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The influence of head strap elasticity on the protective properties of filtering facepiece respirators

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Abstract

The level of occupational respiratory diseases among workers in the mining, machine-building and metallurgical industries remains high. The most common occupational respiratory disease is pneumoconiosis, which is the result of the long-term inhalation of dust. It is possible to minimize the impact of dust on the workers and eliminate such diseases in the future due to the use of filtering mask respirators designed to reduce dust infiltration into the space under the mask. For this purpose, the choice of the type of elastic bands of filtering mask respirators has been substantiated by the geometric shape and tension forces that can ensure a permissible level of leakage of contaminated air into the breathing zone of the respirator during its use. A mathematical model has been developed to describe the influence of parameters of elastomeric headgear on the protective properties of the respirator. The dependence of the change in the residual tensile strength of the elastic bands of the headband has been established, and the dependence of the volume of air suction on the area of the elastic straps at the corresponding tension force has been determined. Using the model, the dependence of the volume of polluted air inflow on the area of the elastic straps at the corresponding tension force has been estimated. The design of the innovative inserts has been offered, which makes it possible to control the tension of the elastomeric head straps of the respirator to visualize the weakening of the pressure forces responsible for maintaining a tight fit.

Keywords:
occupational disease; respiratory protection of workers; filtering mask respirator; elastic strap; improved design

1. Introduction

Occupational respiratory diseases are one of the important problems of workers' health (**Feary et al., 2023; 79 FR 24813**). In recent decades, there have been changes in the industrial structure of many countries of the world. This influenced a change in the profile of occupational exposure to hazards and a decrease in the level of occupational morbidity of respiratory organs, including among workers of mining and metallurgical enterprises (**De Matteis et al., 2017**). The most common occupational respiratory disease among workers in the mining, metallurgical, and machine-building industries is pneumoconiosis. This is a lung disease that appears with the long-term inhalation of industrial dust. Currently, the level of occupational diseases of the respiratory organs at enterprises in the mining industry remains at a high level and takes a leading position among other occupational diseases in the USA (**Laney, Petsonk et al., 2010; Laney, Weissman, 2014; Blackley et al., 2014; Blackley et al., 2016**), China (**Jin et al., 2018**), Poland (**Strzemecka et al., 2019**), Czech Republic (**Tomášková et al., 2017**), Ukraine (**Cheberiachko et al., 2018**).

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Dust in the mine atmosphere is one of the factors that is harmful and dangerous for the health and life of miners (**Nehrii, Volkov et al., 2022; Nehrii, Glyva et al., 2022**). The main way to reduce the level of occupational diseases of the respiratory organs of miners and to reduce the level of injuries is the implementation of preventive measures at workplaces for the effective control of dust. These measures include preliminary moistening of the coal massif, dust removal from the outgoing air streams, use of personal protective equipment for miners' respiratory organs, etc. But even with the comprehensive application of these measures, in mine conditions it is impossible to completely prevent the release of dust into the mine atmosphere and reduce the dust load on the miners' respiratory systems. It is possible to minimize the impact of dust on miners' bodies and eliminate their diseases in the future by using effective means of individual respiratory protection.

Individual respiratory protective equipment plays an important role in ensuring the effective protection of workers, since protecting workers from the development of potential occupational diseases is one of the priority tasks of the management of any enterprise. The problem is exacerbated by the fact that, in most cases, the workplace cannot be fully secured by means of collective protection. That is why there is a need to use filtering means of personal protection, which are characterized by rather low efficiency, despite the claims of their manufacturers, and therefore to look for alternative ways to solve this issue (**Leigh et al., 1999**). This is due to a number of subjective reasons. The main one is untimely and non-constant use of respirators due to discomfort, underestimation of the seriousness of the possible occurrence of an occupational disease. There are also objective reasons for the deterioration of the protective properties of filtering respirators, which arise due to design flaws associated with the lack of a sufficient level of understanding of all physical processes of air flow distribution, the deposition of aerosol particles on the filters, the accumulation of dust sediment, the influence of structural elements on protective properties, and others. This leads to the actualization of any research that may allow a better understanding of the process of protecting workers with filter mask respirators (FFRs) in order to improve their design.

Many scientific studies have been devoted to the improvement of filtering respirators. In particular, there have been proposed: a rational design of the perforated obturator (**Cheberiachko et al., 2023**), a production of filter respirator half-masks with a special frame (**Cai et al., 2018**), reinforcement of the obturator of the filtering respirator in the area of the nose with an additional seal (**Kwon et al., 2022)**, application of sealants between a half mask and a face (**Chopra et al., 2021; O'Kelly et al., 2022; Caggiari et al., 2022**). Multiple use of respirators has been investigated (**Małgorzata et al., 2023**). Therefore, it is urgent to develop measures to reduce the infiltration of harmful substances, including dust, into the space under the mask.

The loose fit of the FFRs' facepiece to the surface of the user's face leads to the excessive suction of polluted air into the breathing zone and, as a result, a decrease in its protective efficiency (**Cheberiachko et al., 2020; Bazaluk et al., 2021; Cheberiachko et al., 2022**). The leakage of dust particles and aerosols through possible gaps formed between the surface of the facepiece and the surface of the worker's face is influenced by: human working positions, body and head movements, and intensity of physical activity during its use. In most cases, the leakage of harmful substances occurs at the bridge of the nose, cheeks and chin, during conversations, during head tilts and during changes in the worker's facial expressions (**Cheberiachko et al., 2020**). The leakage is the highest when fit testing is neglected, resulting in poor size and model selection to the anthropometric features of the users, as well as when working with the shifted half mask (**Campbell et al., 2001; Regli et al., 2021; Cheberiachko et al., 2022**). Such violations of the protective properties may occur during physical exertion with the unsuccessful design of the head strap of FFR. You can reduce slippage of the half mask from the user's face by increasing the headband pressure.

However, high internal pressure can lead to pain, disrupting the comfort of FFR (**Akbar-Khanzadeh et al., 1995; Chen et al., 2015; Graveling et al., 2017**). Maintaining the reliability of sealing is a difficult task that requires a constant search for ways to improve the design of the respirators. The main research areas include developing the facepiece customization techniques (**Cai et al., 2018; Makowski et al., 2019; Pekarcikova et al., 2022**) and introducing changes in the facepiece construction, including diversification of sizes, application of new materials and implementation of additional construction elements (**Han et al., 2018; Mueller et al., 2020; Bazaluk et al., 2021; Rothamer et al., 2021; Okrasa, Nowak et al., 2021; Okrasa, Majchrzycka et al., 2021**).The purpose of this study is to substantiate the choice of the type of elastic head straps of FFR by the criterion of their geometric shape and tension forces, which can ensure an allowable level of leakage of polluted air into the breathing zone of FFR during its use. To achieve this goal, it was necessary to establish the analytical dependencies between the geometric plane of the elastic head straps, the tension force of the facepiece and the air leakage into the breathing zone. Moreover, the design of innovative inserts enabling monitoring of the FFRs' elastomeric head straps tension has been offered to visualize the weakening of the pressure forces responsible for maintaining a leak-tight fit.

2. Methods

2.1 Characteristics of the respirator and elastic straps

The protective properties were tested in relation to the filtering facepiece respirator type: iMask (Standart Company, Ukraine) which was equipped with five different

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Figure 1: Filtering facepiece respirator (a) and elastic straps used for testing (b).

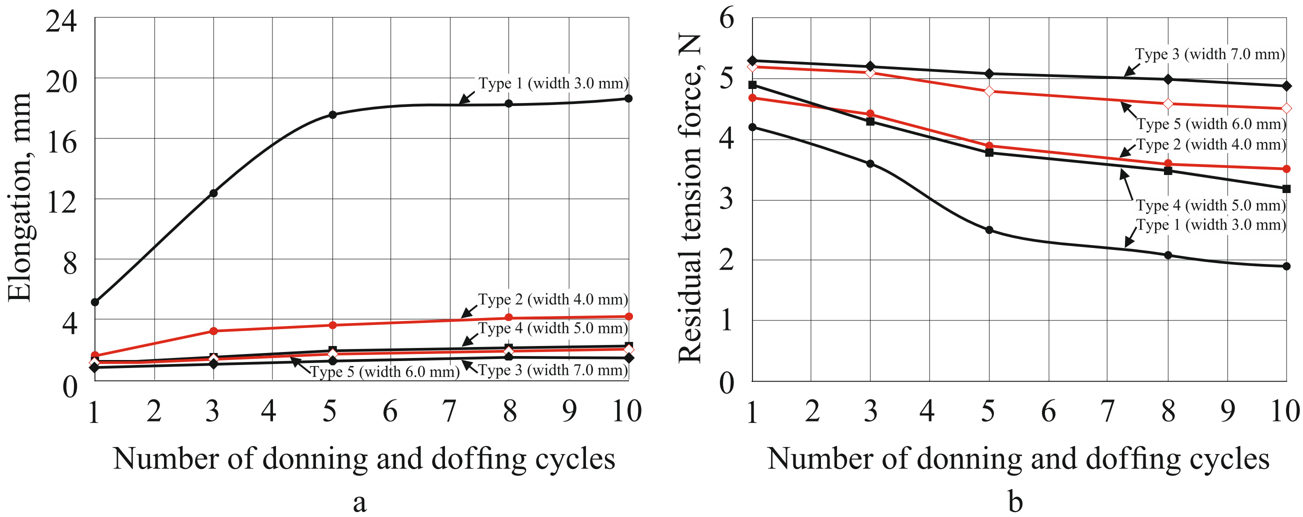

Figure 2: Characteristics of elastic straps depending on the number of donning and doffing cycles: (a) elongation, (b) tension force. Based on the results presented in **Okrasa, Radchuk et al. (2023)**.

types of elastic head straps (see **Figure 1**). Five types of straps with different structures were selected for analysis in order to establish how their structure and properties can affect the magnitude of the head force.

The selection of parameters of elastic head straps of the FFR involves establishing analytical relationships between the main factors that affect its protective properties and reliability. According to the results of our previous research, the volume of air leaking into the breathing zone - Q_p (cm^3/min), changing the calculated area of the head strap - ΔS (mm^2) and the head strap tension force - F (N) were identified as controlled variables (**Okrasa, Radchuk et al., 2023**). It has been found that during the repeated procedure of donning and doffing the head strap of the FFR is stretched by ΔL. The change in the calculated strap area is determined by **Equation 1**:

$$\Delta S = A \cdot \Delta L \tag{1}$$

Where:

A – the width of the strap (mm),

ΔL – the elongation of the strap during the experiments (mm).

Determination of the volume of air leaking into the breathing zone on the face of a mannequin with different tension strength of the headband tapes is calculated as specified in **Golinko et al. (2018)** by **Equation 2**:

$$Q_s = f_1(\Delta P_1 - \Delta P_2) \tag{2}$$

Where:

Q_s – the volume of contaminated air suction (cm^3/min),

f_l – the coefficient that has been determined experimentally for the equipment, which depends on the flexible properties of the elastic strap, $f_1 = 5\times10^{-4}$ (cm⁵/N·min),

ΔP_1 – pressure drop between the external environment and the under-mask space of the FFR on the obturation strip, the surface of which is treated with silicone (Pa),

ΔP_2 – pressure drop on the surface of FFR (Pa).

The respirators with different variants of elastic straps were evaluated on the laboratory installation with mannequins according to the methods specified in EN 149:2001 standard (**EN 149:2001+A1: 2009**) as described in our previous study (**Okrasa, Radchuk et al., 2023**). The summary of measurement results of elastic strap parameters that were used for the modelling study are presented in **Figure 2**.

2.2. *Mathematical model of the FFR*

The experiment planning method was used to determine the mathematical model that describes the influence of the elastomeric head straps' parameters on the respirator's protective properties. The following parameters have been taken into account: the headgear's tension force, the elastomeric strap's width, and the volume of air moving through the gaps between the face and the half mask. The scheme of the object of study, i.e. the elements of the head strap of the FFR, is considered the three-factor with two input and one output parameter (see **Figure 3**). The three-factor model was chosen as rational, taking into account three important parameters: the main one is the amount of suction through the gaps between the face and the half mask, which depends on the area of the strap and the tension force. All other indicators of the straps were taken into account due to the amount of elongation of the strap.

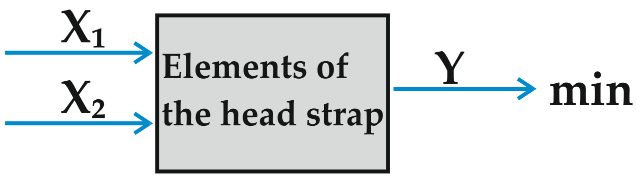

Figure 3: Scheme of the FFR for the modeling study.

The output Y-parameter (response function) is the volume of contaminated air sucked through the obturator strip. While the inputs, X_j (for j = 1, 2), are the area of the FFR head strap and the tension force of the half mask, the vector of which is perpendicular to the stretching vector of the head straps.

When determining the model of the object, we first determined the degree of the polynomial and then calculated its coefficients. The method of experiment planning involves a purposeful change of the values of the input parameters while experimentally determining the output parameter.

The model is based on the following assumptions:

- input parameters change at two levels in the average value range, the upper and lower limits of the

Table 1: Plan of the complete three-factor experiments

Type of the strap	Width of the elastic strap, mm	Experimental conditions in coded values		Experimental conditions in natural values		Experimental response function, cm³/min
		X_1	X_2	ΔS, mm²	F, N	Y
1	3	+1	+1	54	4	174
		-1	+1	15	4	95
		-1	-1	15	2	269
		+1	-1	54	2	324
2	4	+1	+1	17	5	124
		-1	+1	6	5	95
		-1	-1	6	3	165
		+1	-1	17	3	174
3	7	+1	+1	14	6	98
		-1	+1	7	6	95
		-1	-1	7	5	102
		+1	-1	14	5	104
4	5	+1	+1	10	5	116
		-1	+1	5	5	95
		-1	-1	5	3	155
		+1	-1	10	3	165
5	6	+1	+1	12	5	103
		-1	+1	6	5	95
		-1	-1	6	4	111
		+1	-1	12	4	118

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control interval (variation). The following codes are used: $X_{max} \leftrightarrow (+1)$; $X_{min} \leftrightarrow (-1)$;

- steps of varying the input parameters are integer values, the change of which covers the entire range of technical indicators of the straps;
- the degree of the polynomial, which describes the dependence of the initial parameters, is limited in the first order, based on the nature of the intersection of the surfaces of the experimental response values and the error of approximation of the mathematical model under consideration.

According to the experimental results, the ranges of change of the controlled input parameters of the strap width and tension force have been determined. Tabulated values have been calculated using **Equations 1** and **2**. The plan of the three-factor experiment has been developed for each type of strap (see **Table 1**).

According to the results of experimental tests, it is possible to determine mathematical models of the process. We look for the solution of the response function Y in the form of **Equation 3**:

$$Y = f(X_1, X_2, b_0, b_1, b_2, b_3) \qquad (3)$$

Coefficients b_i in mathematical models are determined by the least squares method (**Regli et al., 2021**). We will look for the equation of the response function in the form of the linear function of two variables of **Equation 4**:

$$Y = b_0 X_0 + b_1 X_1 + b_2 X_2 \qquad (4)$$

This model had four experiments, two input parameters and three unknown coefficients. The general form of the system of equations for determining the unknown coefficients of the mathematical model has the **Equation 5**:

$$b_0 \sum_{i=1}^{n} X_0 Y_{ij} + b_1 \sum_{i=1}^{n} X_{1i} Y_{ij} + b_2 \sum_{i=1}^{n} X_{2i} Y_{ij} = \\ = \sum_{i=1}^{n} X_{ij} Y_{ij}, \; j = 0,1,2; i = 1,2,3,4 \qquad (5)$$

Where:

X_{ji} – the value of the j^{th} factor in the i^{th} study,
Y_{ji} – the value of the j^{th} response in the i^{th} study,
Y_i – the value of the response in the i^{th} study,
X_0 – conditional factor, $X_0 = 1$.

3. Results and Discussion

Using the data given in **Table 1**, the sums of the components included in the system of **Equation 5** have been calculated. The example for strap No. 1 is shown in **Table 2**.

Taking into account the obtained values of sums for each parameter, the system of **Equation 5** for strap No. 1 can be presented as **Equation 6**:

$$\begin{cases} 4b_0 + 138b_1 + 12b_2 = 862 \\ 138b_0 + 628b_1 + 414b_2 = 32352 \\ 12b_0 + 414b_1 + 40b_2 = 2262 \end{cases} \qquad (6)$$

By solving **Equation 6**, one obtains the b parameters and thus the equation of the response function Y, as shown in **Table 3**.

The comparison of the response functions (see **Table 3**) has shown that the elastic strap No. 1 has the worst indicators of protective properties and reliability, so this strap is not considered in further optimization calculations. The relative deviation of the calculated value of the elongation of the elastic strap from the experimental is determined by the **Equation 7**:

Table 2: Experimental results for elastic strap No. 1

Experiment number *i*	X_1	X_1^2	X_2	X_2^2	X_1X_2	Y	YX_1	YX_2
1	54	2916	4	16	216	174	9396	696
2	15	225	4	16	60	95	1425	380
3	15	225	2	4	30	269	4035	538
4	54	2916	2	4	108	324	17496	648
Sum	138	6282	12	40	414	862	32352	2262

Table 3: Results of the mathematical modelling

Type of the strap	Coefficients			The equation of the response function Y
	b_0	b_1	b_2	
1	399.2	1.72	-81	$Y = Q_S = 399.2 + 1.72 \cdot \Delta S - 81 \cdot F$
2	239.2	1.70	-30	$Y = Q_S = 239.6 + 1.7 \cdot \Delta S - 30 \cdot F$
3	131.8	0.33	-6.5	$Y = Q_S = 131.8 + 0.33 \cdot \Delta S - 6.5 \cdot F$
4	218.5	3.1	-27.3	$Y = Q_S = 218.5 + 3.1 \cdot \Delta S - 27.3 \cdot F$
5	165.3	1.25	-15.5	$Y = Q_S = 165.3 + 1.2 \cdot \Delta S - 15.5 \cdot F$

Table 4: The results of comparing the calculated and experimental data of the elastic straps under consideration

Total response function	Number of the elastic strap				
	$i = 1$	$i = 2$	$i = 3$	$i = 4$	$i = 5$
$\sum Q_{cal.}$, cm³/min	862	558	399	531	427
$\sum Q_p$, cm³/min	862.16	554.20	397.73	531.10	427.20
$\sum \varepsilon$, %	2.550	1.770	1.260	0.420	0.007

$$\varepsilon = \frac{Q_m - Q_s}{Q_m} \cdot 100\% \tag{7}$$

Where:

Q_m – is the measured value of the volume of contaminated air suction (cm³/min).

The results of comparing the calculated values Y of the response functions in **Table 3** and **Equation 7** with the experimental ones are given in **Table 4**.

From the analysis of the data in **Table 4**, the linear model, which describes the elongation of the strap, adequately approximates the results of the experiment, where relative deviation does not exceed 2.5%. The relative deviation of the theoretical data from the experimental data is in the range from 0.007% to 2.5%, depending on the measured value of the volume of air suction and the value of the pressure drop on the respirators under the condition when air flow is 2.5 dm³/cycle, and the number of inhalations and exhalations of the worker per minute is 12. Under other conditions, the results will vary.

Most of the tasks that need to be solved during the design of personal protective equipment can lead to choosing the best option in one sense or another. Determining the parameters of the head strap design is aquatinted as the optimization. For the optimization parameter, it is accepted to choose the area of the elastic head strap of FFR. The constraints determine the optimal area of the elastic strap:

- the number of donning and doffing cycles is not less than 10;
- the leakage of outside air into the breathing zone does not exceed 1% of the total amount of air inhaled by the user;
- the cost of materials is limited following the requirements specified in the technical conditions for the manufacturing of FFR.

According to the results of experimental research, analytical dependences are obtained (see **Table 3**), which are considered as objective functions with controlled variables *ΔS, F* in **Equation 8**:

$$Y = b_0 + b_1 \Delta S + b_2 F \rightarrow \min. \tag{8}$$

The limits of the level of tension force, the amount of leakage and the cost of the strap are set in **Condition 9**:

$$3.0N \geq F \geq 5.5N;\ Q \leq 120\frac{\text{cm}^3}{\text{min}};\ C < C_p \tag{9}$$

Where:

C_p – maximal cost acceptable by the manufacturer (€).

Target functions do not have extremes within the established limits. The range of optimal values is defined graphically as the points of intersection of the graphs of the change in length at specific head tension forces and the limit value of the suction volume in the obturation strap (see **Figure 4**).

For all the tested types of elastic straps, the volume of air leaking under the facepiece is increased with the surface area of the strap resulting from elongation caused by repeating donning and doffing cycles. The changes in the volume of air leaking under the facepiece were the most significant for the No. 2 strap and the least for the No. 3

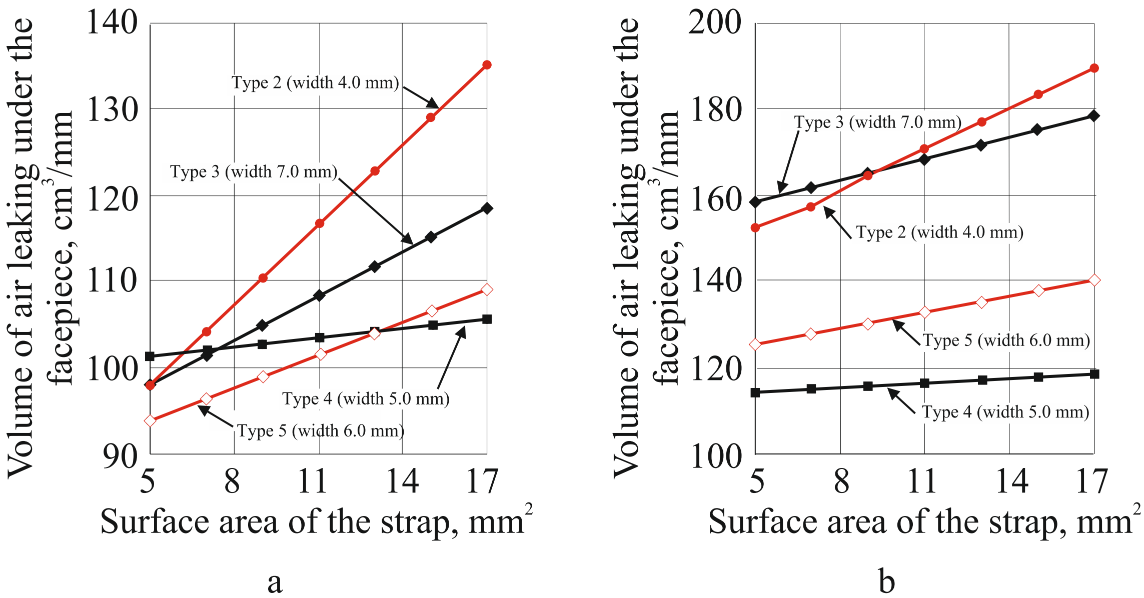

Figure 4: The change in the volume of air leaking under the facepiece on the area of the elastic strap at the tension force of (a) F = 5N and (b) F= 3N.

strap, regardless of the applied tension force. Only for strap No. 3, the leakage was acceptable from the point of view of the limitations described by **Condition 9**.

The theoretical calculations show that the change in the elastic strap area affects the volume of air leaking into the breathing zone due to the gaps between the face and the facepiece, resulting from the weakening of the tension force. Experimental data show the increase in leakage due to the deterioration of the tensile forces of the tape, especially after the first application, which is due to other reasons (**Roberge et al., 2012**). The decrease in the tension forces created by the elastic straps during constant stretching (straps No. 1 and 2) can result from the rupture of some transverse bonds in the middle of the strap or due to the deformation of its spiral shape (its linearization) affecting the strap's ability to recover its original dimensions (**Niezgoda et al., 2013**). It can be argued that the increased leakage of contaminated air is more affected by the structural changes of the strap resulting from repeated donning and doffing, nevertheless leading to its lengthening and changing the total area. The problem is also aggravated by the difference in tension between the upper and the lower strap, leading to an uneven distribution of compressive forces behind the seal (**Roberge et al., 2014**). In this regard, the half mask must be equipped with certain structural elements that allow the control of the tension of the elastic straps while providing timely tightening to restore a sufficient amount of pressure of the facepiece to the face. In most commercially available respirators, such an element is missing. Usually, respirator manufacturers pay more attention to the shape of the seal. After all, this element of the FFR is the most responsible one for isolating the respiratory tract from harmful airborne contaminants (**Okrasa, Nowak et al., 2021; Okrasa, Majchrzycka et al., 2021**). However, regardless of the seal's design, it is important to control the loosening of the headband. Of course, the user can tighten the elastomeric tape at his discretion, but it is difficult for him to achieve with the help of tactile sensation, the uniformity of the tension of the upper and lower tape. Moreover, the user can be unaware of the elongation in some situations. Therefore, it would be beneficial to control the tension force generated by straps allowing for a timely reaction of the user.

There are various options for solving the problem of isolating the face after re-wetting the filter mask (**Lei et al., 2014; Gutierrez et al., 2014; Cai et al., 2018**). One of the new interesting solutions is the use of special inserts with multi-colored indicators, which are fixed to the FFR's facepiece allowing for the constant monitoring of the tension generated by the elastic straps (see **Figure 5**) (**Klymov, 2020**).

Depending on the applied force, the spring stretches and allows the user to control the tension force, focusing on the color change, which is visible through the slot of a special insert. The green color indicates the optimal tension force (in the range of 5-6 N), for which the necessary fit of the FFR should be maintained (**Cheberiachko et al., 2022**). The red color indicates a tension force over 7 N, which could lead to scrapes, indentations, bruising or chafing due to excessive tension (**Tretyakova, 2010**). The orange color indicates insufficient tension force (below 4 N). In this case, the facepiece could quickly move on the face, and as a result, the protective properties of the FFR would be compromised.

The research results are also worth paying attention to because of the importance of selecting the type of elastomeric straps. On the one hand, respirator manufacturers are trying to ensure an acceptable price for FFRs, and on the other hand, there is a need to select straps for different classes of devices. FFRs differ in their protective efficiency (FFP1 – the lowest; FFP3 – the highest) and application. If the strap does not provide the appropriate amount of tension, especially in half masks of protection class FFP3, it leads to a significant risk of dangerous aerosols entering the user's lungs and, over time, occupational diseases. This, in turn, forces employers to approach the selection of respirators more carefully to check their quality at a specific workplace. There is a need to consider the mode of operation, at least the number of removals and donnings of half-masks during one work shift; although there is no such option, it is considered that the respirator is worn once and used during the entire shift. However, there are often cases of the need to reuse respirators (**Richardson et al., 2020**). The knowledge of the use conditions is necessary to pay attention to the area of the tape, which helps monitor and control its efficiency during its use.

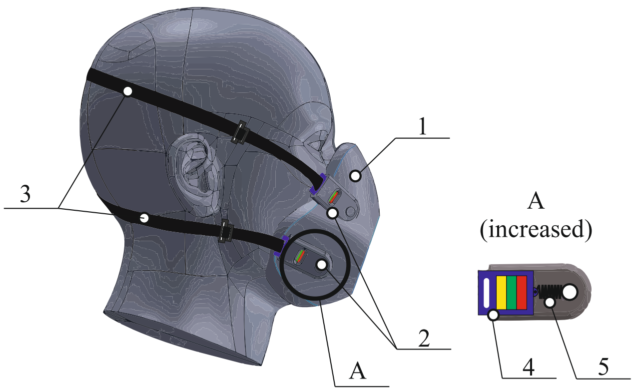

Figure 5: The facepiece of FFR with the special insert to control the tension of a strap: 1 - facepiece; 2 - special inserts for fastening the head strap; 3 - elastic strap; 4 - multi-colored plates; 5 – spring.

4. Conclusions

The approach to selecting geometric dimensions of elastic head straps of the FFR by the criterion of their geometric shape and tension forces has been proposed, which ensures the allowable leakage of polluted air into the mask space during repeated removal and donning of the FFR. The mathematical model has been formed,

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which describes the influence of elastomeric head straps' parameters on the respirator's protective properties. The dependence of the changes in the residual tension forces of the elastic straps has been determined. It has been established that really after eight donning and doffing cycles of the FFR, the elastic forces of elastic straps are weakened due to their stretching from 38 to 74%, which impairs the protective properties of FFR. The dependence of the volume of air entering through the gaps between the face and the half mask, which are formed due to the weakening of the tension force of the head straps due to the change in the area of the elastic strap, was revealed, which allows for the determination of its type for a specific design of the respirator, based on the operating conditions.

A possible solution to this problem would be to introduce special inserts to visualize the level of attenuation of clamping forces to control the level of stretching of the elastomeric head straps of the FFR. Special inserts for controlling the tension force of the elastomeric headgear must have the width (length) of the coloring zone in a certain color (green, yellow, red), which corresponds to the size of the elongation of the elastomeric strap, based on its type, which will be responsible for the permissible and unacceptable value of air entering through the gaps between the half mask and face. An important structural element of such inserts is a spring, the tension force of which should be in the range of 3-5 N, to ensure comfortable conditions for workers and to minimize the volume of air entering through the gaps between the face and half mask. The obtained result is determined by the properties of elastomeric straps (their elasticity, stiffness, wear resistance, breaking force, and construction) depending on the operating conditions, including repeated use.

The research was conducted with respirators of the second class of protection, but the problem under consideration is also relevant for other classes, for which additional experiments must be conducted.

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SAŽETAK

Utjecaj elastičnosti remena za glavu na zaštitna svojstva filtrirajuće respiratorne zaštitne maske

Još uvijek je prisutna visoka razina profesionalnih bolesti dišnoga sustava među radnicima u rudarstvu, strojogradnji i metalurškoj industriji. Najčešća profesionalna bolest dišnoga sustava jest pneumokonioza koja je posljedica dugotrajnoga udisanja prašine. Moguće je smanjiti utjecaj prašine na radnike i eliminirati takve bolesti pomoću filtracijskih respiratora koji smanjuju prodiranje prašine u prostor ispod maske. U svrhu poboljšanja uporabe respiratora istraživan je izbor vrste elastičnih traka filtrirajuće maske na temelju geometrijskoga oblika i sila napetosti koje mogu osigurati dopuštenu razinu propuštanja kontaminiranoga zraka u zonu disanja. Razvijen je matematički model za opis utjecaja parametara izolacijskoga pokrivala za glavu na zaštitna svojstva respiratora. Utvrđena je ovisnost promjene rezidualne vlačne čvrstoće elastičnih traka za glavu te je određena ovisnost volumena usisa zraka o površini elastičnih traka pri odgovarajućoj sili zatezanja. Pomoću modela procijenjena je ovisnost volumena dotoka onečišćenoga zraka o površini elastičnih traka pri odgovarajućoj sili zatezanja. Ponuđen je dizajn inovativnih umetaka koji omogućuje kontrolu napetosti remena za glavu respiratora kako bi se signaliziralo slabljenje sila pritiska odgovornih za održavanje čvrstoga prianjanja.

Ključne riječi:
profesionalna bolest, zaštita dišnoga sustava radnika, respirator maske za filtriranje, elastična traka, poboljšani dizajn

Authors' contribution

Larisa Tretiakova (doctor of technical sciences, professor): initiated the idea, established dependencies and criteria, lead the whole process and supervised. **Yurii Cheberiachko** (doctor of technical sciences, professor): initiated the idea, developed a methodological approach, established dependencies and criteria. **Olena Sharovatova** (PhD, associate professor): analyzed literary sources, processed and analyzed results, constructed graphs. **Tetiana Nehrii** (PhD, associate professor): reviewed the article, completed the literature review, analyzed the results. **Serhii Nehrii** (doctor of technical sciences, professor): analyzed literary sources of information, performed general editing of the article, constructed graphs. **Bohdan Kravchenko** (graduate student): processed the results. **Oksana Zolotarova** (PhD, associate professor): submitted and reviewed the paper.