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Case Study

Analyzing the Vibration Exposure to the Safety and Health at Workplace: A Case in the Urea Granulation Unit of the Fertilizer Factory

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A B S T R A C T

This study aims to evaluate the vibration exposure experienced by workers in the Urea This study aims to evaluate the vibration exposure experienced by workers in the Urea Granulation Screen Unit (UGSU) at the fertilizer factory in Aceh, Indonesia. This study involved 30 labors in charge as operators, mechanical maintenance officers, electrical maintenance officers, instrument maintenance officers, and inspectors. The measurement of vibration was carried out using a Triaxial Accelerometer with Integral Magnet and shows that the vibration exposure on the factory floor of the urea granulation screen unit occurs vertically with a minimum value of 0.298 m/s2 and a maximum of 1.630 m/s2. According to ISO 2631-1:1997, the maximum vibration values that occur are categorized as a likely health risk zone and result in uncomfortable reactions to the workers. Furthermore, this study analyzes the effect of vibrations on musculoskeletal problems using a Nordic Body Map (NBM) questionnaire. It reveals that the average score of musculoskeletal complaints is 71.6, which defines a high degree of pain. The results of the NBM questionnaire also showed that the vulnerable part of the body which experienced musculoskeletal complaints is the knee. The result of vibration exposure on this body part shows the highest value of 3.437 m/s2. To minimize occupational diseases and accidents, it is necessary to manage a working system that takes into account legal standards, ideal working time, and working shifts in the work area.

INTRODUCTION

The physical work environment concerns with factors such as sound and noise, light and lighting, vibration, temperature and humidity. Those factors have positive and negative effects on productivity and occupational health and safety [1-3]. Industries need to pay attention to established the positive effects and minimize the negative one thus creates comfortable working conditions in the workplace.

Vibrations are one of the physical work environment factors which occur as a result of mechanical devices that reach a worker's body and create effects on them. Mechanical vibrations for a long period will be very disturbing to the body because of their irregularity, both in intensity and frequency. The greatest disturbance to an instrument in the body occurs when this natural frequency resonates with the frequency of mechanical vibrations. Mechanical vibrations can interfere the body in terms of working concentration, fatigue, and the emergence of several diseases, including disruption of eyes, nerves, blood circulation, muscles, bones, etc. [4].

General comments on vibrations reveal that vibrations exposure comes from its sensation instead of particular knowledge about vibrations effects which can cause damage and or reduce performance [5]. If possible, the source of the vibration should be reduced such as reducing terrain undulation, reducing the speed at which the vehicle travels, or increasing the balance of a rotating part.

The most commonly felt exposure to vibrations is the whole-body vibration (WBV). WBV occurs when the body is on a vibrating surface, such as sitting in a vibrating chair, standing on a vibrating floor or lying on a vibrating surface. WBV occurs due to various type of industrial machinery and any forms of transportation including road, off-road, rail, sea and air transportation. In the manufacturing industry, vibrations usually occur in the machinery department and heavy work tools.

International standard of WBV refers to ISO 2361-1:1997 concerning vibrations for worker health and comfort. This standard uses a caution zone to classify the vibrations exposure and setting a limit depends on the length of exposure. A condition above this caution zone exposure defines as likely to cause injury.

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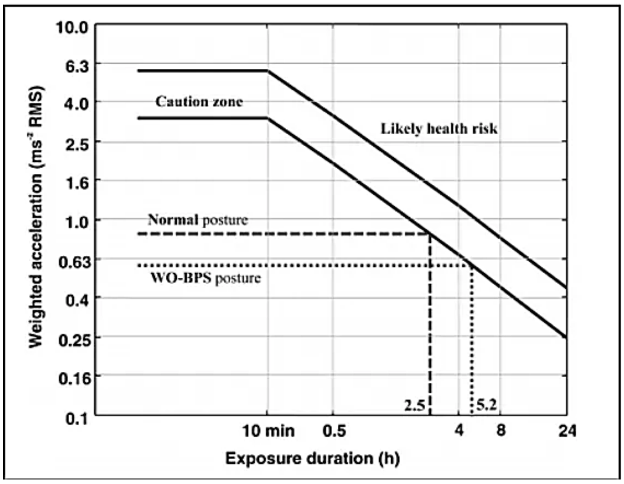

Figure 1. Safety Zone based on ISO 2631-1:1997 [6]

Table 1. Discomfort Rating based on ISO 2631-1:1997 [6]

No.	Vibration (m/s^2)	Consequence
1.	<0.315	Not uncomfortable
2.	0.315 – 0.63	A little uncomfortable
3.	0.5 – 1	Fairly uncomfortable
4.	0.8 – 1.6	Uncomfortable
5.	1.25 – 2.5	Very uncomfortable
6.	>2	Extremely uncomfortable

The safety zone standard (Figure 1) and discomfort rating (Table 1) provide comfort and movement paint based on ISO 2361-1:1997 [6] and will be used as a reference in analyzing data obtained from this study.

WBV affects health, comfort and performances. Vibrations in relation to performance would affect productivity and lead to occupational stress such as eating disorders, aggression, drug abuse, poor relations [7]. However, occupational stress might not always influence performance in a great extent, and the correlation between work performance and stress level as well as physiological coherence might not always be significant [8]. Excessive stress refers to something that would break body's homeostatic relationship between human cognition and the environmental demand; homeostatic defined as internal stability and balance of autonomic nervous systems (ANS) [9]. During mental or emotional stress, the sympathetic activity would increase while parasympathetic activity would decrease, particularly in occupational settings [10-12].

A fertilizer factory in the province of Aceh, Indonesia, called PT PIM, which produces ammonia and urea fertilizers, quite extreme vibrations occur in the Urea Granulation Screen Unit (UGSU). The unit owns two fertilizer screening machines as shown in Figure 2, which operated 24 hours a day along the 365 days in a year. General tasks performed by the workers in the unit include checking the urea volume through the screen to avoid over capacity, ensure the urea flows according to its size and cleaning as necessary. Specific tasks such as maintenance and repairing work occur once a year or as needed.

The screening machines expose highly vibration while operated and impact the working activities in the area. Unavoidable vibrations experienced by the workers while performing their tasks in the area and the effect still exist even after leaving the unit. WBV experienced by the workers may lead to occupational disease if exposed continuously for a long period.

Figure 2. Fertilizer Screening Machines in The UGSU

According to Kesuma et al [13], WBV in relation to operating heavy equipment may lead to musculoskeletal problems. On the study, Khairai et al [8] revealed that 30 out of 45 heavy equipment operators experienced highly vibration exposure and musculoskeletal complaints on the back as the result of vibrations throughout the body and or the use of heavy equipment during work. Furthermore, WBV has significant correlation to low back pain due to mechanical shock. [14]. The study mentioned that mechanical shock contributes to exceeding daily exposure limit, which recommended by the European Union Directive, thus increasing the risk of low back pain.

Looking at the effect of WBV on workers, and the fact that no vibration measurement has been delivered in the urea granulation screen unit yet, it is significant to conduct the study. The aim is to measure the vibration of urea granulation screen and its exposure towards labors who work in the area. This research is important to answer the question of whether the vibration exposure conditions are still safe for workers or are already dangerous and efforts must be made so that the existing conditions are improved to get safer conditions for workers. By knowing the actual conditions, it is good for workers to avoid harm and good for the company because if workers stay healthy it will improve both worker performance and company performance.

METHOD

This study involved labors who own a duty station at the UGSU. The labors (or the participant of this study) consist of factory operators, mechanical maintenance personnel, electrical maintenance personnel, instrument maintenance, and inspectors. The population of the participants is 120 persons. To ease the data collection and processing, this study employs sampling size which introduced by Roscoe [15]. Roscoe [15] mentioned that 30 data (sampling size) are appropriate for most studies which own a population size greater than 30 and less than 500. Therefore, the total respondents are 30 labors. Furthermore, the 30 participants were selected through random sampling, regardless the demographic areas, thus given the opportunity for everyone to involve in this study.

Data collection was conducted in three steps as follow:

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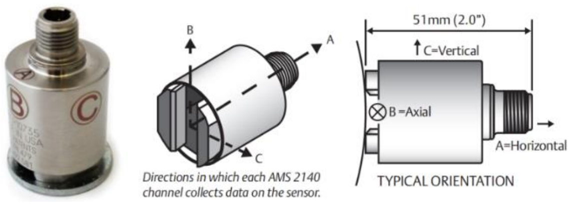


Figure 3. Triaxial Accelerometer with Integral Magnet

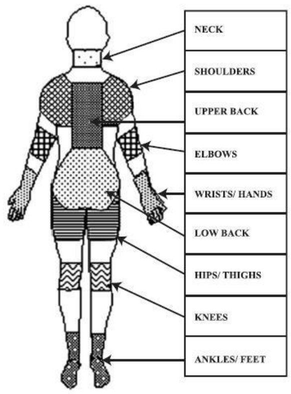


Figure 4. Skeletal Muscles on Nordic Body Map [16]

1. Vibrations measurement at the factory floor of urea granulation screen unit.

   Before conducting the vibrations measurement, firstly the study drew the measurement point based on the factory layout marking line. The aim is to determine the safe and the hazard position based on the measurement result. The study appointed 28 measurement points and the measurement was conducted using a Triaxial Accelerometer with Integral Magnet (Figure 3). Further, the measurement results will be reviewed based on the highest vibration data and lowest vibration data following ISO 2361-1:1997.

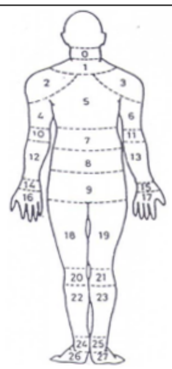
2. Distributing the Nordic Body Map (NBM) questionnaires.

   Nordic Body Map represents skeletal muscles (Figure 4) which potentially were exposed by the vibrations. This study employs NBM questionnaires (Figure 5) to determine the level of musculoskeletal complaints experienced by the labors within the past 12 months as a result of vibration exposure in the urea granulation screen unit. The questionnaires were distributed using google form to perform less-paper work and to easily collect the data in excel sheet thus ready for further measurement.

3. Vibrations exposure measurement on labors body part.

   The study conducted vibration exposure measurement to obtain the level of exposure on labors body part while performing their tasks in the urea granulation screen unit (Figure 6). The exposure measurement was divided into three parts of the body: upper body, midsection, and lower body. According to RULA (Rapid Upper Limb Assessment) and REBA (Rapid Entire Body Assessment), upper body consists of neck, shoulder, back and upper arm; midsection consists of waist, hip, bottom, elbow, lower arm; lower body consists of tight, knee, leg, ankle, and foot [17].

Figure 6. Vibration Exposure Measurement on Labors Body

Muscoloskeletal	Scoring				NBM	Muscoloskeletal	Scoring			
	1	2	3	4			1	2	3	4
0. Upper arm				√		1. Lower neck				√
2. Left shoulder			√			3. Right shoulder			√	
4. Upper left arm			√			5. Bacl				√
6. Upper right arm			√			7. Waist				√
8. Hip			√			9. Bottom		√		
10. Left elbow			√			11. Right elbow				√
12. Lower left arm	√					13. Lower right arm	√			
14. Left wrist				√		15. Right wrist				√
16. Left hand			√			17. Right hand			√	
18. Left thigh		√				19. Right thigh		√		
20. Left knee		√				21. Right knee		√		
22. Left leg			√			23. Right leg			√	
24. Left angkle		√				25. Right angkle		√		
26. Left foot		√				27. Right foot		√		
Sum score Left						Sum score Right				
Individual sum score MSDs = 35 + 40 = 75										

Definition of NBM score

Degree of pain	Score	Degree of pain	Score
No pain	1	Pain	3
Rather pain	2	Very pain	4

NBM Recommendation

Score	Invidual Sum Score	Degree of Risk	Recommendation
1	28 - 49	Low	Does not need improvement
2	50 - 70	Medium	Maybe need improvement
3	71 - 90	High	Need improvement
4	92 -112	Very high	Need improvement as soon as possible

Figure 5. Nordic Body Map (NBM) questionnaire

RESULT AND DISCUSSION

Vibration Exposure on the Factory Floor

Before measuring the vibrations on the factory floor, this study first developed a measurement layout and set the measurement points on the floor where the urea granulation screen unit existed. Figure 7 shows the factory layout and the 28 measurement points which drawn according to the factory marking line, each point has 2 m in distances. Figure 8 also shows vibrations values of each measurement points.

The measurement results show that the highest vibration value occurred at the measurement point No. 8 with the value 1.630 m/s2. While, the lowest vibration value occurred at the measurement point No. 27 with the value 0.298 m/s2. Based on careful observation, the highest value might occur due to its position between the (two) urea granulation screens, whilst the lowest value might occur as a consequence of its position on the urea screen drive, which is rigid.

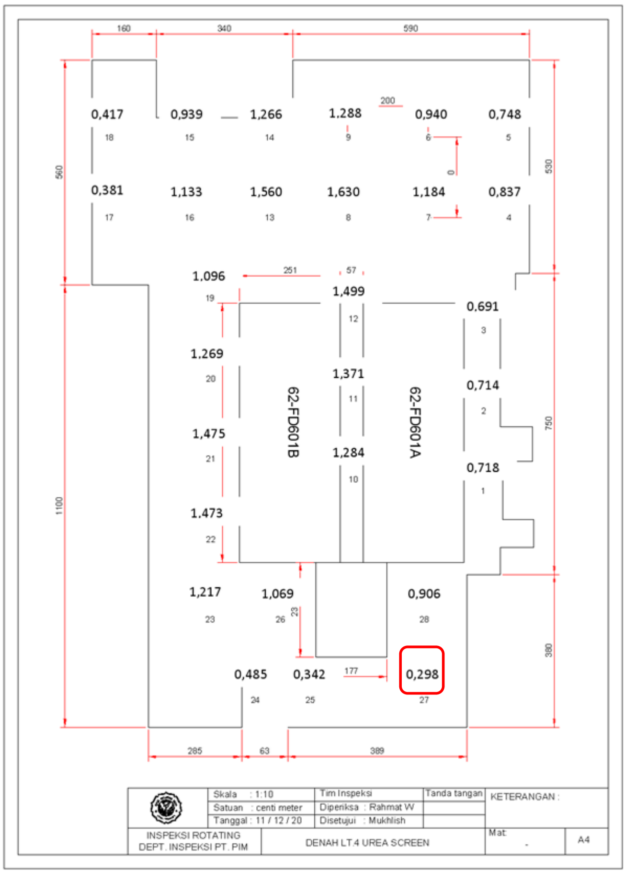


Figure 7. Vibration Measurement Points on the Factory

Figure 8. Vibration Measurement on the Factory Floor

According to ISO 2631-1:1997 [6] safety zone (Figure 1), the highest vibration value that occurred is categorized as likely health risk zone and resulted uncomfortable reaction to the workers (Table 1). However, ISO 2631-1:1997 [6] stated that the workers reaction towards various magnitudes significantly depends on the duration and type of activities that will be accomplished, and the ability of workers to perceive the vibration. Previous study that used ISO 2631-1:1997 to analyze the discomfort reaction mentioned that the interaction between the static object and the moving object may significantly influence the comfort level of a typical vibration condition [18].

Nordic Body Map

The purpose of distributing NBM questionnaire is to determine the level of complaints felt by labors on their body parts as a result of vibrations exposure while working on the factory floor of the urea granulation screen unit. There were 30 labors who fulfilled the questionnaire. The 30 labors or participants were the representative of 120 labors who worked at the urea granulation screen unit and was selected through simple random sampling technique.

Upon collected the NBM questionnaire, this study analyze demographic data of the respondents which according to Erwan et al [19], might include age, sex, years of career, and duty station, and could be added with weight, height based on the need of the analysis. Table 1 shows the demographic data which was calculated using statistic descriptive. The highest data from each category is highlighted in yellow, which might correlate to one of the results of the study. Table 2 shows that most participants are 22-27 years, having 73-80 kg in weight, 166-168 cm in height, and have been working in the company for 1-6 years.

Table 2. Respondent Profiles

Description	Classification	Total (people)
Age (years)	22-27	14
	28-33	7
	34-39	4
	40-45	4
	46-51	0
	52-57	1
Weight (kg)	49-56	3
	57-64	7
	65-72	8
	73-80	9
	81-88	2
	89-96	1
Height (cm)	163-165	6
	166-168	10
	169-171	6
	172-174	5
	175-177	1
	178-180	2
Years of experience	1-6	15
	7-12	4
	13-18	10
	19-24	0
	25-30	0
	31-36	1

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Table 3. Nordic Body Map (NBM) Questionnaire Results

Respondent *i*	**0. Upper neck**	**1. Lower neck**	**2. Left shoulder**	**3. Right shoulder**	**4. Upper left arm**	**5. Back**	**6. Upper right arm**	**7. Waist**	**8. Hip**	**9. Bottom**	**10. Left elbow**	**11. Right elbow**	**12. Lower left arm**	**13. Lower right arm**	**14. Left wrist**	**15. Right wrist**	**16. Left hand**	**17. Right hand**	**18. Left thigh**	**19. Right thigh**	**20. Left knee**	**21. Right knee**	**22. Left leg**	**23. Right leg**	**24. Left ankle**	**25. Right ankle**	**26. Left foot**	**27. Right foot**	**Total individual score**
1	2	2	2	2	2	2	2	3	3	3	3	3	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	69
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	28
3	1	1	1	1	1	2	1	2	2	2	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3	2	2	43
4	1	1	1	1	1	1	1	2	2	3	2	2	2	2	1	1	1	1	3	3	3	3	3	3	4	4	4	4	60
5	1	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	3	3	3	3	4	4	4	4	4	4	73
6	2	2	3	3	3	3	3	3	3	3	2	2	2	2	2	3	2	2	3	3	3	3	4	4	4	4	4	4	81
7	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	2	2	64
8	3	3	2	3	3	3	3	3	3	3	4	4	4	4	3	3	4	4	3	3	3	3	3	3	3	3	3	3	89
9	3	3	3	3	3	4	3	4	4	3	4	4	3	3	3	3	3	3	3	3	4	4	3	3	3	3	4	4	93
10	1	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	67
11	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	84
12	1	1	2	2	2	2	2	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	57
13	3	3	3	3	3	4	3	4	4	4	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	98
14	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	62
15	3	3	3	3	3	4	3	4	4	4	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	98
16	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	56
17	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	28
18	3	2	3	3	2	2	3	2	3	3	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	72
19	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	85
20	2	2	3	3	4	4	4	3	3	3	3	3	4	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	96
21	3	2	3	3	2	4	3	3	3	3	4	4	2	2	3	3	3	3	4	4	4	4	3	3	3	3	3	3	87
22	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	28
23	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	84
24	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	4	4	4	4	4	4	108
25	2	2	2	2	2	2	2	3	3	3	2	2	2	2	1	1	2	2	2	2	2	2	2	2	3	3	3	3	61
26	1	3	3	3	2	3	2	2	2	1	2	2	1	1	1	1	2	2	1	1	2	2	1	1	1	1	1	1	46
27	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	84
28	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	89
29	2	2	2	2	2	2	2	3	3	3	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	69
30	2	2	3	3	3	2	3	3	3	3	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	69
Σ	63	65	71	72	69	**76**	72	79	**82**	81	75	75	72	71	68	69	72	72	82	82	85	85	83	83	86	87	85	86	-
$\bar{X}$	2	2	2	2	2	3	2	3	3	3	3	3	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	-
Individual Score Average Value																													**71.6**

Next, data obtained from the NBM survey is shown in Table 3, which provides the value of individual response towards the part of the body being assessed. The value "1" represents "no pain", "2" represents "rather pain", "3" represents "pain", and "4" represents "very pain". The results show that most of the respondents (25 person) provide the value of response at above 50 point, while 5 of them provide lower value of response. The individual scoring is shown in Table 4.

Table 4. Nordic Body Map (NBM) Scoring

Individual Sum Score	Total Respondent	Degree of Pain	Improvement
28-49	5	Low	Doesn't need
50-70	8	Medium	Maybe need
71-91	**12**	**High**	**Need**
92-112	5	Very high	Need as soon as possible

Furthermore, the NBM questionnaire results, which is shown in Table 3, reveal that the more the vibrations lead to the upper body, the lower the vibration exposure is felt. Conversely, the more it leads to the lower body, the greater the exposure to vibrations or complaints are felt. This condition reinforces the assumption that the lower body is the foundation when experiencing vibrations exposure. The NBM show that the average individual score of musculoskeletal complaints experienced by labors is 71.6 point. According to the total score of Nordic Body Map (Figure 5), the sore is categorized into high degree of risk and requires improvement in the work system. Moreover, the overall NBM individual score is analyzed using NBM scoring and is shown in Table 4. There are 12 respondents in the level of high degree of risk and the other level remain below 10 respondents.

Based on careful observation, the degree of pain experienced by labors indicates a relationship between the vibrations generated by the machines on the factory floor and the musculoskeletal complaints experienced by labors while working in the urea granulation screen unit. The real scenario showed that labors need to maintain their posture stability while performing any tasks, with or without carrying any loads.

Previous study by Hasanuddin et al [20] that analyze the biomechanical posture assessment using NBM survey stated that labors need a forceful performance and an improvement of the work system at the same time to reduce risk and injury while performing their tasks and duty. In other cases which labors experience carrying heavy loads regularly, the musculoskeletal complaints may leads to severe back pain [21]. Therefore, Kroemer [22] suggests industries to consider body dimensions to allow safe limit for carrying out loads. Several methods for example, using the spinal shrinkage principles to determine maximum load weighting could be lifted by labors [23]; using biomechanics method to predict load handling capability [24]; using automatic systems such as a wireless and ambulatory posture monitoring system which monitors movements and detects changes of postures [25]; using NASA-TLX which combining the measurement of mental demand, physical demand, temporal demand, performance, effort, and frustration rate [26]; also establishing safety physical working environment followed by reliable working procedure and working time to minimize psychology effect experienced by the workers while performing their tasks [27].

Vibration Exposure on Labors

The next step is measuring the vibration exposure on labors body part to obtain the level of exposure experienced by labors. To easily assess the exposure, the labors body parts are divided into three sections: upper body, midsection and lower body, which follow the RULA and REBA rules. Each section is represented by one skeletal muscles and was selected based on the highest NMB values for each section. Upper body is represented by "back" (76), midsection is represented by "hip" (82), and lower body is represented by "ankle" (87). Further, all of the 30 respondents were placed in the highest vibration measurement point (No. 8) to measure the vibration exposure on their body parts (or skeletal muscles). The vibration exposure measurement is shown in Table 5.

Generally, the result of the vibration exposure reveals that the vertical axis shows higher value compare to the axial and horizontal axis. It applies on back, hip and ankle sections. Looking at each skeletal muscle, ankle shows the highest value: axial (1.963 m/s^2), horizontal (1.291 m/s^2) and vertical (3.437 m/s^2). According to ISO 2361-1:1997 [6], a vibration exposure

Table 5. Vibration Exposure Measurement on Labors Body Parts

Resp.	Weight (kg)	Height (cm)	Vibration Exposure (m/s^2)								
			Back			Hip			Ankle		
			A	H	V	A	H	V	A	H	V
1	76	168	0.392	0.832	0.736	0.146	0.435	1.272	0.825	0.656	3.193
2	49	170	0.823	0.888	1.320	0.743	0.743	1.186	**1.963**	0.932	2.153
3	70	173	0.352	0.723	2.084	0.639	0.639	1.871	1.084	0.937	2.956
4	60	179	0.978	1.042	0.877	0.705	0.705	0.461	0.906	0.327	2.611
5	79	173	0.826	0.605	1.681	0.763	0.763	1.395	0.691	**1.291**	1.598
6	73	165	0.441	0.620	1.976	0.274	0.982	2.353	0.453	1.004	3.233
7	60	165	0.806	0.747	1.844	0.231	0.745	1.783	1.022	1.016	3.313
8	50	167	0.239	0.706	1.026	0.229	0.947	1.731	0.866	0.744	3.061
9	54	167	0.778	1.140	0.863	0.501	0.585	1.636	1.066	0.713	1.818
10	76	168	0.703	0.884	1.460	0.448	0.660	1.608	1.465	1.278	3.245
11	69	169	0.542	0.944	1.703	0.247	0.560	2.427	1.404	1.159	1.603
12	65	166	0.435	0.803	1.425	0.172	0.894	2.427	1.096	0.467	3.316
13	76	168	0.558	0.595	1.357	0.209	0.538	2.427	0.522	0.724	**3.437**
14	94	170	0.500	0.379	0.827	0.472	0.769	2.427	1.622	0.880	2.715
15	88	168	0.361	0.554	0.594	0.764	0.603	2.427	0.623	0.856	1.655
16	80	165	0.384	0.830	0.398	0.788	0.702	2.345	0.598	0.887	1.599
17	62	167	0.689	0.691	1.689	0.345	0.630	2.834	1.751	1.129	1.436
18	60	174	0.843	1.280	1.580	0.547	0.670	1.701	1.394	1.185	3.178
19	70	170	0.381	0.609	0.746	0.125	0.523	1.245	0.823	0.657	3.203
20	69	169	0.268	0.590	1.123	0.179	0.936	1.723	0.824	0.715	3.231
21	74	165	0.698	0.754	0.922	0.401	0.475	1.247	1.141	0.692	1.911
22	70	176	0.836	0.637	1.673	0.745	1.376	1.421	0.651	1.181	1.576
23	69	169	0.367	1.035	1.966	0.619	0.956	2.345	0.433	1.222	3.245
24	58	172	0.332	0.405	2.074	0.251	0.543	1.861	1.074	0.932	2.826
25	69	167	0.706	0.876	1.934	0.805	0.739	2.001	0.922	1.046	3.234
26	60	173	0.875	0.635	0.857	0.364	0.876	0.371	0.856	0.337	2.531
27	82	179	0.498	0.912	0.893	0.745	0.613	1.356	1.598	0.870	2.615
28	57	165	0.813	0.830	1.220	0.199	0.615	1.184	1.863	0.942	2.174
29	75	168	0.467	0.691	1.109	0.214	0.498	1.547	0.567	0.699	2.987
30	74	163	0.457	1.280	1.356	0.788	0.789	0.987	0.969	0.541	3.432

A = Axial, H = Horizontal, V = Vertical

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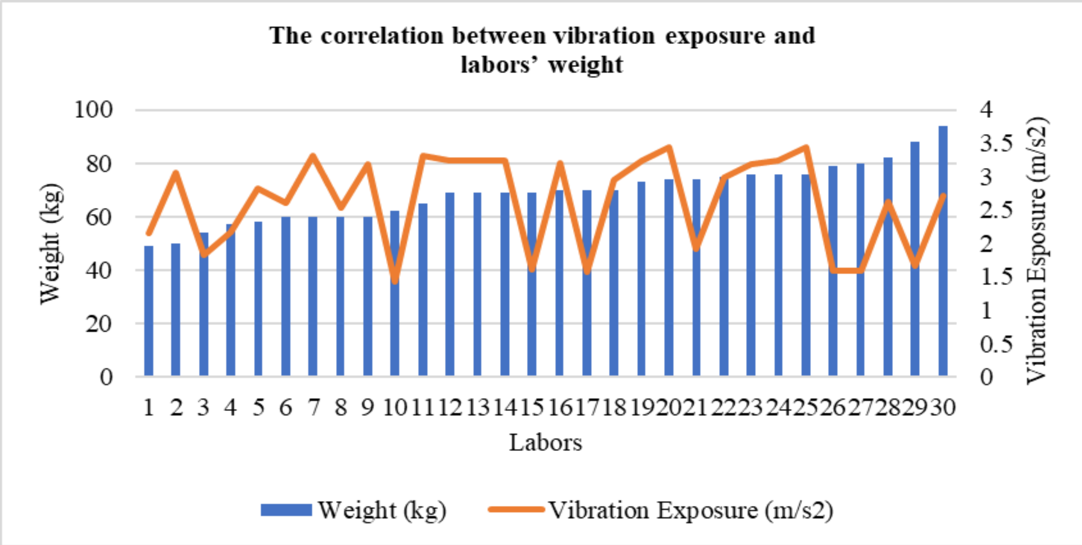

Figure 9. The Correlation between Vibration Exposure Value and Labors' Weight

value above 2 m/s^2 will create extremely uncomfortable effect on labors. The condition is align with the classification of the NBM results shown in Table 3, wherein the average labor experience a high degree of pain due to the vibration exposure.

However, the direction of the vibration exposure experienced by the worker is inversely related to the direction of the resulting vibration. The vibration exposure is felt vertically, while the vibrations generated by the urea granulation screen unit occur horizontally. The condition states that the direction patterns of vibrations caused by machines and or work equipment are not always directly proportional to the model or direction of vibration exposure experienced by labors. The vertical vibration exposure experienced by labors indicates a relationship between the model or direction of vibration exposure and the knees on which the labors rely on while performing their work in the vibration area.

Moreover, this study correlates the results of the vibration exposure in the ankle muscle-vertical axis with labors' weight and height, which are illustrated in Figure 9 and Figure 10. The objective is simply to look at how the respondents' weight and height correlate with the vibration exposure results. No statistical analysis were performed.

Figure 9 illustrates nonlinear pattern between respondents' weight and their vibration exposure value. This mean, in general, respondents' weight does not necessarily exposed to high or low vibrations. A respondent with the lightest weight as of 49 kg experienced 2.153 m/s^2 vibration exposure value, meanwhile, the heaviest respondent with 94 kg experienced 2.715 m/s^2 vibration exposure value. The highest vibration exposure value as of 3.437 m/s^2 was experienced by a respondent with 76 kg in weight. The results of this study shows similar circumstance with previous studies by Blood et al [28] who "…demonstrated a casual observation to significant negative association between body mass and vibration exposure." However, another study mentioned that "body mass is significantly associated with quad bike induced WBV in a group of New Zealand rural workers" [29]. Different results may occur and are influenced by different research objects and environment conditions.

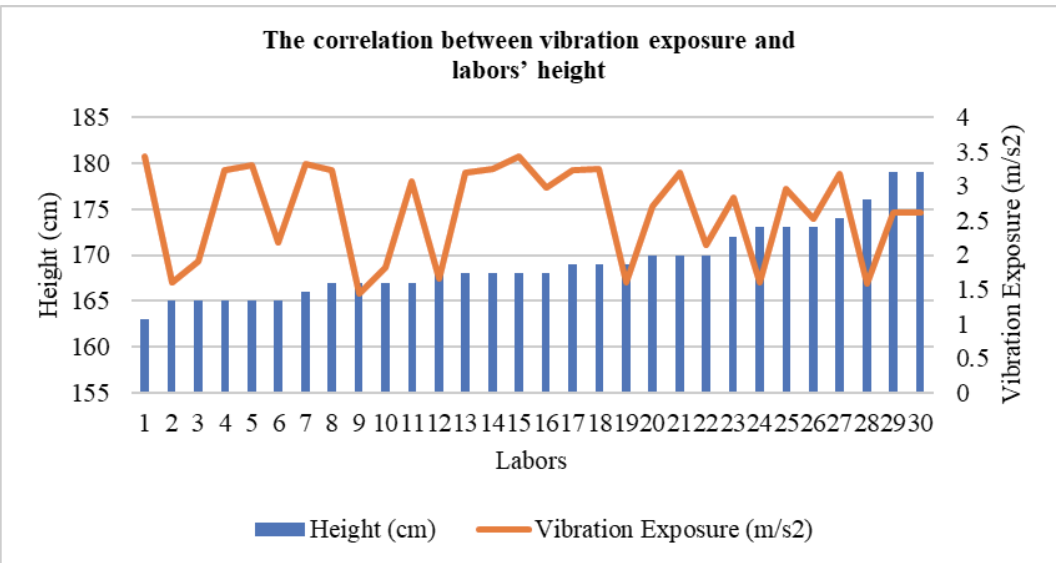

Figure 10. The Correlation between Vibration Exposure Value and Labors' Height

Furthermore, Figure 10 shows similar circumstance with Figure 9. The graph shows nonlinear correlation between respondents' height with their vibration exposure value. The shortest respondent involved in this study with 163 cm in height experienced 3.432 m/s^2. Meanwhile, the tallest respondent involved in this study with 179 cm in height experienced 2.611 m/s^2. The highest vibration exposure value as of 3.437 m/s^2 was experienced by a respondent with 168 cm in height. This circumstance reveals that labors with lower or higher height do not necessarily experience high vibration exposure.

Study Recommendation

According to the results of both vibration exposure measurements and musculoskeletal complaints obtained from NBM questionnaire, the working systems are suggested to be improved to reduce risks and injury in the urea granulation screen unit.

The following recommendations have been discussed within the labors' supervisors and carefully considered to allow industry to take immediate actions towards the labors and the working conditions.

1. Evaluating the current labors working shift implemented in the urea granulation screen unit.
   This recommendation correlate with minimizing risks related to occupational diseases. If a task in the urea granulation screen unit needs to be performed longer, it is necessary to create a replacement group or work shift arrangement.
2. Conducting a regular survey using the Nordic Body Map (NBM) questionnaire.
   This recommendation aims to early determine the effect of vibrations exposure to labors. Method could be adjusted or changed following monitoring and evaluation activities of appropriate method to be used.
3. Evaluate the needs of additional vibration damper on the factory floor of urea granulation screen unit to reduce the vibration sources and its effect to labors.
   This recommendation aims to provide safety and comfortable physical working environment for labors as a result of vibration exposure in the urea granulation screen unit.

CONCLUSIONS

This study aims to analyze vibration exposure measurements on the factory floor and labors of urea granulation screen unit of PT Pupuk Iskandar Muda (PIM) Aceh. Vibrations measurement was conducted by determining measurement points and measuring the magnitude of the vibration at each point using the Triaxial Accelerometer with Integral Magnet. From the measurement results, there is one point on the factory floor that produces high vibrations with a horizontal direction of 1.630 m/s2. At this point, labors were placed to measure the exposure to the vibrations they feel while in the area. Vibration exposure measurements were carried out on the parts of the body that had been determined based on the Nordic concept and the results of the Nordic Body Map (NBM) questionnaire. The measurements were focused on shoulders, waist and knees.

Based on the vibrations measurement results on the factory floor, vibrations exposure measurement to labors, and NBM questionnaire, this study concludes that the overall vibrations generated pose a risk to occupational safety and health in the urea granulation screen unit. According to ISO 2631-1:1997, the vibrations value is categorized as likely health risk zone and the effect which measured using NBM questionnaire might cause a high degree of pain. To minimize occupational accidents and diseases, it is necessary to establish a safety and comfortable working procedures in the urea granulation screen unit. Moreover, future study is needed to extend the analysis of this study, which will include statistical analysis and hypothesis.

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