

Research of Acoustic Properties of Materials with the Purpose of Their Use at Design of Special Noise Protective Clothes for Oil and Gas Industry

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Abstract. The article is devoted to the substantiation of the choice of a rational package of materials, which has the greatest noise-protective properties when designing special clothes with reference to the oil and gas industry. Studies were conducted to assess the factors that have the most significant effect on the noise-protective properties of clothing. Conclusions are made about the possibility of using the developed technique for studying the noise-protective properties of materials in selecting rational packages of materials for the production of special clothes with high noise-protective properties.

1. Introduction

Modern technology develops in the direction of increasing power, increasing the speed regime and, naturally, this leads to the appearance of large dynamic loads, which, in turn, determines the noise intensity. In the fight against such negative phenomena, special attention is required, since the weakening of industrial noise greatly improves working conditions, increases efficiency, and positively affects people's health. That is why scientific research in this field has become very active lately.

The tick of the basic directions of the solution of this problem concerns not only the creation of techniques that work with less noise; isolation of equipment creating increased noise, but also the development of tools that protect people from noise [1,2]. For each of the above tasks, in large volumes and more actively. We will focus on the third direction. At the same time, as an example, the research will be carried out with reference to the oil and gas industry, where the noise factor, as unfavorable, is very weighty. The working technological equipment (pumps, compressors, electric motors) is a source of increased noise and vibration, which adversely affects the person. To combat dangerous and harmful production factors special clothing is called for.

2. Results and Discussion

The choice of material is one of the important parameters of the process of designing special clothes. When studying and analyzing the quality of tissues, the evaluated properties are grouped according to certain characteristics, depending on the goals and tasks set [3,4].

Research in the field of noise protection is based on the definition of the most rational package of materials, which has the greatest noise-protective properties [5,6,7,8].

As an optimization criterion, the final sound power in *dB* was chosen for the materials that make up the package, face up – *Y*.

The factors that have the most significant effect on the noise-protective properties of clothing:

- X_1 – Surface density;
- X_2 – Thickness of the material package;
- X_3 – Frequency of sound [9,10].

These factors are compatible and independent, which makes it possible to use them for setting up a full-factor experiment.



Based on the technological possibilities of the experiment, we varied the factors at two levels: upper and lower. The number of experiments for setting up such a full-factor experiment is determined from the expression:

$$N = 2^k, \quad (1)$$

where N is the number of experiments in the plan, k is the number of factors.

In a particular case, $N = 23$ experiments should be performed for one package of materials. In each of the experiments the measurements were carried out repeatedly, which makes it possible to increase the accuracy of the study. The determination of the necessary number of repetitions of each experiment was found on the basis of the results of a preliminary series of experiments (Table 1). In this case, the values of the confidence probability (0.95) and the required deviation of the average measurement result from the true value of the measured quantity $\varepsilon(\bar{y}) = 0.1 \bar{y}$.

Table 1- Results of a preliminary series of experiments.

№ experience	The measured value Y, dB
1	75.3
2	76.5
3	76.5
4	77.2

After mathematical processing of the results of the preliminary series of experiments. All the results of the experiments were statistically processed.

The calculated required number of repetitions of each experiment to obtain a reliable result of the experiment with a significance level of 0.95 is equal to 7. Thus, a minimum of 7 packets of materials should be investigated.

Based on the analysis of the study of the acoustic properties of tissues [9,10,11,12,13] and materials, the following packages were identified:

- 1 package: Greta + batting + flannel
- 2 package: Greta + cotton wool clothing + artificial lining
- 3 package: Leader comfort 250 + woolstone + flannel
- 4 package: "Coverstat-RW" + woolstone + flannel
- 5 package: Titanregular 190 + woolstone + flannel
- 6 package: "Coverstat-RW" 253 + antistatic impregnation + woolstone + flannel
- 7 package: "Coverstat-RW" 190 + woolstone + flannel

For each of these packets, a full factorial experiment was carried out, including 7 experiments on 7 measurements in each.

Levels of factor variation in the implementation of a full-factor experiment for all packets of tissues and materials are presented in Table 2.

Table 2 - Factors and levels of variation.

Name factor	Unit measurements	Variation levels			Variation intervals
		lower	null	upper	
1 package:Greta + batting + flannel					
Surface density X ₁	g /m ²	214.0	232.0	250.0	18.0
Packing thickness X ₂ of materials	m	0.00747	0.007845	0.00822	0.000375
Frequency of sound X ₃	Hc	500.0	1750.0	3000.0	1250.0

2 package: Greta + cotton wool clothing + artificial lining					
Surface density X_1	g/m^2	214.0	232.0	250.0	18.0
Packing thickness X_2 of materials	m	0.00827	0.008575	0.00888	0.000305
Frequency of sound X_3	Hc	500.0	1750.0	3000.0	1250.0
3 package: Leader comfort 250 + woolstone + flannel					
Surface density X_1	g/m^2	214.0	232.0	250.0	18.0
Packing thickness X_2 of materials	m	0.00876	0.008785	0.00881	0.000025
Frequency of sound X_3	Hc	500.0	1750.0	3000.0	1250.0
4 package: "Coverstat-RW" + woolstone + flannel					
Surface density X_1	g/m^2	190.0	221.5	253.0	31.5
Packing thickness X_2 of materials	m	0.00869	0.00874	0.00879	0.00005
Frequency of sound X_3	Hc	500.0	1750.0	3000.0	1250.0
5 package: Titanregular 190+ woolstone + flannel					
Surface density X_1	g/m^2	190.0	200.0	210.0	10.0
Packing thickness X_2 of materials	m	0.00867	0.00871	0.00874	0.00003
Frequency of sound X_3	Hc	500.0	1750.0	3000.0	1250.0
6 package: "Coverstat-RW"253+ antistatic impregnation + woolstone + flannel					
Surface density X_1	g/m^2	253.0	256.5	260.0	3.5
Packing thickness X_2 of materials	m	0.0087	0.00883	0.00895	0.00013
Frequency of sound X_3	Hc	500.0	1750.0	3000.0	1250.0
7package: "Coverstat-RW"190 + woolstone + flannel					
Surface density X_1	g/m^2	190.0	200.0	210.0	10.0
Packing thickness X_2 of materials	m	0.000869	0.00479	0.00871	0.00392
Frequency of sound X_3	Hc	500.0	1750.0	3000.0	1250.0

The possibility of applying a linear regression equation for the processing of experiments is confirmed by the fact that for the range of amplitudes of sound waves that do not lead to the destruction of the protective device, its characteristics (density, thickness, etc.) can be considered independent of the sound level. Thus, the noise transmittance of the protective device will not depend on the amplitude of the sound wave. Mathematical models of the investigated packages of fabrics and materials, obtained on the basis of formulas for calculating the coefficients of the regression equation, are presented in Table 3.

Table 3 - Regression equations that characterize the influence of the factors studied on the noise-protective properties of clothing.

Package number	The equation
1	$\tilde{Y} = 67.25 - 0.675X_1 - 0.1X_2 - 7.966X_3 + 0.475X_1X_2 - 0.025X_1X_3 - 0.05X_2X_3 + 0.125X_1X_2X_3$
2	$\tilde{Y} = 70.0375 + 0.7375X_1 - 0.1285X_2 - 7.3125X_3 - 0.3125X_1X_2 + 0.9375X_1X_3 - 0.1625X_2X_3 - 0.0125X_1X_2X_3$
3	$\tilde{Y} = 67.75 + 0.05X_2 - 9.49X_3 - 0.05X_2X_3$
4	$\tilde{Y} = 66.9625 - 0.7625X_1 - 0.0285X_2 - 9.7125X_3 - 0.1375X_1X_2 - 0.4875X_1X_3 + 0.0125X_2X_3 - 0.0625X_1X_2X_3$
5	$\tilde{Y} = 65.9875 - 0.0125X_1 + 0.0215X_2 - 10.0875X_3 + 0.0875X_1X_2 - 0.0375X_1X_3 + 0.0625X_2X_3 - 0.0375X_1X_2X_3$
6	$\tilde{Y} = 59.45 - 0.35X_1 - 0.1X_2 - 3.45X_3 + 0.25X_1X_3 - 0.25X_2X_3 + 0.25X_1X_2X_3$
7	$\tilde{Y} = 66.9125 - 0.7625X_1 - 0.0125X_2 - 9.7625X_3 - 0.0875X_1X_2 - 0.4875X_1X_3 + 0.0125X_2X_3 - 0.0125X_1X_2X_3$

To assess the significance of the coefficients of the regression equations, a confidence interval was calculated, which made it possible to exclude from the model non-significant coefficients. Coefficients are significant if their absolute values correspond to and satisfy inequality

$$|b_i| > t \sqrt{S_{(\beta)}^2}, \quad (2)$$

where t - is the Student's test; $S_{(\beta)}^2$ - variance associated with errors in the determination of regression coefficients, the value of which is determined by the formula:

$$S_{(\beta)}^2 = \frac{S_u^2}{Nm}, \quad (3)$$

where S_u^2 - the experimentally average variance of reproducibility.

Dispersion of reproducibility S_u^2 is calculated as:

$$S_u^2 = \frac{\sum_{i=1}^n \sum_{j=1}^m (Z_{ij} - Y_i)^2}{N(m-1)}, \quad (4)$$

where N is the total number of experiments, m is the number of observations in one experiment, Y_i - arithmetic mean of m observations at one point, Z_{ij} - result of a separate j observations in i experience.

Criterion Student t is determined from the degree of freedom of distribution $n = N(m-1) = 48$ and the level of significance with confidence 0.95: $t = 2.021$.

Taking into account the number of repetitions of the experiment in each experiment, $m = 7$ and the results of the study, the significance of each individual coefficient is determined. Table 4 shows the inequalities, the fulfillment of which guarantees the significance of the coefficients being checked.

Table 4 - Results of the study of the significance of the coefficients of the regression equation.

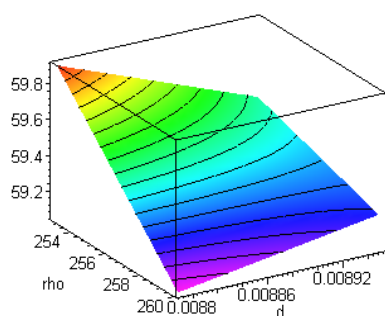
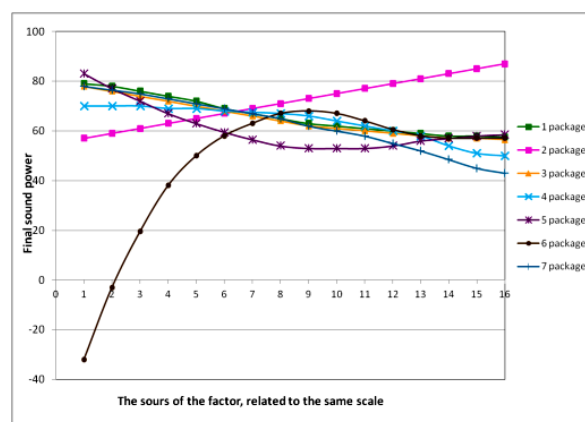
Package number	Condition
1	$ b_i > 0.4892$
2	$ b_i > 0.2669$
3	$ b_i > 0.0929$
4	$ b_i > 0.0748$
5	$ b_i > 0.0793$
6	$ b_i > 0.0705$
7	$ b_i > 0.0699$

Thus, the regression equations acquire the form presented in Table 5.

Table 5 - Mathematical models of influence of investigated factors on the noise-protective properties of clothing without taking into account insignificant coefficients.

Package number	The equation
1	$\tilde{Y} = 67.25 - 0.675X_1 - 7.966X_3$
2	$\tilde{Y} = 70.0375 + 0.7375X_1 - 7.3125X_3 - 0.3125X_1X_2 + 0.9375X_1X_3$
3	$\tilde{Y} = 67.75 - 9.49X_3$
4	$\tilde{Y} = 66.9625 - 0.7625X_1 - 9.7125X_3 - 0.1375X_1X_2 - 0.4875X_1X_3$
5	$\tilde{Y} = 65.9875 - 10.0875X_3 + 0.0875X_1X_2$
6	$\tilde{Y} = 59.45 - 0.35X_1 - 0.1X_2 - 3.45X_3 + 0.25X_1X_3 - 0.25X_2X_3 + 0.25X_1X_2X_3$
7	$\tilde{Y} = 66.9125 - 0.7625X_1 - 9.7625X_3 - 0.0875X_1X_2 - 0.4875X_1X_3$

The adequacy of the obtained models was checked using the F-test of Fisher. The results allow us to conclude that the models obtained are adequate. Consequently, the regression equations from Table 5 correspond to real processes. Graphical interpretation of the dependence on the regression equation for the three variables of the recommended package of materials No. 6 is shown in Figure 1.

**Figure 1.** Graph of the dependence on the regression equation for a package of materials № 6.**Figure 2.** Graphs of regression equations related on a single scale.

Analysis of regression equations shows that the X_2 фактор frequency of sound has the greatest influence on the noise-protective properties of clothing, with the increase in which the optimization criterion Y decreases. A slightly smaller influence on the criterion of optimization is due to the factor X_1 , the surface density of the tissue.

The factor X_2 is the thickness of the packet, to a lesser extent affects the noise-protective properties of clothing. However, the joint contribution of factors X_1 , X_2 and X_3 to the investigated process significantly decreases the optimization criterion Y .

The received mathematical models can be used for selection of materials in a package possessing the greatest noise-protective properties. To do this, graphically, the values taken by the functions obtained in one interval, where factor X_1 varies from 190 to 260 with a step of variation of 5, factor X_2 from 0.006 to 0.009 in increments of 0.0002, and factor X_3 from 500 to 3500 in increments of 200.

3. Conclusions

As follows from the graph in Figure 2, the smallest final sound power transmitted through a packet of materials is observed in experiments with package No.6: "Coverstat-RW" 253 + antistatic impregnation + woolstone + flannel, and therefore it can be recommended as the main one Manufacture of noise-protective special clothes for operation in enterprises with increased noise load. The developed technique for studying the noise-protective properties of materials makes it possible to develop rational packages for the manufacture of special clothes with high noise-protective properties.

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