graphical dependences of the most significant factors, such as the area of the compensation slot and the angular orientation of the compensation slot, which, in turn, allows visual analysis of this relationship.

The most significant effect on the tensile strength of the material of the circular saw has the area of the compensation slot (see Fig. 2).

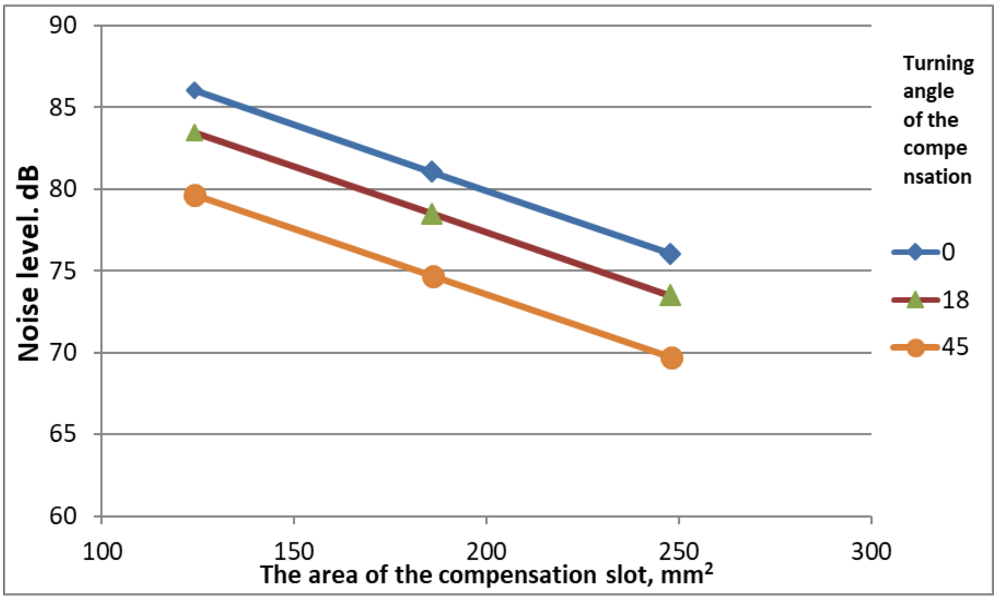

Fig. 2.
The relationship between the noise level, the area of the compensation slot and the angular orientation of the compensation slot.

The test results showed that the level of noise generated by the circular saw during rotation decreases with increasing the area of the compensation slot and its angular orientation.

The influence of the angular orientation of the compensation slot on the noise level at certain values of the compensation slots is shown in Fig. 3.

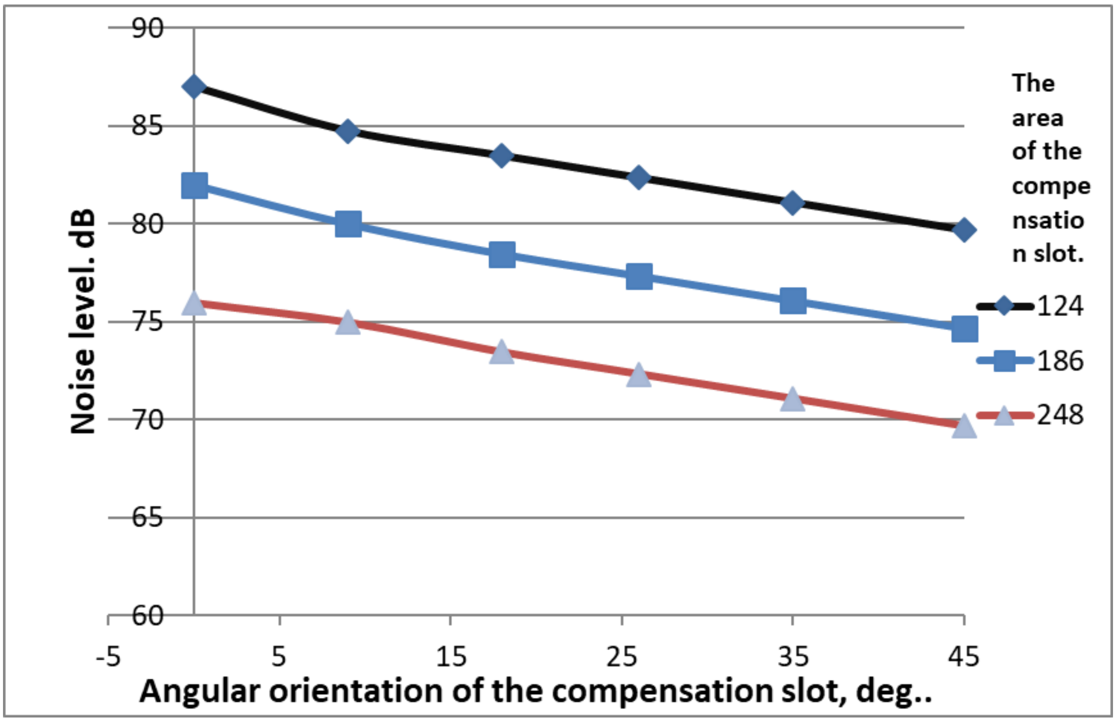

Fig. 3.
Influence of the angular orientation of the compensation slot on the noise level at certain values of the compensation slots.

According to the regression equation (1), a three-dimensional graph of the dependence of the noise level on the angular orientation of the compensation slot and its area is constructed (see Fig. 4).

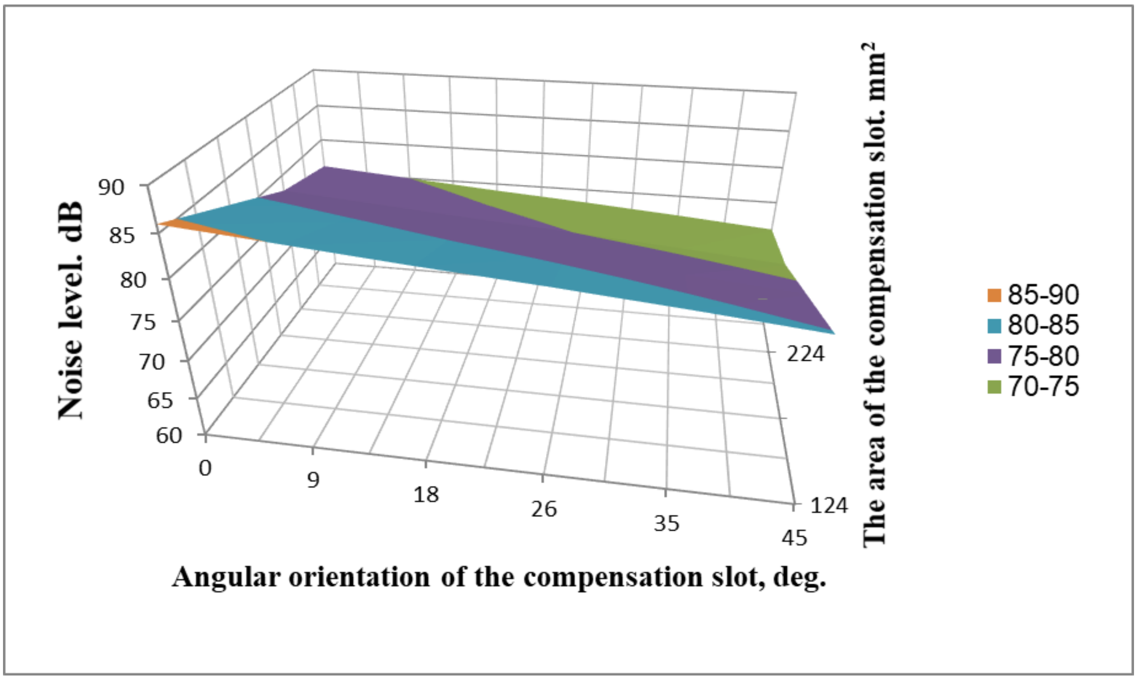

Fig. 4.
Graph of the dependence of the noise level on the** angular orientation **of the compensation slot and its area.

The graph in Fig. 4 shows that in order to reduce the noise level during the operation of circular saws, it is necessary to choose larger values of the angular orientation of the compensation slot and its area. The data obtained from the experiments can be used in production conditions when sawing with circular saws.

CONCLUSIONS

1. An analysis of literary sources has shown that one of the effective methods to reduce the impact of thermal stresses in circular saw blades and, accordingly, noise reduction during operation, is the method of creating slots in the blade, but there are no theoretical data for choosing their optimal shapes, sizes and location.
2. The experimental studies on the influence of the sizes, shapes, and location of the slots, patented by the authors, in the form of Archimedes' spirals have shown that their use reduces the noise pressure level from 87 dB to 70 dB.
3. The experimental studies have also shown that the minimum value of the noise level is obtained at the maximum values of the angle of orietation of the compensation slot, which is 45˚ and the area of the slot being 248mm^2.

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