EVALUATION OF IMPACT SYSTEMS NOISE LEVEL IN GRAIN PRODUCTION
/
ОЦЕНКА УРОВНЯ ШУМА УДАРНЫХ СИСТЕМ В ЗЕРНОПРОИЗВОДСТВЕ

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Keywords: *threshing and separating device, noise conditions, industrial disease, acoustic properties*

ABSTRACT

Threshing of grain mass in the threshing and separating devices is one of the most «noisy» operations. The main noise sources of a working thresher are the processes of impact interaction of grain with the threshing device cover. Based on the simulation of dynamic and acoustic processes, a formula for calculating the noise level generated by the dynamic contact of free grain with the details of the thresher design, which allows planning of the organizational and technical measures to reduce noise at workplaces, was obtained.

РЕЗЮМЕ

Обмолот хлебной массы в молотильно-сепарирующих устройствах является одной из наиболее «шумных» операций. Основными источниками шума работающей молотилки являются процессы ударного взаимодействия зерна с кожухом молотильного устройства. На основе моделирования динамико-акустических процессов получена формула для расчета уровня шума, создаваемого динамическим контактом свободного зерна с деталями конструкции молотилки, позволяющая спланировать организационно-технические мероприятия по снижению шума на рабочих местах.

INTRODUCTION

One of the most common harmful factors, the physiological effect of which causes damage to the acoustic apparatus and derangements in the central nervous system of a human being is noise. So, in the structure of industrial diseases, due to the impact of physical factors of the labour process, sensorineural hearing loss prevails and it represents about 55.9% of the number of all diseases. According to the same source, sensory neural hearing loss is at the level of 11.2% *(Pogonysheva I.A. et al, 2015; Zewdie Retta and Kic Pavel, 2017; Guida H.L. et al, 2010).* In the eyes of a number of researchers, this pathology in relation to various «noise» occupations can reach 70-77% *(Lie A. et al, 2016; Marlene E.B. et al, 2016)*. In *(Ilkaeva E.N. et al, 2008)* it is noted that working in an acoustic environment with a sound pressure level of 85.2 dB SPL, disorders of the nervous system and cardiovascular diseases are more common than of those who work at a sound pressure level of 42.5 dB SPL, on average, by 5% and 30% respectively.

Among the main occupational risks associated with industrial diseases, noise is ranked second after back pain *(Pogonysheva I.A. et al, 2015; Ilkaeva E.N. et al, 2008)*. In agricultural production, the share of noise, ultrasound air and infra sound, in the total amount of harmful and dangerous factors affecting workers, is more than 9.3% and is prevalent among the working environment factors *(Lie A. et al, 2016; Ilkaeva E.N. et al, 2008; Lashgari M. and Maleki A., 2015)*. Thus, industrial noise remains one of the main problems of work safety in agriculture.

The process of grain mass threshing in the threshing and separating devices (TSD) is one of the most «noisy» among the operations used in agriculture *(Li Y.M. and Sun P., 2014; Calvo A. et al, 2016; Rodimtsev S.A. et al, 2016)*. The equivalent sound level of an operating TSD of a combine harvester can reach 156 dB or more; stationary sheaf thresher used in the processes of selection and primary seed production is not less than 110 dB. At the same time, the maximum permissible sound level and the equivalent sound level for the workplaces of agricultural machines and equipment service personnel is 80 dB *(Li Y.M. and Sun P., 2014; Calvo A. et al, 2016; Jahanbakhshi A. et al, 2016; Rodimcev S.A. et al, 2014)*.

The analysis of the noise impact on the operator (fig. 1) *(Rodimtsev S.A. et al, 2016)*, using the example of the laboratory head thresher WINTERSTEIGER LD 180, showed that the main sources of noise with the maximum impact level are a working engine, moving structural elements (mainly mechanical energy transfer devices) and impact noise caused by the multiple interaction of grain with working bodies and the threshing device cover. The share of the latter in the overall structure of the acoustic impact is rather large and it even exceeds the noise of the electric motor, as well as the noise caused by dynamic processes in the kinematic pairs of the thresher drive.

It can be assumed that the main factors determining the noise level from the impact of free grain interaction with the details of the thresher construction are the impact speed, inertial parameters, state and properties of vegetable origin materials and construction details.

In this regard, the development of measures to reduce the level of noise at workplaces to acceptable values is relevant. The theoretical underpinning of interaction of the grain material with the structural elements of the process equipment is of particular interest.

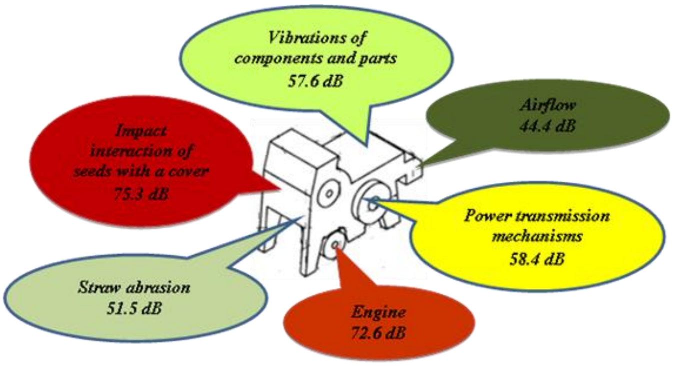


Fig. 1 - Sources of noise of the laboratory thresher «WINTERSTEIGER LD 180»

MATERIALS AND METHODS

The study of noise level influence on workers was carried out using the example of head thresher MK-1M (Russia). This thresher is used in the seed-breeding process for threshing individual heads and bunches of grain, leguminous plants and other crops with the release of light impurities. The main technical features of the thresher are given in table 1.

Table 1

Technical features of the thresher MK-1M

Features	Value
Productivity, ears per hour/h	320
Installed engine capacity, kW	0.25
Rotation frequency, min^{-1}: - **Drum** - **Ventilator**	 1000;1300;1600 3400
Drum diameter, mm	194
Quantity of renewal concaves, pcs.	3
Size of the concaves units, mm	6×32; 4×25; 3×20
Dimensional specifications, mm	570×330×485
Mass, kg	21.3

To study the dependence of the noise level on the distance outdoors an individual technique was developed.

The research on the noise impact of the head thrasher was carried out applying the orientative method for open platforms absolutely excluding any kind of barriers and reflection of sound waves. Regarding the noise source, eight axes were identified (fig. 2), in the direction of which measurements were made. Each axis was divided into ten points, in step size of one meter. The height from the floor level at each point was chosen to be 1560 mm, which roughly corresponds to the ordinate of the position of the adult's auditory analyzer, according to anthropometric indicators used in ergonomics.

The measurements were carried out at steady working state of the thresher. For threshing, prepared bunches of winter wheat «Moskovskaya 39» (Russia) were used. The drum rotation frequency was 1300 min^{-1}.

To compile a noise map and organize the empirical data into homogeneous groups, the cluster analysis method was used.

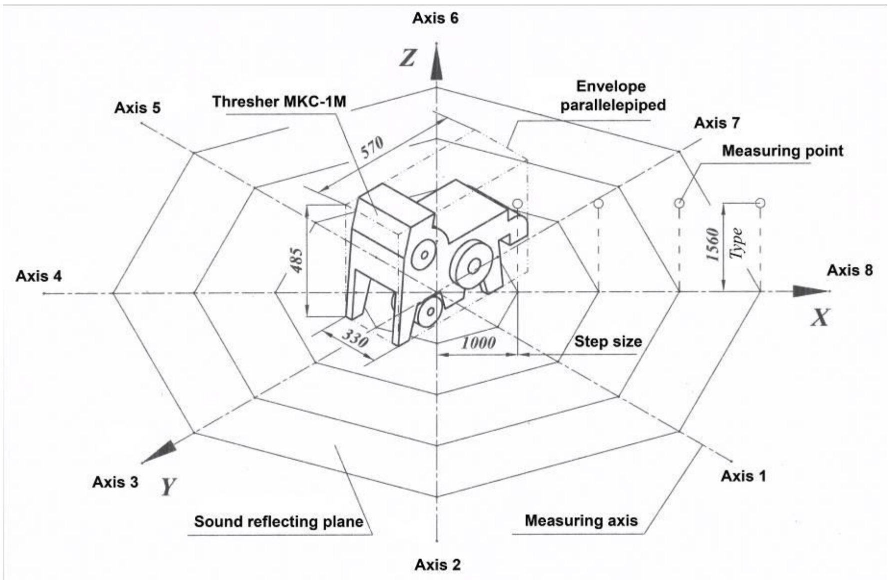


Fig. 2 - Measurement scheme

To convert natural values into coded units, a linear scaling index formula was used:

$$Index = \frac{x - x_{\min}}{x_{\max} - x_{\min}}, \tag{1}$$

where: x – the first value in the row;

x_{max}, x_{min} – the maximum and minimum values of the indicators.

To distribute the obtained values over the intervals of the numerical series, the number of groups was determined using the Sturges formula *(Boldin A.P. and Maksimov V.A., 2012)*:

$$n = 1 + 3.32 \lg N \tag{2}$$

where: N - the number of measurements.

The interval step size was determined by the formula:

$$h = \frac{x_{\max} - x_{\min}}{n} \tag{3}$$

where: x_{max}, x_{min} - the maximum and minimum values of the indicators;

n - the number of groups.

A special windproof device was developed to reduce the impact of wind gusts on the measurement accuracy as well as to capture sound waves in the direction of the measurement axis (fig. 3). It allows getting a sharply directional microphone sound level meter when assessing the noise level in extreme situations, under the conditions of ambient noise and to remote sound sources. The use of a windproof device reduces the influence of external noise by 75-80%.

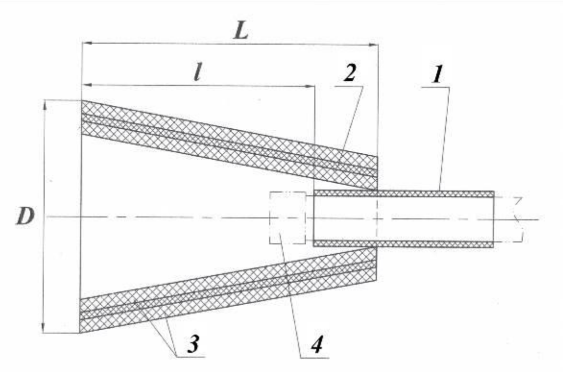


Fig. 3 - Windproof device

1 - carrier sleeve; 2 - protective housing; 3 – sound insulator (felt); 4 - sensor (microphone)

The simulation of the shock processes in the threshing chamber was carried out by dropping the same number of grains from a certain height onto the cantilever plate. The number of discarded grains in each portion was 10 pieces for each of the crops. The time interval between dropping grains was 1 sec. This was enough to fix the level of sound impact from each grain in one portion and calculate the arithmetic average value. For the experiment, a special device was used, allowing fixing height of dropping grains relative to the cantilever plate (Fig. 4). The studies were conducted with a technical method in the laboratory, with a free sound field above the sound reflecting plane.

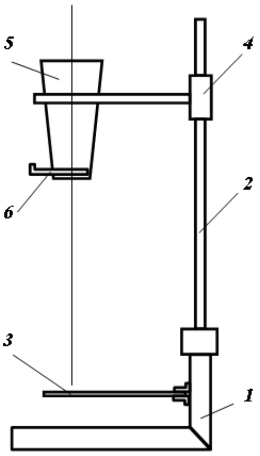


Fig. 4 - Scheme of the device for the study of shock-acoustic effect

1 - base; 2 - stand; 3 - replaceable cantilever plate; 4 - bracket; 5 – entry guide; 6 - valve

The following grain crops were used for the research: beans, peas, wheat, different in weight, shape and geometric dimensions. The mass of grains varied from 1.7 to 3.3%, relative to the arithmetic mean value (table 2).

Table 2

Grain weight of crops used in the research

Crop	Average weight of grain, g	Mean square deviation, σ, g	Coefficient of variation, K_v, %
Peas	0.12	0.002	1.7
Wheat	0.03	0.01	3.3
Beans	0.41	0.01	2.4

To assess the dependence of the noise level by the interaction of grains with the surfaces of various materials rubber, metal and wooden plates were used (table 3). The height of grain dropping was taken to be equal to 10, 310, 610, 910 and 1210 mm.

Table 3

Characteristics of the impact surfaces

Plate material	Dimensional specifications, mm: length width height	Modulus of elasticity Young, $E\times10^{-5}$, MPa*
Tree (pine tree)	200×70×10	10000
Rubber (heat-and-acid-alkali resistant)	200×70×10	5
Steel (St.3)	200×70×10	200000

* Reference data *(Doronin F.A., 2018)*

The noise level was measured with a noise-level meter Octave-101 AM (Russia) *(Ivanov N.I., 2008)*. A microphone preamplifier «KMM 400» with a microphone capsule «VMK-205» was used. The microphone was mounted at the distance of 1.2 m from the noise source and at the height of 1 m.

RESULTS

During thresher operation, it was found that the greatest sound pressure of the equivalent noise level reaches 81.2 dBA, while the acceptable value of the equivalent sound levels for workplaces in laboratories with noisy equipment, according to *(GOST 12.1.003-2014)*, is not more than 75 dBA.

With increasing distance from the noise source, the sound pressure level decreases. As it can be seen from table 4, the maximum values of the noise level can correspond to both the measurement points closest to the noise source and immediately following them. This is explained both by the location in relation to the measuring point of the main sources of sound vibrations (motor, drive, fan) and the vibrating parts of the thresher that create additional noise. In addition, a slight decrease in the sound pressure level near the thresher may be caused by the shielding effect of the construction protruding elements.

Table 4

Values of the equivalent sound levels in control points during work of the threshing machine MKS-1M, dBA

Distance from the noise source	Measurement axis number							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	81.2	75.9	76.2	76.8	76.8	75.5	76.5	76.2
2	77.5	75.7	75.4	74.6	75.4	76	77.1	77.1
3	75.7	75.8	74.6	73.4	74.3	75.5	74.7	75.3
4	75.7	74.3	71.7	73.2	72.8	75.1	73.8	73
5	76.3	76.1	74	74.8	74.4	74.2	75.8	75.7
6	76	74.5	73.5	73.7	73.8	74.4	74.7	74.6
7	77.1	75.8	74.8	75	75.1	75.7	76	75.9
8	76	73.7	72.7	72.9	73	73.6	73.9	73.8
9	74	71.4	70.4	70.6	70.7	71.3	71.6	71.5
10	73	71	70	70.2	70.3	70.9	71.2	71.1

Experimental studies conducted under laboratory conditions concerned a comparative assessment of the equivalent sound level caused by the impact interaction of agricultural crop grains with a fixed surface.

It was established that regardless of the impact surface material, the level of the impact sound increased with increasing height of grain dropping (fig. 5). In general, for all the crops with an increase in the height of grain dropping from 10 to 1210 mm, the sound level rose 1.3 times.

We'll denote the dependence of the sound level on the height of grain dropping, as:

$$y = f(x) \tag{4}$$

where: *y* - the sound level, [dB];
x - height of grain dropping, [m].

Then, the nature of the change of dependence (4) obeys the law

$$y = a \cdot \ln(x) + b \tag{5}$$

where: *a, b* - free coefficients depending on the conditions of the experiment.

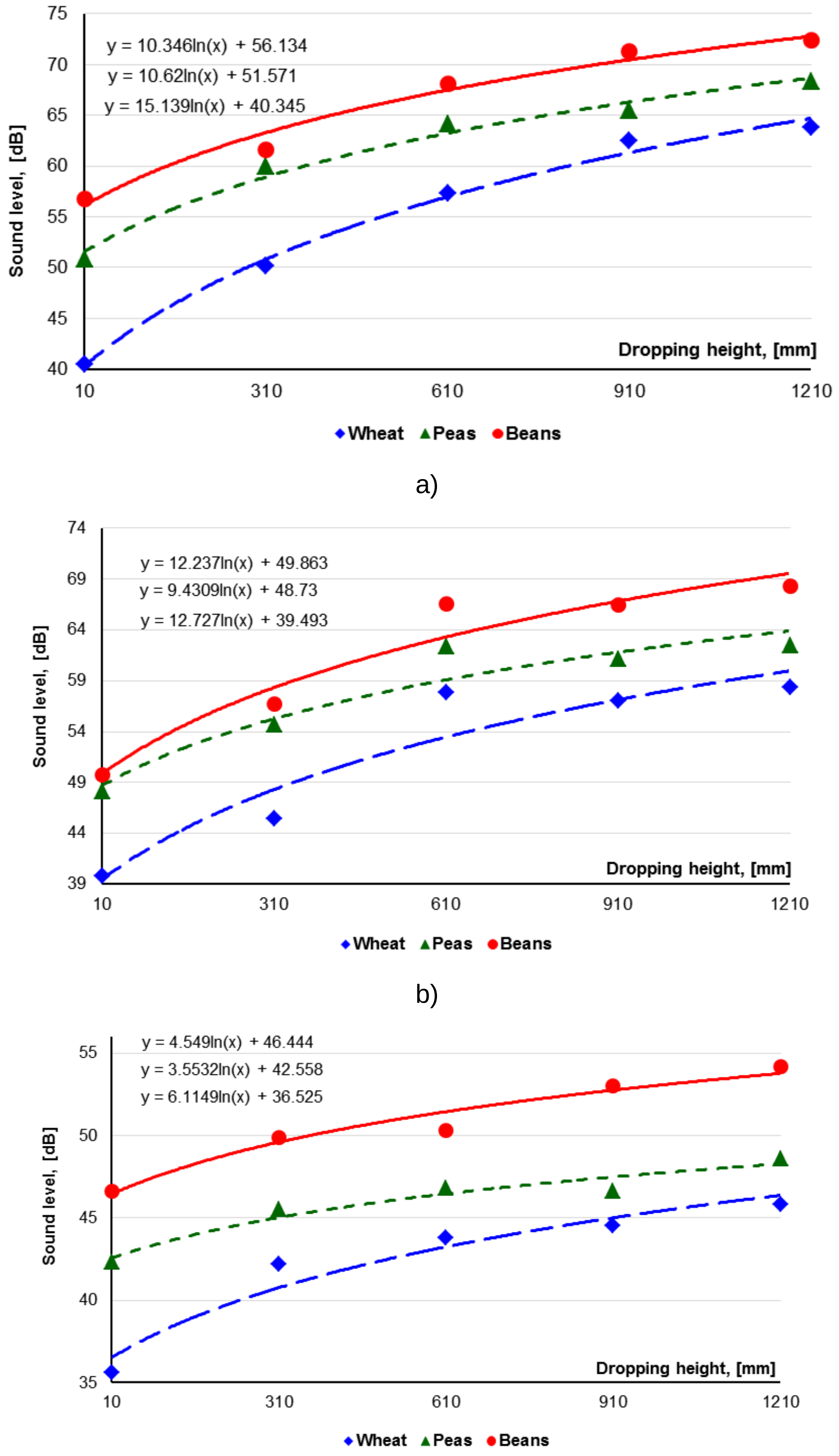
The mass of grains also influences significantly the sound level. It was established that the sound level when striking a metal surface of wheat grains, with an average weight of 0.03 g was 40.5; 57.3 and 63.8 dB, with a drop height of 10, 610 and 1210 mm, respectively. Beans, having an average mass of 0.41 g, when dropped from a similar height, generated a sound of 56.8; 68.1 and 72.4 dB, which, in general, was 1.2 times higher than the sound level from the impact interaction with the metal console of wheat grains.

The sound level when dropping peas onto a metal surface was 50.8; 64.1 and 68.3 dB with an average grain mass of 0.12 g and dropping height of 10; 610 and 1210 mm.

The sound level from the impact interaction of grains with the contact surface depends significantly on the material properties of this surface, which is confirmed by a number of studies *(Li Y.M. and Sun P., 2014; Jahanbakhshi A. et al, 2016; Krolczyk J.B. et al, 2014)*. From the graphs shown in figure 6 it can be seen that the most «noisy» is the process of contacting grains with a metal surface.

Thus, the sound level when dropping grains from the height 1210 mm was 63.8; 68.3 and 72.4 dB - for wheat, peas and beans, respectively. When dropping the grains of these crops on a wooden surface, the sound level was 58.4; 62.5 and 68.3 dB. The sound level at the contact of the grains with the surface of the rubber was minimal. So, for grains of wheat, peas and beans, when dropped from a height of 1210 mm, the sound level values were 45.8; 48.6 and 54.2 dB. These values are 1.31 times lower than the corresponding sound level indicators for the same crops when dropped on a metal surface.

As it can be seen, the acoustic parameters of the process of grain interaction with an impact surface are determined by the dynamic characteristics of this process.



a)

b)

c)

Fig. 5 - Dependence of the sound level by the impact on the height of the grain dropping on the steel (a), wooden (b) and rubber (c) cantilever surfaces

For the mathematical description of the relation of acoustic and dynamic parameters of grain collision process with a fixed surface, a decimal logarithm of the ratio of two values of the force value, expressed in decibels, was used *(Ivanov N.I., 2008)*:

$$D = 20 \cdot \lg \frac{F_1}{F_0}\text{, [dB]} \tag{6}$$

where: F_0; F_1 - the threshold (fiducial) and current values of the force value, respectively, [N].

Based on the law of similarity used in calculating the acoustic characteristics of sources *(GOST 12.2.028*), we proposed an expression for the analytical description of the dependence of the sound level LH created in the full-scale process of the “seed-casing system” impact interaction on the impact interaction force *(Rodimtsev S.A. et al, 2014)*:

$$L_H = L_M + (\psi \cdot \log \frac{F_H}{F_M}) \tag{7}$$

where: L_M - the sound level during impact interaction in the model process, [dB];

ψ - coefficient taking into account the conditions of natural dynamic process;

F_H, F_M - the force of the grain impact interaction with the contact surface, with the full-scale and model processes, [N].

In the formula (7), the numerical values of the force F_M and the corresponding sound level value L_M are determined in a specially conducted model experiment. The coefficient ψ depends on the similarity level of the natural process to the model process and can take numerical values from 0 to 1. In the research carried out by the authors, ψ, as a rule, took a value from 0.8 to 1.0.

Assuming that the undeformed state of the impacted bodies is not fully restored and the grain gravity centre after impact and before the impact moves at different speeds, we have the classic case of a central, not quite elastic impact. For a theoretical description of the quantity F_H entering the formula (7), we use the principle on the change of the momentum of a material point in the integral form, applied to instantaneous forces *(Doronin F.A., 2018)*:

$$mV_2 - mV_1 = \sum_{k=1}^{n} S(F_k) \tag{8}$$

or, in projection on the axis *n*:

$$mV_{2n} - mV_{1n} = \sum_{k=1}^{n} S_n(F_k) \tag{9}$$

where: *m* - body mass;

V - body speed;

S - body impulse;

F - force.

The right side of the equation (9) is the vector sum of impulses of instantaneous forces. In application to the problem in question, the only instantaneous force is the reaction of the plate F_n. Therefore, we can write:

$$\sum_{k=1}^{n} S_n(F_k) = \int_t^{t+\tau} F_n dt \tag{10}$$

where: *t* - the beginning of the impact;

τ - duration of the impact.

Based on the generalized mean-value theorem *(Yakovlev G.N. et al, 2009)*, if the functions *f(x)* and *g(x)* are integrable on the interval [a, b], and the function f(x) is continuous, then on this interval there will be such an «average» point $\bar{x}$, that

$$\int_a^b f(x)g(x)dx = f(\bar{x})\int_a^b g(x)dx \tag{11}$$

Using the property (11) to the right side of the equation (10), we write:

$$\int_t^{t+\tau} F_n dt = F_{ncp} \int_t^{t+\tau} dt \tag{12}$$

Here, F_{ncp} - average value of the plate reaction.

As

$$F_{ncp}\int_{t}^{t+\tau} dt = F_{ncp}\cdot t + F_{ncp}\cdot \tau - F_{ncp}\cdot t \tag{13}$$

then, the expression (12) will have the following form:

$$\int_{t}^{t+\tau} F_n dt = F_{ncp}\cdot \tau \tag{14}$$

Using (9) and taking into account the found equalities (10) and (14), after simple transformations, we obtain the initial dependence for determining the impact reaction of the plate.

$$F_{ncp} = \frac{m(V_{2n} - V_{1n})}{\tau} \tag{15}$$

The free movement of a body without an initial velocity (V_0 = 0) will be described by the following equations:

$$V_n = gt\text{ , [m s}^{-1}\text{]} \tag{16}$$

$$h = \frac{gt^2}{2}\text{ , [m]} \tag{17}$$

where: g - the gravitational acceleration, [m/s^2];
h - drop height, [m].

It follows from the formula (17):

$$t = \sqrt{\frac{2h}{g}}\text{ , [s]} \tag{18}$$

Therefore, the speed of the body V_1, at the beginning of the impact will be:

$$V_1 = \sqrt{2gh_1}\text{ , [m/s]} \tag{19}$$

After not a quite elastic impact on the plate, the grain begins to rise upward at a speed of V_2. At the highest lifting point h_2, the grain speed is zero. Consequently:

$$V_2 = \sqrt{2gh_2}\text{ , [m/s]} \tag{20}$$

To find the unknown value h_2, we use coefficient of restitution k.

The relation between the velocity modules of a grain gravity center at the beginning and at the end of the impact is the following:

$$V_1 = k\cdot V_2\text{ , [m/s]} \tag{21}$$

where: k - coefficient of restitution of the body by the impact.

Substituting the values of V_1 and V_2 from (19) and (20) into the formula (21), we obtain:

$$k = \sqrt{\frac{h_2}{h_1}} \tag{22}$$

Then the unknown value of h_2 will be:

$$h_2 = k^2 h_1\text{, [m]} \tag{23}$$

Using the found speeds of the body before and after the impact onto the surface of the plate, the formula (15) will be finally the following:

$$F_{пср} = \frac{m \cdot \sqrt{2gh_1} \cdot (k-1)}{\tau}, \text{ [N]} \tag{24}$$

where: m - weight of one grain of an agricultural crop, [kg];
g - gravitational acceleration, [m/s^2];
h_1 - height of grain dropping, [m];
k - coefficient of restitution of grains by the impact;
τ - duration of impact, [s].

Based on the research data of a number of authors *(Shkodkin VN et al, 2017; Glebov LA, 1979)* the duration τ of the active interaction of a single grain with a steel working surface can be from (1.2-2.5)×10^{-5} to (4-5)×10^{-5} s.

Using (24) and taking $F_н$=$F_{пср}$, the formula (7) will be finally written in the form:

$$L_H = L_M + \left(\psi \cdot \log \frac{m \cdot \sqrt{2gh_1}(k-1)}{F_M \cdot \tau} \right), \text{ [dB]} \tag{25}$$

CONCLUSIONS

When the parameters of the impact force of the grains with the contact surface F_M and sound level L_M, were found in the model experiment, as well as the corresponding reference values, the obtained analytical dependence (25) allows us to calculate the expected sound level L_H when the grains interact with structural elements of various process equipment in the field.

The obtained results will allow planning organizational and technical measures to reduce the sound impact on a person at workplaces, in areas of processing crop products, depending on the conditions of the technological operations, as well as physical and mechanical properties and state of the processing object.

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