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Research article

ASSESSING DEGREE OF EXPOSURE TO VIBROACOUSTIC OCCUPATIONAL FACTORS FOR MINING INDUSTRY WORKERS IN ARCTIC ZONE

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Assessment of occupational health risks for workers with basic mining occupations including those exposed to elevated levels of vibroacoustic factors remains a topical issue. Given that, the aim of this study was to assess degree of exposure to occupational vibroacoustic factors and its effects on mining industry workers in the Arctic zone using occupational risk as a basic criterion.

Prior risk assessment relied on results of hygienic assessment of vibroacoustic factors according to data derived by the Special Assessment of Working Conditions (SAWC) and verified by instrumental research. Posterior risk quantification was performed using data on occupational incidence among workers over the last 10 years considering their numbers.

Unacceptable prior occupational risks caused by exposure to noise were detected for all analyzed occupations. According to instrumental research, risks levels higher than those identified by SAWC were detected for open face miners and cargo handling machine operators. According to SAWC data, unacceptable prior occupational risks caused by exposure to vibration were identified only for cargo handling machine operators; additional instrumental research identified such levels of occupational risks for them as well but also for blast hole drillers. Occupational risk quantification established that unacceptable (above $1 \cdot 10^{-3}$) levels of occupational risk caused by vibration disease (VD) and sensorineural hearing loss (SHL) were detected in all analyzed occupational groups. The highest risk levels caused by exposure to vibration were identified for such an occupational group as 'cargo handling machine operators' and ranked as 'average' ($1.37 \cdot 10^{-2}$). The highest risk levels caused by exposure to noise were identified for timbermen and were also ranked as 'average' ($1.32 \cdot 10^{-2}$).

Results obtained by quantification of occupational health risks for mining industry workers in the Arctic zone refine results of prior assessment can be applied in planning activities aimed at mitigating health risks for workers caused by exposure to vibroacoustic factors.

Keywords: *vibroacoustic factors, noise, quantification, occupational risks, categorization, mining industry workers, Arctic zone, cargo handling machine operators.*

A priority task of the state social policy is to protect health of employed population as this helps strengthen the country's labor potential and facilitates the stable growth of the society wellbeing. Working conditions that do not conform to sanitary-hygienic standards can still be found in many industries, in particular, at mining enterprises. Given that, occupational health protection that relies on providing hygienic safety in workplace settings remains the most significant issue in the state economic policy [1, 2].

Assessment of occupational health risks caused by exposure to basic occupational risk factors provides solid grounds for planning and organizing prevention activates. They aim

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to create optimal working conditions considering occupational peculiarities in a given workplace setting [3]. This assessment makes it possible to identify likelihood of negative health outcomes in workers such as occupational and work-related diseases together with considering severity of such outcomes [4].

Underground mining involves stably high occupational incidence rates. In addition to chemical pollution in workplace air, workers' health is influenced considerably by occupational physical factors [5, 6].

Vibration and noise remain leading physical factors that influence occupational incidence rates [7–12]. Occupational vibration disease and sensorineural hearing loss, together with lung diseases, hold leading rank places in occupational incidence of miners with basic mining occupations [13–16]. Therefore, assessment of occupational health risks for workers with basic mining occupations [17–20] exposed to elevated levels of vibroacoustic factors remains a topical issue since it helps develop relevant prevention activities.

In 2023, the Rospotrebnadzor Regional Office in the Krasnoyarsk krai accomplished field control (surveillance) inspections at mines located in the Arctic zone; this was done within the federal state sanitary-epidemiological control (surveillance). These control (surveillance) inspections were aimed at determining whether economic entities complied with the mandatory requirements fixed in the sanitary legislation of the Russian Federation. In particular, surveillance involved estimating levels of occupational vibroacoustic factors for workers with basic mining occupations employed in the Arctic zone. The inspections revealed violations of the existing hygienic standards as regards noise and overall vibration and this justified further assessment of occupational risks for workers' health.

In this study, our objective was to assess levels of exposure to occupational vibroacoustic factors and its effects on mining industry workers in the Arctic zone using occupational risk as a basic criterion**.**

Materials and methods. Hygienic assessment of occupational health risks for workers relied on the results obtained by the Special Assessment of Working Conditions (SAWC). The SAWC results were verified by accomplishing sample examinations concentrating on actual levels of vibroacoustic factors (overall vibration and noise) and estimating their results. The examinations were performed in workplace settings of the following basic mining occupations: blast-hole driller, cargo handling machine operator (hereinafter CHM operator), timberman, and open face miner. Two mines were inspected in the course of control (surveillance) activities where occupational physical factors were measured using an EKOFISIKA-110 noise and vibration meter and spectrum analyzer (the state register number is 48906-12).

Further prior assessment of occupational health risks as per the results obtained by SAWC and instrumental research was accomplished in accordance with the Guide R 2.2.3969-23[1] (hereinafter the Guide). Based on the results obtained by instrumental measurements of overall vibration, prior occupational health risk assessment was accomplished with identifying specific categories of risk levels relying on hygienic assessment of occupational risk factors described in the Guide. Prior quantification of occupational health risks caused by exposure to occupational noise was accomplished using the methodology for application of prior occupational health risk assessment models described in the Guide. Based on identified equivalent noise levels per a shift (Lp,Aeq,8h), a noise dose (Lnd(t)) was determined in accordance with

[1] Guide R 2.2.3969-23. Rukovodstvo po otsenke professional'nogo riska dlya zdorov'ya rabotnikov. Organizatsionno-metodicheskie osnovy, printsipy i kriterii otsenki [The Guide on Assessment of Occupational Health Risk for Workers. O organization and methodical essentials, principles and assessment criteria]. Moscow, The Federal Service for Surveillance over Consumer Rights Protection and Human Wellbeing, 2023, 77 p. (in Russian).

the Guide depending on work records for a given occupation; next, likelihood of occupational disease ($Risk^{rOD}$) was calculated followed by calculation of occupational risk.

Posterior occupational risk quantification for an occupational group was accomplished based on likelihood of occupational diseases among workers with analyzed occupations. It relied on using data about occupational incidence of sensorineural hearing loss (SHL) and vibration disease (VD) among workers over 10 years from 2013 and 2022 inclusive. Likelihood of occupational diseases was calculated as the ratio of occupational diseases (VD or SHL) identified at a mine per year to the total number of workers employed at this mine. Occupational health risks were assessed at workplaces at the first and second mine with the total number of workers being as follows: blast-hole drillers, 89 and 102; open face miners, 36 and 84; timbermen, 44 and 46; CHM operators, 115 and 153 people accordingly. Severity of occupational diseases used in quantification of occupational health risks of a specific occupational group and quantitative criteria used to identify a risk category were taken in accordance with the Guide.

Results and discussion. According to the accomplished instrumental research, the equivalent adjusted overall vibration (vehicle-related) level was 1 dB higher than the hygienic standard (112 dB) at workplaces of CHM operators (working conditions category or WCC is 3.1 whereas WCC is between 3.1 and 3.2 according to the SAWC results). The equivalent adjusted level of overall technological vibration was 1 dB higher than the hygienic standard (100 dB) at workplaces of blast-hole drillers (WCC is 3.1 whereas SAWC WCC is only 2.0).

The measured equivalent noise level was higher than the established hygienic standard (80 dBA) and the excess reached 9 dBA at workplaces of CHM operators (WCC 3.2); 2 dBA at workplaces of timbers (WCC 3.1); 7 dBA at workplaces of open face miners (WCC 3.2). Results obtained by laboratory tests confirmed the SAWC conclusions on existing occupational health risks; it is noteworthy that vibration was estimated rather differently at workplaces of blast-hole drillers. Working conditions were quite similar at both analyzed mines.

The risk was established to be moderate and WCC was established to be 3.1 at workplaces of blast-hole drillers and CHM operators according to prior occupational risk assessment based on the obtained field data on exposure to overall vibration. As regards exposure to the equivalent noise level, WCC was 3.1 and the risk was moderate at workplaces of timbermen; WCC was 3.2 and the risk was medium at workplaces of open face miners in accordance with the criteria stipulated in the Guide. It is worth noting that these results differ from those obtained by the SAWC. According to the SAWC, unacceptable risk levels caused by exposure to vibration were identified only for CHM operators (WCC reaching 3.2, medium risks); unacceptable risks caused by exposure to noise were identified for all the analyzed occupations (WCC reaching 3.2, medium risks).

Prior quantification of likelihood of occupational disease ($Risk^{rOD}$) that was based on calculation of a noise dose depending on work records (Lnd(t)) established that this noise dose would vary between 92 and 105 dB and $Risk^{rOD}$, between 0.035 and 0.184 at a workplace of a CHM operator in case the equivalent shift noise level is 89 and work records are between 2 and 40 years; Lnd(t) would vary between 85 and 98 dB and $Risk^{rOD}$, between 0.011 and 0.082 at a workplace of a timberman in case the equivalent shift noise level is 82 and work records are between 2 and 40 years; Lnd(t) would vary between 90 and 103 dB and $Risk^{rOD}$, between 0.025 and 0.147 at a workplace of an open face miner in case the equivalent shift noise level is 87 and work records are between 2 and 40 years.

Occupational risks of sensorineural hearing loss were calculated based on the identified likelihood of occupational disease and considering severity of sensorineural hearing loss (0.193). They varied between $6.76 \cdot 10^{-3}$

and $3.55 \cdot 10^{-2}$ (between moderate and high risks) for CHM operators; between $2.12 \cdot 10^{-3}$ and $1.58 \cdot 10^{-2}$ (between moderate and medium risks) for timbermen; between $4.83 \cdot 10^{-3}$ and $2.84 \cdot 10^{-2}$ (between moderate and high risks) for open face miners.

The results of the prior occupational risk assessment performed for workers from the analyzed occupational groups indicate that the analyzed vibroacoustic factors are likely to have negative effects on workers' health. We have also identified certain differences in risk categories estimated using instrumental research data and SAWC results (Tables 1 and 2).

Table 1

Prior occupational health risk assessment as regards vibration

Occupation	Risk category estimated by using instrumental research data	Risk category according to the SAWC data
Blast-hole driller	Moderate risk	Low risk
Open face miner	No measurements	Low risk
Timberman	No measurements	Low risk
CHM operator	Moderate risk	Medium risk

According to the SAWC data, unacceptable prior occupational risks caused by vibration were identified only for CHM operators whereas such categories were identified as per instrumental research data not only for CHM operators but blast-hole drillers as well.

Unacceptable prior occupational risks caused by exposure to noise were identified for all the analyzed occupations. It is noteworthy that higher risk levels were identified for open blast miners and CHM operators as per instrumental research data in contrast with the SAWC results.

Still, results of prior occupational risk assessment are considered preliminary; given that, it seemed advisable to supplement them with their posterior assessment. According to the Guide, such an assessment is accomplished by using actual data on workers' health.

Table 3 provides the results of posterior occupational health risk assessment with respect to VD (considering its severity being equal to 0.131) caused by exposure to vibration.

Posterior risk quantification indicates that unacceptable risks caused by VD development belong to categories from 'moderate' to 'medium' risks for blast-hole drillers and CHM operators. The highest risk levels assigned into 'medium risk' category (higher than $1 \cdot 10^{-2}$) are detected at the Mine No. 1. The highest risk levels are $1.18 \cdot 10^{-2}$ and $1.37 \cdot 10^{-2}$ for blast-hole drillers and CHM operators accordingly.

Tables 4 and 5 provide the results of posterior occupational health risk of SHL (considering its severity being equal 0.193) due to exposure to noise.

Unacceptable risk due to developing SHL was estimated as moderate for blast-hole drillers. Risks caused by developing SNL were categorized as moderate to medium for open face miners. The highest health risks that belong to 'medium risk' category (higher than $1 \cdot 10^{-2}$) were identified at the Mine No.1. The highest risk levels were $4.34 \cdot 10^{-3}$ and $1.07 \cdot 10^{-2}$ for blast-hole drillers and open face miners accordingly.

Table 2

Prior occupational health risk assessment as regards noise

Occupation	Risk category estimated by using instrumental research data	Risk category according to the SAWC data
Blast-hole driller	No measurements	Medium risk
Open face miner	High risk	Medium risk
Timberman	Medium risk	Medium risk
CHM operator	High risk	Medium risk

Table 3

Posterior occupational health risk assessment as regards vibration for blast-hole drillers and CHM operators

Mine	Year	Blast-hole driller			CHM operator		
		Number of cases	Likelihood, ‰	Risk	Number of cases	Likelihood, ‰	Risk
No. 1	2013	1	11.24	$1.47 \cdot 10^{-3}$	11	95.65	$1.25 \cdot 10^{-2}$
	2014	7	78.65	$1.03 \cdot 10^{-2}$	12	104.35	$1.37 \cdot 10^{-2}$
	2015	7	78.65	$1.03 \cdot 10^{-2}$	10	86.96	$1.14 \cdot 10^{-2}$
	2016	7	78.65	$1.03 \cdot 10^{-2}$	-*	-	-
	2017	8	89.89	$1.18 \cdot 10^{-2}$	8	69.57	$9.11 \cdot 10^{-3}$
	2018	6	67.42	$8.83 \cdot 10^{-3}$	6	52.17	$6.83 \cdot 10^{-3}$
	2019	2	22.47	$2.94 \cdot 10^{-3}$	5	43.48	$5.70 \cdot 10^{-3}$
	2020	2	22.47	$2.94 \cdot 10^{-3}$	7	60.87	$7.97 \cdot 10^{-3}$
	2021	1	11.24	$1.47 \cdot 10^{-3}$	6	52.17	$6.83 \cdot 10^{-3}$
	2022	4	44.94	$5.89 \cdot 10^{-3}$	8	69.57	$9.11 \cdot 10^{-3}$
No. 2	2013	3	29.41	$3.85 \cdot 10^{-3}$	5	32.68	$4.28 \cdot 10^{-3}$
	2014	3	29.41	$3.85 \cdot 10^{-3}$	3	19.61	$2.57 \cdot 10^{-3}$
	2015	-*	-	-	9	58.82	$7.71 \cdot 10^{-3}$
	2016	5	49.02	$6.42 \cdot 10^{-3}$	5	32.68	$4.28 \cdot 10^{-3}$
	2017	1	9.80	$1.28 \cdot 10^{-3}$	2	13.07	$1.71 \cdot 10^{-3}$
	2018	3	29.41	$3.85 \cdot 10^{-3}$	1	6.54	$8.56 \cdot 10^{-4}$
	2019	1	9.80	$1.28 \cdot 10^{-3}$	1	6.54	$8.56 \cdot 10^{-4}$
	2020	1	9.80	$1.28 \cdot 10^{-3}$	4	26.14	$3.42 \cdot 10^{-3}$
	2021	2	19.61	$2.57 \cdot 10^{-3}$	4	26.14	$3.42 \cdot 10^{-3}$
	2022	1	9.80	$1.28 \cdot 10^{-3}$	3	19.61	$2.57 \cdot 10^{-3}$

Note: * means no disease cases were registered in that year.

Table 4

Posterior occupational health risk assessment as regards noise for blast-hole drillers and open face miners

Mine	Year	Blast-hole driller			Open face miner		
		Number of cases	Likelihood, ‰	Risk	Number of cases	Likelihood, ‰	Risk
No. 1	2013	-*	-	-	1	27.78	$5.36 \cdot 10^{-3}$
	2014	1	11.24	$2.17 \cdot 10^{-3}$	-*	-	-
	2015	1	11.24	$2.17 \cdot 10^{-3}$	1	27.78	$5.36 \cdot 10^{-3}$
	2016	1	11.24	$2.17 \cdot 10^{-3}$	2	55.56	$1.07 \cdot 10^{-2}$
	2017	1	11.24	$2.17 \cdot 10^{-3}$	1	27.78	$5.36 \cdot 10^{-3}$
	2021	2	22.47	$4.34 \cdot 10^{-3}$	-*	-	-
	2022	-*	-	-	1	27.78	$5.36 \cdot 10^{-3}$
No. 2	2013	1	9.80	$1.89 \cdot 10^{-3}$	1	11.90	$2.30 \cdot 10^{-3}$
	2014	1	9.80	$1.89 \cdot 10^{-3}$	1	11.90	$2.30 \cdot 10^{-3}$
	2015	-*	-	-	1	11.90	$2.30 \cdot 10^{-3}$
	2017	-*	-	-	2	23.81	$4.60 \cdot 10^{-3}$

Note: * means no disease cases were registered in that year.

Table 5

Posterior occupational health risk assessment as regards noise for timbermen and CHM operators

Mine	Year	Timbermen			CHM operator		
		Number of cases	Likelihood, ‰	Risk	Number of cases	Likelihood, ‰	Risk
No. 1	2013	1	22.73	$4.39 \cdot 10^{-3}$	4	34.78	$6.71 \cdot 10^{-3}$
	2017	1	22.73	$4.39 \cdot 10^{-3}$	-*	-	-
	2018	3	68.18	$1.32 \cdot 10^{-2}$	-*	-	-
	2019	1	22.73	$4.39 \cdot 10^{-3}$	-*	-	-
	2021	-*	-	-	1	8.70	$1.68 \cdot 10^{-3}$
No. 2	2013	-*	-	-	1	6.54	$1.26 \cdot 10^{-3}$
	2014	-*	-	-	1	6.54	$1.26 \cdot 10^{-3}$
	2015	-*	-	-	1	6.54	$1.26 \cdot 10^{-3}$
	2020	-*	-	-	1	6.54	$1.26 \cdot 10^{-3}$
	2022	-*	-	-	1	6.54	$1.26 \cdot 10^{-3}$

Note: * means no disease cases were registered in that year.

Unacceptable risk due to developing SHL was estimated as moderate for CHM operators. Risks caused by developing SNL were categorized as moderate to medium for timbermen. The highest health risks were $1.32 \cdot 10^{-2}$ and $6.71 \cdot 10^{-3}$ for timbermen and CHM operators accordingly. It is worth noting that the highest risk levels caused by exposure to occupational noise were identified at the Mine No. 1 as well.

Occupational risk quantification established that unacceptable (higher than $1 \cdot 10^{-3}$) levels of occupational risks caused by developing VD and SHL were detected in all the analyzed occupational groups at the Mine No. 2 but this excludes timbermen since no SHL cases were registered in this occupational group over the analyzed 10 years.

Posterior quantification of occupational risks caused by such occupational diseases as VD and SHL due to exposure to vibroacoustic factors confirms the existing unacceptable health risks for workers established as per the results of prior assessment. It also helps identify risk categories more precisely.

Conclusion. In this study, we assessed effects produced by occupational vibroacoustic factors on miners employed in the Arctic zone (in the Krasnoyarsk krai). As a result, we established unacceptable occupational health risks for workers, both by prior occupational risk assessment and posterior occupational risk quantification. The results of posterior risk quantification confirm the prior assessment results and make them more precise.

Prior assessment of exposure to vibration established the highest risk levels to belong to ‘moderate’ and ‘medium’ risk category; posterior quantification ranked them as medium risks. As regards exposure to occupational noise, the highest risk levels were ranked as high by prior assessment and as medium by posterior quantification.

The highest risk levels caused by exposure to vibration were identified for CHM operators and ranked as medium ($1.37 \cdot 10^{-2}$). The highest risk levels caused by exposure to occupational noise were identified for timbermen and ranked as medium ($1.32 \cdot 10^{-2}$).

Results obtained by quantification of occupational health risks for mining industry workers in the Arctic zone can be applied when planning activities aimed at mitigating health risks for workers caused by exposure to vibroacoustic factors.

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