

RISK ASSESSMENT IN MINING INDUSTRY ARISING FROM HAND-ARM VIBRATION

Momir Prašćević¹, Darko Mihajlov²

¹ University of Niš, Faculty of Occupational Safety of Niš, 18000 Niš, Čarnojevića 10a, momir.prascevic@znrfak.ni.ac.rs

² University of Niš, Faculty of Occupational Safety of Niš, 18000 Niš, Čarnojevića 10a, darko.mihajlov@znrfak.ni.ac.rs

ABSTRACT. The risk from injuries and occupational diseases arising from vibration can be identified in many industries and occupations, especially in mining industry. The risk is greatly increased with use of higher vibration equipment and with prolonged and regular use of the equipment. However, investigation have shown that the vibration hazards can be controlled and risk reduced by good management system. Because of that it is necessary to follow out the procedure of risk assessment in the working environment for the work places exposed to vibration. The results of risk assessment in mining industry based on European Directive 2002/44/EC on the minimum health and safety requirements regarding the exposure of workers to vibration are shown in this paper.

ОЦЕНКА НА РИСКА В МИННАТА ИНДУСТРИЯ, ПРОИЗТИЧАЩ ОТ ВИБРАЦИИ РЪКА-РАМО

Момир Прашчевић¹, Дарко Михајлов²

¹ Универзитет в Ниш, Факултет по безопасност на труда, 18000 Ниш, Чарнојевића 10а, momir.prascevic@znrfak.ni.ac.rs

² Универзитет в Ниш, Факултет по безопасност на труда, 18000 Ниш, Чарнојевића 10а, darko.mihajlov@znrfak.ni.ac.rs

РЕЗЮМЕ. Рискът от наранявания и професионални заболявания причинени от вибрации може да бъде идентифициран в много индустрии и професии, особено в минната индустрия. Рискът се увеличава значително при използването на оборудване с висока вибрация и с продължително и редовно използване на това оборудване. Въпреки това, проучванията показват, че опасностите от вибрации могат да се контролират и че рискът може да се намали с добра система за управление. Поради това е необходимо да се следва процедурата за оценка на риска в работната среда по работните места, изложени на вибрации. В този доклад са показани резултатите от оценката на риска в минната индустрия на базата на Европейската директива 2002/44/ЕЦ, относно минималните изисквания за здраве и безопасност, свързани с излагането на работниците на рисковете от физически агенти (вибрации).

Introduction

The human body is a relatively complex vibratory system, because it contains both linear and nonlinear "springs" and "dampers." For the frequency range below about 40 Hz, the human body can be modeled approximately by a system of masses (the head, upper torso, hips, legs, and arms), spring elements, and damping elements (Cvetkovic and Prascevic, 2005).

Generally, exposure to vibration at the workplace is more severe than vibration exposure at environment, in terms of both levels of vibration and duration of vibration exposure. Most of the work-related whole-body vibration (WBV) exposure arises from forces transmitted through the person's feet while standing, or the buttocks while seated. Hand-arm vibration exposure may also occur while holding vibration tools. Hand-arm vibration (HAV) is when vibration is transmitted to the hand and arm. The vibration can be transmitted during the operation of hand-held power tools and hand-guided equipment, or when holding materials being processed by machines. Hand-arm vibration is commonly experienced in mining workplaces by workers who regularly use tools such as jackhammers, grinders, drills, riveters and torque wrenches.

Much of the tools used in mining workplaces create vibration in order to achieve their role. A little vibration transmission back to the operator can be beneficial in that it indicates that the tool is working. However, as the level of vibration

transmission to the hand-arm increases it can cause annoyance, disturbance, fatigue and at higher exposures there is a risk of injury (Foster and Burgess).

Exposure to hand-arm vibration can result in disrupted blood and oxygen circulation in the hand and forearm, as well as damage to nerves and tendons, muscles bones and joints. It can cause a range of conditions collectively known as hand-arm vibration syndrome and specific disorders such as carpal tunnel syndrome and lateral epicondylitis (commonly known as 'tennis elbow'). The most common condition resulting from exposure to hand-arm vibration is known as 'vibration white finger'.

The importance of establishing exposure limits for human vibration in the workplace was recognised by the European Union and in 2002 a directive was issued by the European Parliament on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration). The agreement on this directive meant that the European countries were obliged to introduce legislation and regulations defining vibration exposure limits in the workplace. Serbia adopted regulation with exposure limits in 2011 (SER 2011). The Serbian regulation will be applied from 2015, January 1.

The results of risk assessment in mining industry based on European Directive 2002/44/EC on the minimum health and safety requirements regarding the exposure of workers to hand-arm vibration will be shown in this paper.

Risk assessment procedure

Directive 2002/44/EC (EC 2002) and Serbian regulation (SER 2011) give „exposure limit values“ and „exposure action values“ as well as specific employers' obligations with regard to determining and assessing risk arising from exposure to vibration. Any employer who intends to carry out work involving risks arising from exposure to vibration must first determine and assess arising from exposure to vibration and provide information to workers.

The evaluation and assessment of risks arising from exposure to hand-arm vibration can be complicated. Guide on hand-arm vibration (Griffin et al., 2006) prepared under contract VC/2004/0341 for the European Commission Directorate General Employment, Social Affairs and Equal Opportunities can facilitate the assessment of risks from exposure to hand-arm vibration.

Risk assessment is one of steps in risk management process (Fig 1) which involves (McPhee et al., 2009):

- identifying vibration hazards
- assessing a risk to health and safety of employees
- controlling those factors that do pose a risk
- monitoring and evaluating controls/solutions

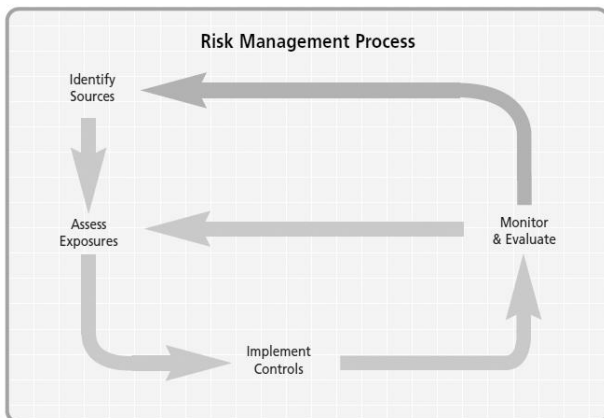


Fig. 1. Risk management process (McPhee et al., 2009)

Generally risk assessment and risk assessment act enacted by the employer is the basis for the planning of risk management and achievement of safety and health at work. The ultimate goal is a healthy and satisfying work environment and a healthy, active and productive worker without professional or other diseases, capable and motivate to carry out their daily work with a sense of satisfaction and with the further development of their skills as a worker and as a person.

The risk assessment is based on the systematic recording and assessing all hazards and harmfulnesses in the work process, the analysis of the probability of occurrence and severity of possible injury, damage to health or illness of workers. Risk assessment is carried out for every registered hazard or harmfulness, by comparison with the allowable values prescribed in the relevant legislation in the field of safety and health at work.

Systematic recording of hazards and harmfulnesses in the workplace is performed on the basis of review of existing documentation at the disposal of the employer, observation and monitoring of the process of work at the workplace, collecting data from workers using different checklists and grouping of hazards and harmfulnesses depending on the type and nature.

Bearing in mind the degree of presence of the harmful effects of hand-arm vibration that appears in the work process, especially when working with hand-held tools in mining and construction, where the vibration are used as an active tool for the execution of an operation, special attention should be paid to the assessment of risk from the negative effects of such vibration.

Hand-arm vibration risk should give answers to the following questions:

- Is there a problem?
- How big is the problem?
- What causes the problem?
- How to reduce the problem?
- How to prevent the problem?

When assessing the risk from hand-arm vibration in the workplace it should have answers to all the questions mentioned above. The following steps are carried out for this purpose:

- Identification of workplaces where there may be a risk of vibration by checklists, monitoring the process, talking with workers ...;
- Determination of daily exposure duration;
- Determination of the magnitude of vibration;
- Calculation of the daily vibration exposure;
- Comparison with limit values;
- Identification of available measures for vibration control;
- Identification of planned steps to control and vibration monitoring.

After identification of workplaces where there is a hand-arm vibration risk it is necessary to determine the daily exposure duration, as an important factor in determining the daily vibration exposure. Greater time exposure to vibration - higher daily vibration exposure and more likely to take the adverse effects of vibration on the human body.

Values of hand-arm vibration can be determined in three ways:

- based on the manufacturer's emission data,
- based on the measured values of vibration, and
- using the web site containing information about the vibration generated by certain types of hand-held tools (e.g. <http://vibration.arbetslivsinstitutet.se/eng/havhome.lasso>, http://www.las-bb.de/karla/index_.htm).

In many situations it will be necessary to measure vibration magnitudes because sometimes it may not be possible to obtain adequate information from equipment suppliers or other sources on the vibration produced by a hand-held tool. Human exposure to hand-arm vibration should be evaluated using the method defined in standard „Mechanical vibration - Measurement and evaluation of human exposure to hand-transmitted vibration - Part 1: General requirements“ (EN ISO 5349-1:2001) and detailed practical guidance on using the method for measurement of vibration at the workplace is given in standard „Mechanical vibration - Measurement and evaluation of human exposure to hand-transmitted vibration - Part 2: Practical guidance for measurement at the workplace“ (EN ISO 5349-2:2001).

The vibration magnitude is expressed as the frequency-weighted acceleration of the surface of the handle of tools or workpiece that is in contact with the hand:

$$a_{hw} = \sqrt{\sum_i (W_{hi} a_{hi})^2} \quad (1)$$

where

W_{hi} is the weighting factor for the i -th one-third-octave band and a_{hi} is the root mean square acceleration measured in the i -th one-third-octave band.

Measurement procedure is based on the simultaneous measurement of vibration in three directions x , y and z . The value used for assessment of exposure is the vibration total value, a_{hv} , which combines the three a_{hw} values for the axes x , y and z , using:

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} \quad (2)$$

where

$a_{hwx}, a_{hwy}, a_{hwz}$ are the frequency-weighted acceleration in three directions x , y and z , respectively.

The assessment of exposure level to hand-arm vibration is based on daily vibration exposure, $A(8)$, calculated based on 8-h energy equivalent frequency-weighted vibration total value and daily exposure duration:

$$A(8) = a_{hv(eq,8h)} = a_{hv} \sqrt{\frac{T}{T_0}} \quad (3)$$

where

T is the total daily exposure duration and T_0 is the reference duration of 8h.

If a worker is exposed to more than one source of vibration, because they use two or more different during the day, then the partial vibration exposures are calculated from the magnitude and duration for each one. The partial vibration values are combined to give the overall daily vibration exposure value, $A(8)$, for that worker:

$$A(8) = \sqrt{A_1(8)^2 + A_2(8)^2 + A_3(8)^2 + \dots} \quad (4)$$

Directive 2002/44/EC (EC 2002) and Serbian regulation (SER 2011) set the minimum requirements for controlling risks in the workplace who are exposed to negative effects of vibration. These documents define the exposure limit and action values for hand-arm vibration (Table 1).

Table 1
Exposure action values and limit values

Hand-arm vibration	A(8)
Exposure limit value	5 m/s ²
Exposure action value	2.5 m/s ²

Based on the allowable values of daily vibration exposure three zones can be formulated for risk assessment from the negative effects of hand-arm vibration (Table 2). Some employers have developed a green / yellow / red „red traffic“ system (Table 3), where each tool is clearly marked with a hand-arm vibration colour coding, dependent on expected daily vibration exposure (Griffin et al., 2006).

Table 2
Risk assessment zones

	A(8)
Alarm (red zone)	>5 m/s ²
Alert (yellow zone)	2.5 ÷ 5m/s ²
Tolerant (green zone)	<2.5 m/s ²

Table 3
Color coding scheme for „traffic-light“ system

	Time to reach exposure action value	Time to reach exposure limit value
Red	Less than 30 minutes	Less than 2 hours
Yellow	30 minutes to 2 hours	2 to 8 hours
Green	More than 2 hours	More than 8 hours

Comparing the daily vibration exposure values with acceptable values it can be determined which zone belongs observed exposure to vibration, and on that basis to assess the risk of damage to the tissues and organs of the human body due to long exposure to vibration.

Risk assessment in lead and zinc mine

The described procedure of risk assessment from hand-held vibration applied in Serbian mine of lead and zinc „Rudnik“ located in Western Serbia near Gornji Milanovac.

The investigation included all hand-held tools used in the mine and the results for two are shown in this paper. The technical data of these are shown in Table 4.

Table 4
Technical data of underground rock drills

Model	Panther BBD 94W	
Version	Pusher leg rock drill	Stoper for soft to medium hard rock
Weight	28 kg	40 kg
Impact rate	3300 blows/min	3000 blows/min
Piston diameter	90 mm	75 mm
Stroke length	45 mm	45 mm
Hole diameter	27-41 mm	27-41 mm



Fig. 2. Rock drills - Panther BBD 94W (left) and Falcon 46WS-8 (right)

The risk assessment from hand-held vibration in the mine included the following steps:

1. measurement of frequency-weighted acceleration in order to determine the vibration total value;
2. Determination of daily exposure duration;
3. Calculation of the daily vibration exposure.

In order to ensure that the measured data could be used for comparison with other available data it was decided to follow the relevant ISO standards (EN ISO 5349-1:2001 and EN ISO 5349-2:2001). By following these guidelines it was ensured that the data could be used to evaluate the vibration level against Directive 2002/44/EC and Serbian regulation norms.

Brüel & Kjær's Human Vibration Analyzer Type 4447 was used for hand-arm vibration measurements. Type 4447 implements the health and safety measurement requirements of the international standard ISO 8041:2005 - Human response to vibration - Measuring instrumentation. Hand-arm vibration was measured with the supplied triaxial accelerometer, type 4524-B-001. The accelerometer was connected to the measurement surface on the tool handle by handle adaptor UA-3016 (Figure 3) and connected to the instrument's triaxial input with Cable AO-0693.

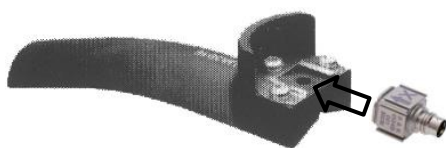


Fig. 3. Handle adaptor for HAV measurements

To determine the vibration total value in hand-arm measurements, the orientation of the transducer is not important, as all the axes have the same weighting. However, the vibration values on each orthogonal axis may be important for documentation and tool evaluation. It is, therefore, always good practice to correctly orient the transducer. The coordinate system employed when the device was placed on the handle of the equipment is indicated in Figure 3. The idea of this measurement procedure is to measure the vibration level at the point where it actually enters the body of the operator. Therefore, hand-arm vibration was measured by placing an accelerometer on the handle of the tools under investigation. As the measurement can be influenced by the strength of the grip of the operator, in all cases the operator was explicitly instructed to grip the transducer very tightly to ensure that an accurate and repeatable measurement was obtained.

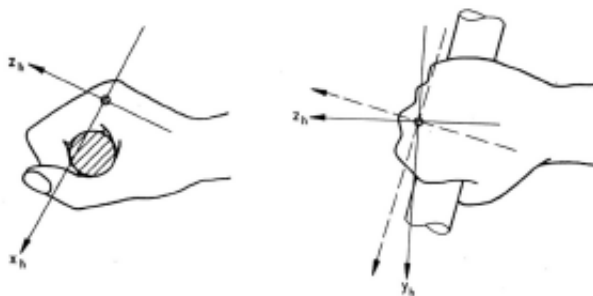


Fig. 4. HAV measurements co-ordinate measurements

The measurement was carried out during the process of drilling holes for blasting. Horizontal holes were drilled by rock drill „Panther BBD 94W” and vertical ones by rock drill “Falcon 46WS-8”. The measurement was repeated five times for each tool. Single measurement time was 2 minutes, which corresponds to the time of drilling holes.

The results of simultaneous measurement of vibration in three directions x , y and z . obtained in the measurement procedure are given in Table 5 for rock drill „Panther BBD 94W” and in Table 6 for rock drill “Falcon 46WS-8”. The values of the total vibration for all three directions are also given in tables.

Table 5
Measured values of acceleration for Panther BBD 94W

No. of meas.	a_{hwx} [m/s ²]	a_{hwy} [m/s ²]	a_{hwz} [m/s ²]	a_{hv} [m/s ²]
1	24.4	12.7	10.9	29.8
2	26.4	14.9	12.2	33.0
3	26.8	14.9	12.2	33.4
4	26.8	12.2	12.3	32.2
5	24.1	10.9	11.5	29.0
mean value	25.7	13.1	11.8	31.5

Table 6
Measured values of acceleration for Falcon 46WS-8

No. of meas.	a_{hwx} [m/s ²]	a_{hwy} [m/s ²]	a_{hwz} [m/s ²]	a_{hv} [m/s ²]
1	11.1	4.9	6.6	13.7
2	10.6	6.2	7.0	14.0
3	11.6	5.9	7.2	14.9
4	12.2	6.2	7.7	15.6
5	7.8	6.0	8.4	11.6
mean value	10.7	4.3	7.9	13.8

In the second step, the daily exposure duration to hand-arm vibration during handling the rock drills was determined by monitoring process of drilling holes and activities of miners in the preparation of mine holes. The results of monitoring process are shown in Table 7 for rock drill „Panther BBD 94W” and in Table 8 for rock drill “Falcon 46WS-8”. The values of the daily exposure duration calculated based on data given in Table 7 and Table 8 are given in Table 7 and Table 8.

In the third step value, the daily vibration exposure values $A(8)$, were calculated using equation (3) and the results of the total vibration and the daily exposure duration. The values obtained in this procedure can be compared with exposure and action value of given in Table 1. The results of comparison are given in Table 9.

As the values of daily vibration exposure for both rock drills exceed the limit and action exposure values defined by Directive 2002/44/EC and Serbian regulation norms, the allowable values of daily exposure duration can be calculated so that the action and limit exposure value is not exceeded. The allowable values of daily exposure duration are given in Table 10.

Table 6

Survey of activities of miners in the preparation of mine holes using rock drill „Panther BBD 94W”

No. of holes	Drilling start	Drilling duration	Pause to adjust the supporting leg	Next drilling start	Drilling duration	Pause to adjust the supporting leg	Next drilling start	Drilling duration	Drilling end	Pause for next drilling	Effectively operating time of tool
1.	10h20'	2'	15"	10h20'15"	1'30"	20"	10h22'05"	1'05"	10h23'10"	25"	4'35"
2.	10h23'35"	1'58"	20"	10h25'53"	2'	15"	10h26'08"	34"	10h26'42"	20"	4'32"
3.	10h27'02"	2'	16"	10h29'18"	1'30"	17"	10h31'05"	1'28"	10h32'33"	22"	4'58"
4.	10h32'55"	1'59"	20"	10h35'14"	1'45"	17"	10h37'16"	44"	10h38'00"	18"	4'28"
5.	10h38'18"	2'	21"	10h40'39"	1'25"	20"	10h42'24"	1'17"	10h43'41"	21"	4'42"
6.	10h44'01"	1'55"	19"	10h46'15"	1'50"	26"	10h48'31"	40"	10h49'11"	20"	4'25"
7.	10h49'31"	2'	17"	10h51'48"	1'46"	20"	10h53'54"	39"	10h54'33"	28"	4'19"
8.	10h55'01"	1'30"	21"	10h56'52"	2'	18"	10h59'10"	50"	11h00'00"	35"	4'20"
9.	11h00'35"	2'	18"	11h02'53"	1'30"	20"	11h04'43"	45"	11h05'28"	22"	4'15"
10.	11h05'50"	1'30"	20"	11h07'40"	1'55"	19"	11h09'54"	1'01"	11h10'55"	20"	4'26"
11.	11h11'15"	2'	16"	11h13'31"	1'38"	18"	11h15'28"	50"	11h16'18"	33"	4'28"
12.	11h16'51"	1'56"	20"	11h19'07"	1'50"	19"	11h21'16"	30"	11h21'46"	25"	4'16"
13.	11h22'11"	2'	19"	11h24'30"	1'50"	21"	11h26'41"	35"	11h27'16"	17"	4'25"
14.	11h27'33"	2'	23"	11h29'56"	2'	15"	11h32'11"	34"	11h32'45"	38"	4'34"
15.	11h33'23"	2'	-	-	-	-	-	-	11h35'23"	25"	2'
16.	11h35'48"	2'	-	-	-	-	-	-	11h37'23"	34"	2'
17.	11h37'57"	2'	25"	11h40'22"	2'	24"	11h42'46"	25"	11h43'11"	-	4'25"
Total time for all holes	2403"=32'48"	290"=4'50"	-	1589"=26'29"	267"=4'27"	-	717"=11'57"	-	403"=6'43"	71'14"	
Mean value per hole	1'55"	17"	-	1'33"	16"	-	42"	-	24"	4'11"	

Daily exposure duration: 71'14"

Table 7

Survey of activities of miners in the preparation of mine holes using rock drill "Falcon 46WS-8".

No. of holes	Drilling start	Drilling duration with 60cm drill	Drilling duration with 60cm drill	Pause to replace 60cm drill	Next drilling start with 120cm drill	Drilling duration with 120cm drill	Drilling end	Pause for next drilling
1.	8h46'	2'	8h48'	29"	8h48'29"	1'58"	8h50'27"	15"
2.	8h50'42"	1'59"	8h52'51"	30"	8h53'21"	2'	8h53'21"	16"
3.	8h55'37"	1'58"	8h56'35"	28"	8h57'03"	1'58"	8h59'01"	20"
4.	8h59'21"	2'	9h01'21"	31"	9h01'52"	2'	9h03'52"	17"
5.	9h04'09"	1'57"	9h06'06"	30"	9h06'36"	1'59"	9h08'32"	20"
6.	9h08'52"	1'59"	9h10'51"	29"	9h11'20"	2'	9h13'20"	19"
7.	9h13'39"	2'	9h15'39"	30"	9h16'09"	2'	9h18'09"	20"
8.	9h18'29"	2'	9h20'29"	30"	9h20'59"	2'	9h22'59"	20"
9.	9h31'30"	1'58"	9h33'28"	30"	9h33'58"	1'59"	9h35'57"	20"
10.	9h36'17"	2'	9h38'17"	29"	9h38'46"	2'	9h40'46"	18"
11.	9h41'04"	1'59"	9h43'03"	30"	9h43'33"	1'57"	9h45'30"	21"
12.	9h45'51"	2'	9h47'51"	28"	9h48'19"	1'59"	9h50'18"	19"
13.	9h50'37"	2'	9h52'37"	25"	9h53'02"	2'	9h55'02"	16"
14.	9h55'18"	1'57"	9h57'15"	30"	9h57'45"	1'58"	9h59'43"	17"
15.	10h00'00"	2'	10h02'00"	29"	10h02'29"	2'	10h04'29"	20"
16.	10h04'49"	1'58"	10h06'47"	30"	10h07'17"	1'59"	10h09'16"	15"
17.	10h09'31"	2'	10h11'31"	27"	10h11'58"	2'	10h13'58"	20"
18.	10h14'18"	1'59"	10h16'17"	30"	10h16'47"	1'58"	10h18'45"	18"
19.	10h19'03"	2'	10h21'03"	28"	10h21'31"	2'	10h23'31"	17"
20.	10h23'48"	1'57"	10h25'45"	29"	10h26'14"	1'59"	10h28'13"	20"
21.	10h28'33"	2'	10h30'33"	30"	10h31'03"	2'	10h31'03"	18"
22.	10h31'21"	1'58"	10h33'19"	28"	10h33'47"	2'	10h35'49"	20"
23.	10h36'09"	2'	10h38'09"	30"	10h38'39"	1'59"	10h40'28"	18"
24.	10h40'46"	1'58"	10h42'44"	28"	10h43'12"	2'	10h45'12"	20"
25.	10h45'32"	2'	10h47'32"	30"	10h48'02"	2'	10h50'02"	20"
Total time for all holes	2977"=49'37"	-	728"=12'08"	2983"=49'43"	-	414"=6'54"		
Mean value per hole	1'59"	-	29"	1'59"	-	17"		

Daily exposure duration: 99'20"

Table 9

Comparasion calculated and allowable acceleration values

	T [s]	a_{hv} [m/s ²]	A(8) [m/s ²]	Exceeding [m/s ²]	
				action values	limit values
Panther BBD 94W	71'14"	31.5	12.1	9.6	7.1
Falcon 46WS-8	99'20"	13.8	6.3	3.8	1.3

Table 10

Allowable values of the daily exposure duration

	Time to action value	Time to limit value	No. of mine holes to limit value
Panther BBD 94W	3 min	12 min	≈3
Falcon 46WS-8	16 min	63 min	≈15

Conclusion

Measurement and risk assessment of hand–arm vibration exposure levels in mining industry can help identify tools and activities that are producing excessive vibration levels. This information can be useful in establishing priorities and assessing the effectiveness of control measures in reducing these levels. The implementation of the Directive 2002/44/EC has led to manufacturers and suppliers paying greater attention to the vibration levels of their tools.

It is clear from the measured results that the vibration levels measured on rock drills are above the action and limit value and it can't be classified as safe and healthy. Hand-arm vibration risk in mining industry can be classified in alarm risk assessment zone. Once the vibration risk has been identified and assessed control measures in reducing the daily vibration exposure value can be taken.

Successful hand–arm vibration exposure reduction usually requires a combination of control measures. Such measures can include:

- selecting tools to eliminate or minimize exposure to vibration;
- modifying existing tools to either dampen the vibration or prevent the vibration from moving into the handle of the tool;
- modifying the work methods to reduce exposure to vibration;
- maintaining equipment on a regular basis to minimize vibration;
- providing personal protective equipment, such as gloves and protective clothing, to keep workers warm and dry and encourage good circulation; and
- providing training, including advice on good work practices and tool maintenance, and information on the vibration effects.

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