VIBRATION EXPOSURE ASSESSMENT OF SAWMILLING OPERATIONS USING HAND-ARM-VIBRATION EXPOSURE ANALYSIS

Abiola Olufemi Ajayeoba*

Department of Mechanical Engineering, Ladoke Akintola University of Technology,
Ogbomoso, Nigeria.

Adewoye Alade Olanipekun

Department of Civil & Environmental Engineering,
Bells University of Technology, Ota, Nigeria.

Oluwaseun Oluwagbemiga Ojo

Department of Mechanical Engineering, Adeleke University, Ede, Nigeria.

Oluremilekun Ropo Oyetunji

Department of Mechanical Engineering, Ladoke Akintola University of Technology,
Ogbomoso, Nigeria.

Wasiu Adewale Raheem

Department of Systems Engineering, University of Lagos, Lagos, Nigeria.

*Corresponding Author

ABSTRACT

Sawmills are workshops where woods are turned into finished products through the use of industrial machines and sophisticated implements. However, sawmills workers become exposed to awkward working postures and vibration from the machines they work with every day, leading to Raynaud's disease and muscle damage. Therefore, this study investigated the effects of the sawmill-machine-generated vibrations on the musculoskeletal disorders of sawmill workers in the Southwestern part of Nigeria using hand-arm-vibration analysis. Sawmills that were fully functional in Osun, Oyo, Ondo, Ekiti, Lagos, and the Ogun States of the Southwestern part of Nigeria were used for this study. After reconnaissance visits, four sawmills operating at full capacities in two cities of each State (i.e. 2 sawmills per city) were eventually chosen and used for data collection, thereby making a total of 24 selected sawmills. Circular Machines (CMs), Planer Machines (PMs), and Band-saw Machines (BMs) which are the commonly used machines by sawmills were considered for analysis, while two machines each of CMs, PMs, and BMs were also selected in each sawmill,

making a total of forty-eight (48) machines each of CMs, PMs, and BMs. Vibration level data were collected in m/s^2 using Extech VB 450 vibration meter in triplicates, and the corresponding exposure time was obtained. The vibration acceleration magnitude and exposure time data were collected for six days (Monday to Saturday). The daily Exposure Action Value (EAV), Exposure Limit Value (ELV), and exposure points were then determined for each daily operations of the considered sawmilling machines.

The average Wood Vibration Acceleration Magnitude (WVAM) ranges in CMs and PMs in each sawmill were $34.2 - 104.1 m/s^2$ and $104.1 - 173.7 m/s^2$, respectively, while the average Machine Vibration Acceleration Magnitude (MVAM) range in BMs in each sawmill was $10.7 - 48.0 m/s^2$. Also, the minimum and maximum WVAMs in CMs and PMs and MVAMs in BMs in all sawmills were 32.2/106.7, 99.1/187, and 10.2/49.3 m/s^2 , respectively.

The Analysis of Variance (ANOVA) results revealed that there are statistically significant differences in the WVAMs of CMs and PMs and MVAMs of BMs in all the six states. The vibration exposure analysis showed that none of the average values falls within the limit and action values, because the values were well above the exposure limit value of 400 points. The study concluded that the contributing factors responsible for the high values of the exposure analysis experienced by workers were obsolete machines, lack of proper working tools, worker's carelessness, and general negligence by workers.

Keywords: Exposure, Magnitude, Musculoskeletal Disorders, Sawmills, Vibrations.

Cite this Article: Abiola Olufemi Ajayeoba, Adewoye Alade Olanipekun, Oluwaseun Oluwagbemiga Ojo, Oluremilekun Ropo Oyetunji and Wasiu Adewale Raheem, Vibration Exposure Assessment of Sawmilling Operations using Hand–ARM–Vibration Exposure Analysis. *International Journal of Mechanical Engineering and Technology*. 11(12), 2020, pp. 33-44.

<https://iaeme.com/Home/issue/IJMET?Volume=11&Issue=12>

1. INTRODUCTION

Griffin [1] stated that forests occupy four billion hectares of the earth's land surface and 3.5 billion m^3 of their mature stock were removed from the forests in 2005. North Korea, Asia, and Western Europe are the chief producers of the world's wood demand [2]. Wolfgang and Burgess-Limerick [3] observed that the demand for sawn timber and wood products is rising globally and this trend is expected to continue. According to the Bureau of Labour and Statistics, sawmills are workshops where the woods obtained from the forests are turned into finished products through the use of industrial machines and sophisticated implements [4]. Furthermore, Zhao and Schindler argued that whenever these machines are used, vibrations become inevitable especially for the workers who operate them and work in sawmills [5].

According to Zinck [6], thousands of workers become exposed daily to highly repetitive, awkward postures and forceful exertions or vibrations while doing their jobs. These factors all contribute to the rising costs of claims for musculoskeletal disorders such as low back pain and carpal tunnel syndrome [7]. Also, Seidel [8] and Bovenzi *et al.*, [9] explained that in industrial environments especially sawmills, workers often become exposed to varying levels of two different types of vibration, which are the whole-body vibration and hand-arm vibration. Furthermore, Mansfield [10] submitted that the whole-body vibrations are transmitted to all parts of the body while operating equipment, tools, and vehicles which eventually have different effects on the tissues and joints.

The hand-arm vibration on the other hand according to European Union Parliament, is transmitted to the hands and arms when operating vibrating tools (chain saws and hand grinders) and vibrating controls (steering wheels and levers) [11]. The International Organization for Standardization (ISO) [12] emphasized that exposure to hand-arm vibrations over several years can result in permanent physical damage commonly known as Raynaud's disease or White finger syndrome and the vibration can damage the muscles or joints of the wrist and elbow. Wilder [13] also confirmed that early symptoms of Raynaud's disease include pain, tingling, numbness or loss of feeling and control in the fingers, followed by blanching of the fingers caused by damage to the arteries and nerves in the hands. After a time, these symptoms may be irreversible. According to the Federal Environmental Protection Agency [14] and the Environmental Protection Authority [15], vibrations occurring between 8 Hz - 1000 Hz are of concern when measuring hand-arm vibration, with frequencies in the range of 25 Hz - 150 Hz associated with the development of Raynaud's disease. Also, Punnett *et al.*, [16] said that the whole-body vibration is transmitted through the feet (standing on a vibrating surface), buttocks, or back (through the seat or backrest). Long term exposure can even result in serious physical damage to the low back or it can disturb the nervous system, while vibration levels occurring between 1 Hz - 80 Hz are of most concern when measuring whole-body vibration [11; 17 and 18].

The Exposure Action Value (EAV) is a daily amount of vibration exposure above which workers are required to take action to control exposure while the Exposure Limit Value (ELV) is the maximum amount of vibration workers may be exposed per day. For hand-arm vibration, the EAV is a daily exposure of $2.5 \text{ m/s}^2 \text{ A}(8)$ and ELV is a daily exposure of $5 \text{ m/s}^2 \text{ A}(8)$. The EAV is equivalent to 100 points and ELV is equivalent to 400 points. However, a total exposure point value ≥ 100 indicates an increased risk to employees, thus, there should be control to reduce the risk [19]. Also, total exposure point value ≥ 400 shows that the workers have exceeded the safe limits and they are exposed to notable risk which is capable of leading to hand-arm vibration syndrome and immediate control should be implemented to reduce vibration magnitude exposure [19]. Consequently, this study sought to assess the vibration exposure of sawmilling workers using the hand-arm-vibration exposure analysis method to expose the threat of vibration on the operators and to recommend solutions to mitigate the effects of the vibration on the sawmill workers.

2. MATERIALS, METHODS, AND DATA COLLECTION

This study was carried out in Osun, Oyo, Ondo, Ekiti, Lagos, and the Ogun States of the Southwestern part of Nigeria where reconnaissance surveys were first carried out to select sawmills that were fully operational and thus, fit for this study. Consequently, two fully operational sawmills in two cities (2 sawmills per city) of each state were eventually selected and used for data collection, making a total of 24 sawmills visited. CMs, PMs, and BMs which are the commonest types of machinery in the sawmilling industries were considered. Two machines each of CMs, PMs, and BMs were considered in each sawmill selected, making a total of forty-eight (48) machines each of CMs, PMs and BMs.

Vibration level data were collected using Extech VB 450 vibration meter and all stabilized measurements were taken three times at different intervals. Data were also collected between the working hours of 7 am and 7 pm every day, for six days (Monday to Saturday). They usually started work early enough depending on the availability of electricity supply and whenever electricity was unavailable, the workers usually spent their time cleaning, arranging, and preparing the logs or planks for work before putting on the generator.

The sensor (housed in a magnetic adapter) was placed on the wood (where the operators held the wood) for CMs and PMs, while the sensor was placed on the machine (where the

operators held the machine) for BMs. This was done to measure the exact vibration magnitude transmitted to the hand/arm as depicted in the HAV analysis. The magnitude (acceleration (Peak value) in m/s^2) of the wood/machines and the exposure time were taken and compared with the Ready-Reckoner shown in Fig. 1. The daily EAV, ELV, and exposure points were then determined for each daily magnitude of the wood/machines using the HAV calculator [19].

3. RESULTS AND DISCUSSION

3.1. Vibration Data Analysis

The average Vibration Acceleration Magnitudes (VAM) before and after the break with their overall average are shown in Table 1, while the minimum and maximum VAM are shown in Table 2. Table 1 showed that the overall Average Wood Vibration Acceleration Magnitude (WVAM) in CMs and PMs during operations for each sawmill ranged from 34.2 to 104.1 m/s^2 and 104.1 to 173.7 m/s^2 , respectively, while the Average Machine Vibration Acceleration Magnitude (MVAM) in BMs during operations for each sawmill ranged from 10.7 to 48.0 m/s^2 . Also, the minimum and maximum WVAMs in CMs and PMs, and MVAMs in BMs for all sawmills are 32.2/106.7 m/s^2 , 99.1/187 m/s^2 , and 10.2/49.3 m/s^2 , respectively. Consequently, from Table 1, the least average WVAMs for all CMs (34.2 m/s^2 (ON11)) and PMs (104.1 m/s^2 (ON42)) and average MVAMs for BMs (10.9 m/s^2 (OY41)) are more than the daily EAV (i.e. 2.5 m/s^2 A (8)) and ELV (i.e. 5 m/s^2 A (8)).

	15 m	30 m	45 m	1 h	1.5h	2 h	2.5 h	3 h	3.5 h	4 h	4.5h	5 h	5.5 h	6 h	6.5h	7 h	7.5h	8 h	10 h
40	801																		
30	450	901	1351																
25	313	626	938	1251															
20	200	400	600	801	1201														
15	181	361	542	723	1084	1445													
18	162	324	486	649	973	1297													
17	145	289	434	578	868	1157	1446												
16	128	256	384	512	769	1025	1281												
15	113	225	338	450	676	901	1126	1351											
14	96	196	294	392	588	785	981	1177	1373										
13	85	169	254	338	507	677	846	1015	1184	1350									
12	72	144	216	288	432	576	721	865	1009	1153	1297	1441							
11	61	120	182	242	363	484	605	725	848	969	1090	1211	1332	1450					
10.5	55	110	166	221	331	441	552	662	772	883	993	1103	1214	1324	1434				
10	50	100	150	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400			
9.5	45	90	135	181	271	361	452	542	632	723	813	903	994	1084	1174	1265	1355	1445	
9	41	81	122	162	243	324	405	486	567	649	730	811	892	973	1054	1135	1216	1297	
8.5	36	72	108	145	217	289	362	434	506	578	651	723	795	868	940	1012	1087	1157	1446
8	32	64	96	130	192	256	320	384	448	512	576	641	705	769	833	897	961	1025	1281
7.5	28	56	84	113	169	225	281	338	394	450	507	563	619	676	732	788	844	901	1126
7	25	49	75	98	147	196	245	294	343	392	441	490	539	588	637	686	736	785	981
6.5	21	42	63	85	127	169	211	254	296	338	381	423	465	507	550	592	634	677	846
6	18	36	54	72	108	144	180	216	252	288	324	360	396	432	468	504	540	576	723
5.5	15	30	45	61	91	121	151	182	212	242	272	303	333	363	394	424	454	484	605
5	13	25	38	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	500
4.5	10	20	30	41	61	81	101	122	142	162	182	203	223	243	263	284	304	324	405
4	8	16	24	32	48	64	80	96	112	128	144	160	176	192	208	224	240	256	320
3.5	6	12	18	25	37	49	61	74	86	98	110	123	135	147	159	172	184	196	245
3	5	9	14	18	27	36	45	54	63	72	81	90	99	108	117	126	135	144	180
2.5	3	6	9	12	18	25	31	38	44	50	56	63	69	75	81	88	94	100	125

Figure 1 Ready-Reckoner Chart

The ANOVA results in Tables 3, 4, and 5 showed that there are statistically significant differences within the VAMs among the six states as their P values are < 0.05 for the Wood Vibration Acceleration Magnitude (WVAM) in CM and PM and Machine Vibration Acceleration Magnitudes (MVAM) in BM. However, the tables also reflected that there are no statistically significant differences within all the samples taken, while the interaction within the samples and the machines in the six States as their P values are > 0.05 . But

comparing the wood acceleration magnitude for CM, PM, and BM acceleration magnitude levels, the ANOVA analysis in Table 6 revealed that there are statistically significant differences within the vibration acceleration magnitudes among the six States, within all the samples taken, within the interaction of the samples and the machines in the six States as their P values are < 0.05 .

Considering the wood acceleration magnitude level ANOVA analysis for CMs and PMs as shown in Tables 7 and 8, the results showed that there are statistically significant differences within the vibration acceleration magnitudes among the six States as their P values are < 0.05 , but there are no statistically significant differences within all the samples taken, the interaction within the samples and the machines in the six States as their P values are > 0.05 . Also in Table 9, BM acceleration magnitude ANOVA analysis for CMs and PMs showed statistically that, there are no significant differences within the vibration acceleration magnitudes among the six states, within all the samples taken and the interaction within the samples and the machines in the six states as their P values are > 0.05 .

Table 1 Average WVAMs in CMs and PMs and MVAMs in BMs Operations

State	Sawmill	WVAM _{avg} on CMs (m/s ²)			WVAM _{avg} on PMs (m/s ²)			MVAM _{avg} on BMs(m/s ²)		
		BB	AB	overall	BB	AB	Overall	BB	AB	Overall
OS	SM1	96.4	92.1	94.3	161.9	160.8	161.4	13.9	14.3	14.1
	SM2	83.7	81.8	82.8	143.3	146.2	144.8	15.5	15.8	15.7
	SM3	78.2	82.6	80.4	138.5	136.7	137.6	37.2	38.5	37.9
	SM4	82.0	80.8	81.4	135.1	133.6	134.4	25.1	25.5	25.3
	SM5	103.8	103.7	103.8	179.5	167.8	173.7	17.8	17.7	17.8
	SM6	82.6	81.2	81.9	162.9	161.8	162.4	19.4	19.8	19.6
	SM7	61.3	60.0	60.7	165.9	163.3	164.6	17.3	19.4	18.4
	SM8	66.4	69.0	67.7	142.4	142.7	142.6	17.9	20.1	19.0
ON	SM1	33.8	34.6	34.2	103.2	105.3	104.3	14.4	15.4	14.9
	SM2	42.9	43.6	43.3	104.8	106.9	105.9	34.7	32.9	33.8
	SM3	33.6	36.5	35.1	122.6	120.8	121.7	37.0	37.5	37.3
	SM4	40.6	39.4	40.0	110.5	108.4	109.5	21.0	21.6	21.3
	SM5	91.4	90.5	91.0	110.8	115.7	113.3	17.7	18.1	17.9
	SM6	81.3	80.1	80.7	111.3	111.0	111.2	19.5	22.2	20.9
	SM7	89.6	90.4	90.0	106.0	105.5	105.8	23.1	21.1	22.1
	SM8	90.8	91.5	91.2	104.4	103.7	104.1	23.7	24.7	24.2
EK	SM1	38.3	37.4	37.9	134.7	129.6	132.2	13.4	12.9	13.2
	SM2	35.7	36.6	36.2	111.6	110.3	111.0	13.7	14.9	14.3
	SM3	65.8	68.0	66.9	117.3	115.3	116.3	44.9	45.7	45.3
	SM4	74.4	73.3	73.9	115.2	112.0	113.6	25.3	26.8	26.1
	SM5	73.2	71.4	72.3	126.2	115.6	120.9	47.7	48.3	48.0
	SM6	76.0	73.9	75.0	114.6	111.8	113.2	44.3	45.0	44.7
	SM7	90.7	89.7	90.2	149.5	139.3	144.4	18.8	17.7	18.3
	SM8	103.4	104.7	104.1	123.1	122.0	122.6	20.4	19.4	19.9
OY	SM1	73.2	71.3	72.3	158.6	157.4	158.0	16.6	17.6	17.1
	SM2	79.9	78.8	79.4	119.6	113.1	116.4	17.2	18.3	17.8
	SM3	33.8	34.6	34.2	142.8	130.4	136.6	22.7	23.8	23.3
	SM4	45.7	48.9	47.3	145.9	150.1	148.0	19.3	20.7	20.0
	SM5	65.8	68.3	67.1	134.5	128.0	131.3	44.3	41.9	43.1
	SM6	77.5	77.8	77.7	139.4	127.4	133.4	32.7	30.8	31.8
	SM7	61.1	60.2	60.7	149.3	153.2	151.3	10.4	10.9	10.7
	SM8	65.8	69.8	67.8	144.8	143.8	144.3	13.8	14.2	14.0
OG	SM1	61.3	59.7	60.5	142.3	147.9	145.1	14.9	14.4	14.7
	SM2	66.6	70.8	68.7	129.6	134.5	132.1	26.4	26.2	26.3
	SM3	73.2	71.2	72.2	119.1	115.0	117.1	39.1	38.9	39.0
	SM4	72.9	71.8	72.4	120.7	116.8	118.8	18.8	20.4	19.6
	SM5	90.2	90.8	90.5	107.3	105.6	106.5	23.0	19.9	21.5
	SM6	94.8	90.1	92.5	107.9	106.1	107.0	37.5	37.4	37.5
	SM7	91.1	90.0	90.6	150.7	139.3	145.0	19.5	17.6	18.6
	SM8	90.1	89.5	89.8	139.0	126.9	133.0	18.9	16.9	17.9
LA	SM1	34.1	34.5	34.3	139.6	139.8	139.7	44.5	43.0	43.8

	SM2	50.4	49.9	50.2	112.3	113.0	112.7	12.9	13.8	13.4
	SM3	89.6	90.5	90.1	106.0	105.4	105.7	12.3	12.9	12.6
	SM4	85.7	85.1	85.4	111.2	111.2	111.2	32.4	30.3	31.4
	SM5	71.1	70.1	70.6	111.9	115.0	113.5	17.6	17.4	17.5
	SM6	64.2	66.2	65.2	112.8	111.8	112.3	16.0	15.1	15.6
	SM7	67.9	68.8	68.4	130.7	126.3	128.5	14.9	14.8	14.9
	SM8	71.6	69.6	70.6	199.4	132.6	166.0	18.3	18.1	18.2

Table 2 Minimum and Maximum WVAMs in CMs and PMs and MVAMs in BMs.

State	sawmill	WVAMs in CMs (m/s ²)		WVAMs in PM (m/s ²)		MVAMs in BM (m/s ²)	
		Min	Max	Min	Max	Min	Max
OS	SM1	90.7	98.9	154.6	168.9	13.6	15.3
	SM2	81.4	84.6	138.5	152	15	16.1
	SM3	69.4	83.6	135.6	139.1	35.1	40
	SM4	80.1	82.7	132.7	136	23.1	27.3
	SM5	99.7	106.7	158.1	187	16.1	20.1
	SM6	79.9	84.2	156.4	169.9	18.2	21.3
	SM7	59.6	61.9	158.6	176.9	16.6	20
	SM8	62.7	72.5	137.1	150.1	16.9	20.9
ON	SM1	32.2	35.9	99.1	110.6	13.7	16.5
	SM2	41.4	44.9	99.7	112.5	32.2	35.2
	SM3	32.3	40.7	118.5	126.9	34.9	39.1
	SM4	36.3	44.2	105.8	114.8	19.5	23.5
	SM5	89.4	93.1	101.1	121	15.9	20.3
	SM6	77.5	83.8	109.6	111.8	18.1	22.8
	SM7	88.6	91.2	99.8	110.8	20.2	23.8
	SM8	89.6	92.4	99.7	111.1	23.5	25.1
EK	SM1	35.9	39.8	121.4	150.3	11.9	13.8
	SM2	34.5	38.2	109.9	112.8	13.2	15.3
	SM3	61	71.6	111.5	121.3	44.5	46.7
	SM4	71.2	75.3	109.6	121.7	24.9	27.2
	SM5	70.6	73.8	109.4	130.7	46.4	49.3
	SM6	72.9	76.6	110.3	121	42.6	46.4
	SM7	88.3	91.1	129.4	157	17.1	19.4
	SM8	101.8	105.6	121.1	124.2	19	21.5
OY	SM1	70.6	73.8	148.6	168.9	16.1	17.9
	SM2	77.6	81.4	107.3	135	16.8	18.8
	SM3	32.2	35.9	112.9	157	21.2	23.9
	SM4	44.2	53.4	143.1	155.3	18.1	20.9
	SM5	61.9	71.6	122.2	150.2	41.5	46.4
	SM6	76.6	78.9	110	153.9	29.8	34.9
	SM7	59.5	61.9	146.9	158.5	10.2	11.2
	SM8	63.4	74.6	139.2	153	13.3	14.7
OG	SM1	58.7	61.9	135.4	156.2	14.2	15.1
	SM2	57.7	71.9	123.1	143.7	26.2	26.5
	SM3	70.6	73.8	110.7	132.4	38.4	39.8
	SM4	71	73.6	111.9	134.5	18.6	20.7
	SM5	89.3	91.6	101.4	111.3	19.5	23.5
	SM6	88.8	96.8	101.6	112	36.6	38.6
	SM7	88.9	92.1	132.7	153.2	16.9	20.3
	SM8	86.7	92.7	120	141.3	16	19.6
LA	SM1	32.2	36.3	137.5	141.2	42.7	45.8
	SM2	47.9	52.1	110.1	114.6	12.3	14.5
	SM3	88.6	91.2	99.4	110.8	12	13.1
	SM4	84.7	86.8	110.2	112.2	30.1	33.5
	SM5	67.6	72.1	110.6	121.2	16.1	18.9
	SM6	59.8	70.2	110.5	113.2	14	17.7
	SM7	65.5	71.1	123.5	133.2	14.5	15.2
	SM8	68.7	72.6	131.2	133.4	17.8	19
MIN		32.2	35.9	99.1	110.6	10.2	11.2
MAX		101.8	106.7	158.6	187	46.4	49.3

Table 3 ANOVA analysis results of comparison within WVAMs during the working period of the CMs

Source of Variation	SS	df	MS	F	P-value	F crit
States	15691.34	5	3138.269	8.526992	1.78E-07	2.249846
Samples	189.2849	5	37.85697	0.102861	0.991494	2.249846
Interaction	98.00014	25	3.920006	0.010651	1	1.549845
Within	92745.93	252	368.0394			
Total	108724.6	287				

Table 4 ANOVA analysis results of comparison within WVAMs during the working period of the PMs

Source of Variation	SS	df	MS	F	P-value	F crit
States	55389.2	5	11077.84	31.27186	1E-24	2.249846
Samples	3929.909	5	785.9818	2.218764	0.052973	2.249846
Interaction	3168.822	25	126.7529	0.357813	0.998331	1.549845
Within	89269.27	252	354.2431			
Total	151757.2	287				

Table 5 ANOVA analysis results of comparison within MVAMs during the working period of the BMs

Source of Variation	SS	df	MS	F	P-value	F crit
States	2059.815	5	411.9631	3.751725	0.002706	2.249846
Samples	11.55781	5	2.311563	0.021051	0.999813	2.249846
Interaction	49.24031	25	1.969612	0.017937	1	1.549845
Within	27671.19	252	109.8063			
Total	29791.8	287				

Table 6 ANOVA analysis results of comparison within WVAMs during the working period of the CMs and PMs and MVAMs during the working period of BMs

Source of Variation	SS	df	MS	F	P-value	F crit
Sample	5130.326	5	1026.065	4.569086	0.00073	2.286184
Columns	267098.9	2	133549.4	594.6979	6.65E-65	3.0681
Interaction	7055.316	10	705.5316	3.141744	0.001285	1.90661
Within	28295.42	126	224.5668			
Total	307579.9	143				

Table 7 ANOVA analysis results of comparison within WVAMs during the working period of the CMs before and after the break

Source of Variation	SS	df	MS	F	P-value	F crit
Sample	5228.125	5	1045.625	2.867774	0.019348	2.323126
Columns	0.06	1	0.06	0.000165	0.989795	3.954568
Interaction	6.85	5	1.37	0.003757	0.999997	2.323126
Within	30627.42	84	364.6121			
Total	35862.45	95				

Table 8 ANOVA analysis results of comparison within WVAMs during the working period of the PMs before and after the break

Source of Variation	SS	df	MS	F	P-value	F crit
Sample	18454.29	5	3690.858	16.07707	4.3E-11	2.323126
Columns	315.375	1	315.375	1.373747	0.244483	3.954568
Interaction	180.43	5	36.086	0.157188	0.977278	2.323126
Within	19284.12	84	229.5728			
Total	38234.21	95				

Table 9 ANOVA analysis results of comparison within the MVAMs during the working period of the BMs before and after the break

Source of Variation	SS	df	MS	F	P-value	F crit
Sample	688.8705	5	137.7741	1.261087	0.288431	2.323126
Columns	0.087604	1	0.087604	0.000802	0.977476	3.954568
Interaction	7.053021	5	1.410604	0.012912	0.999943	2.323126
Within	9177.024	84	109.2503			
Total	9873.035	95				

3.2. Vibration Exposure Analysis

Table 10 (the minimum, maximum and average working hour) revealed that the least time spent on CMs, PMs, and BMs are 1.91 (LA31), 2.07 (EK41), and 1.43 hrs (EK41), respectively while the highest time spent on CMs, PMs and BMs are 4.69 (ON22), 7.55 (OS21) and 6.96 hrs (ON42), respectively. CMs are more than the PMs and BMs in all the visited sawmills, thus, more CMs were working at the same time compared with the number of PMs and BMs working per day. Consequently, the working hour on each CM was lesser compared with PM and BM because there were many CMs to do the needed work compared with the few available PMs and BMs. Table 11, which shows the calculated EAV, ELV, and total exposure points for CMs, PMs, and BMs, revealed that with minimum/maximum EAV and ELV of PMs lesser than zero minutes was an indication that the WVAM and exposure time were too high as shown in tables 1 and 10 and thus, made PMs have the highest average exposure points. However, even though BMs have higher exposure time compared with CMs, the BM vibration acceleration magnitude is lesser compared with CM's Wood Vibration Acceleration Magnitude (WVAM), herewith this reason, the CMs had higher average exposure points, compared with the BMs. However, BMs having the least vibration acceleration magnitude might be to the facts that the Machine Vibration Acceleration Magnitude (MVAV) was measured (because the operators were holding the handles of the machine and not the wood) compared with the CMs and PMs where the operators were holding (pushing and pulling) the wood logs. Though all the machine average exposure points were well above 400 points, and according to Health and Safety Executive [20], exposure limit value is a level of vibration exposure that must not be exceeded, therefore, necessary actions like looking for ways to reduce the vibration magnitude by use of dampers, change all the machinery to new ones or reduce the workers' exposure time use be adopted.

Table 10 Minimum, Maximum and Average Time spent on each Machine

Sawmills	CMs			Sawmills	PMs			Sawmills	BMs		
	Min (hr)	Max (hr)	Average (hr)		Min (hr)	Max (hr)	Average (hr)		Min (hr)	Max (hr)	Average (hr)
LA42	1.96	2.58	2.31	EK41	2.07	6.56	3.63	OS41	2.15	3.39	2.83
LA31	1.91	2.64	2.33	EK32	3.12	4.04	3.75	OS32	2.05	4.41	3.00
EK41	2.45	2.66	2.55	LA32	2.23	6.05	3.76	ON32	2.38	3.48	3.02
ON41	2.50	2.76	2.64	OS22	2.53	4.88	3.77	OS42	2.15	4.24	3.10
ON42	2.58	2.84	2.69	OG32	2.53	5.67	3.87	OY31	2.15	4.10	3.14
EK11	2.59	2.90	2.76	OY21	3.36	4.84	4.04	OY12	2.06	4.02	3.26
LA21	2.54	2.99	2.83	LA11	3.10	5.27	4.06	OG32	2.15	4.21	3.38
LA12	2.64	3.08	2.91	EK21	3.15	5.13	4.07	ON22	2.01	4.18	3.39
OS42	2.68	3.11	2.96	OY31	3.42	5.51	4.15	OY21	2.70	4.10	3.45
OG22	2.54	3.26	2.97	LA12	3.66	5.24	4.15	LA32	2.32	5.17	3.49
OS21	2.65	3.17	2.99	OY32	3.13	5.53	4.20	EK11	2.37	4.59	3.50
OY32	2.47	3.35	2.99	ON41	3.71	4.64	4.22	OS21	2.60	4.11	3.52
OG12	2.67	3.17	3.00	OY12	3.61	4.86	4.23	ON31	2.98	4.16	3.52
EK22	2.84	3.16	3.02	ON21	3.30	4.66	4.28	EK32	2.76	4.20	3.52
LA11	2.79	3.27	3.05	OS41	3.86	5.33	4.30	EK12	2.93	4.26	3.58
LA41	2.88	3.23	3.06	OG12	4.07	4.74	4.40	EK41	1.43	4.71	3.58
OS11	2.88	3.22	3.08	OY42	3.79	5.72	4.50	LA11	2.63	4.60	3.59
OY31	2.93	3.28	3.11	OY41	2.72	5.17	4.51	OS22	2.32	4.48	3.75
LA22	2.94	3.33	3.18	OS42	3.89	5.93	4.56	LA21	2.73	5.21	3.76
ON12	2.92	3.35	3.20	OG21	3.96	5.74	4.65	OG11	3.07	4.48	3.80
OS12	2.87	3.39	3.21	ON22	3.35	6.09	4.66	OY42	3.34	4.91	3.84
EK21	3.10	3.37	3.22	ON12	4.51	5.06	4.66	OG21	3.19	4.78	3.90
OG42	2.90	3.42	3.22	LA42	4.18	5.15	4.67	OY22	2.33	6.16	3.92
OG41	2.94	3.40	3.23	OS11	3.44	5.37	4.75	EK22	3.44	4.93	3.94
OY41	2.72	3.60	3.24	ON32	4.06	5.34	4.76	OS31	3.33	5.17	3.96
OY22	2.98	3.58	3.31	ON42	3.48	5.69	4.78	ON41	3.52	4.23	3.98
ON11	3.10	3.52	3.34	OG42	4.17	5.18	4.79	OS12	3.38	4.43	4.03
OS32	3.02	3.63	3.41	OY22	3.40	6.00	4.85	OG41	2.28	7.59	4.14
OG32	2.95	3.75	3.43	LA21	3.41	5.70	4.91	EK42	3.70	4.67	4.18
OG31	3.32	3.82	3.65	EK11	3.65	6.01	4.93	OS11	3.23	5.10	4.25
OY21	3.48	3.87	3.67	ON11	4.26	5.44	4.98	OG22	2.87	6.04	4.31
EK42	3.52	3.83	3.69	OG11	4.51	7.01	5.01	LA31	3.48	5.92	4.33
OG11	3.43	3.99	3.74	OG31	3.90	5.88	5.07	EK21	3.27	5.78	4.34
OS22	3.37	3.97	3.76	EK22	4.44	5.61	5.10	OY32	2.98	5.21	4.36
OY12	3.52	4.02	3.78	OG22	3.50	6.01	5.14	LA12	3.21	4.83	4.41
ON21	3.70	3.87	3.80	OG41	2.55	7.11	5.15	OY41	3.99	5.21	4.49
OG21	3.12	4.40	3.89	ON31	4.62	6.28	5.26	ON11	4.03	5.38	4.58
ON32	3.84	4.09	3.97	OY11	4.90	5.78	5.28	ON12	4.01	4.98	4.59
OY42	3.31	4.58	4.07	EK31	4.65	5.63	5.30	OG12	3.36	5.29	4.66
OS31	3.61	4.33	4.08	LA22	4.56	6.65	5.35	LA41	3.34	6.76	4.73
EK12	4.01	4.24	4.13	LA41	3.74	6.42	5.38	OY11	3.86	6.34	4.74
OS41	3.85	4.37	4.14	OS32	4.19	6.55	5.40	OG31	4.04	5.77	4.76
OY11	4.12	4.45	4.29	LA31	4.84	5.91	5.49	EK31	3.47	5.87	4.79
EK31	4.29	4.56	4.42	OS12	5.16	6.59	5.67	OG42	4.51	5.40	4.85
LA32	4.18	4.62	4.43	EK12	4.31	6.54	5.97	LA22	4.43	5.42	4.85
EK32	4.34	4.66	4.51	OS31	4.87	7.00	6.00	ON21	4.19	5.93	5.06
ON31	4.46	4.66	4.56	EK42	5.50	7.07	6.28	LA42	3.95	6.32	5.41
ON22	4.41	4.69	4.58	OS21	5.93	7.55	6.69	ON42	4.54	6.96	5.67

Table 11 Calculated EAV, ELV and Total Exposure Points for CMs, PMs, and BMs

CMs				PMs				BMs			
Sawmill	Time to Reach EAV (min)	Time to Reach ELV (min)	Exposure Points	Sawmill	Time to Reach EAV (min)	Time to Reach ELV (min)	Exposure Points	Sawmill	Time to Reach EAV (min)	Time to Reach ELV (min)	Exposure Points
LA11	3	10	7314.59	OG32	0	1	90555.73	OY41	26	105	1038.02
ON11	3	10	7964.37	ON41	0	1	95346.19	LA21	19	76	1205.47
EK11	2	8	8061.12	EK32	0	1	96155.75	EK11	17	9	1231.70
OY21	3	10	8750.62	LA32	0	1	97191.25	EK12	15	59	1477.84
ON21	2	10	9516.50	ON42	0	1	105493.50	OY42	15	61	1520.20
EK12	2	9	11002.43	LA12	0	1	105612.05	LA12	17	67	1598.89
ON12	2	6	12202.18	ON12	0	1	106898.83	OG11	14	56	1658.40
LA12	1	5	14919.44	ON11	0	1	110311.32	OS11	15	60	1705.82
ON22	2	8	14938.79	LA21	0	1	111026.65	LA32	12	49	1714.89
OY22	1	5	15096.65	EK21	0	1	112467.43	OS41	9	35	1934.80
LA42	1	2	23471.45	ON22	0	1	114290.20	OS12	12	49	2005.42
LA31	1	2	23675.15	OY12	0	1	115408.79	ON11	14	54	2052.83
OY41	1	3	24296.41	OG31	0	1	117314.64	OY12	9	38	2085.11
OS42	1	3	27656.31	ON32	0	1	120374.53	LA41	14	54	2120.42
OG11	1	3	27906.85	OG21	0	1	127924.98	OS42	8	33	2259.63
OY31	1	3	28502.65	ON21	0	1	129161.10	ON31	9	37	2277.78
OG12	1	3	28864.20	EK22	0	1	133478.39	OS32	8	31	2327.21
LA41	1	3	29142.24	LA22	0	1	135420.72	EK41	9	36	2421.03
EK21	1	3	29378.53	ON31	0	1	137981.10	OS31	9	38	2533.00
OS41	1	3	31044.73	OS22	0	1	139208.10	ON32	7	27	2663.13
OG22	1	2	31692.47	OY31	0	1	143349.09	LA31	10	39	2677.25
EK22	1	2	33576.62	LA31	0	1	143693.58	OY11	10	41	2798.30
OY32	0	2	36752.18	OG22	0	1	145977.36	OG41	9	35	2892.12
OY42	1	3	38140.35	EK12	0	1	149926.86	ON22	7	26	3105.98
LA32	1	3	38390.89	OY21	0	1	151371.70	OG42	9	37	3138.26
OS21	0	2	39401.20	OY32	0	1	151580.42	OY22	8	30	3166.50
OG21	1	2	41338.31	EK41	0	1	152236.98	EK42	8	30	3342.03
EK41	0	1	42294.65	OG12	0	1	155718.37	OG22	8	31	3343.03
ON41	0	1	43593.19	EK31	0	1	157112.55	LA42	9	36	3618.43
OS12	0	2	44809.23	LA11	0	1	162277.90	OY21	6	22	3781.85
ON42	0	1	45560.85	OG42	0	1	172197.24	ON41	6	25	3925.09
OY11	1	2	45652.52	EK11	0	1	173676.52	OG31	6	26	4442.58
OS32	0	2	46628.20	LA41	0	1	180834.86	OS22	5	19	4847.10
LA21	0	1	46781.99	OS42	0	1	189705.52	EK22	4	18	5419.07
EK31	1	2	47100.77	OY42	0	1	190032.79	OG12	4	17	6508.53
LA22	0	2	47279.00	EK42	0	1	192046.04	ON42	5	20	6705.24
OY12	0	2	48519.48	OY41	0	1	208917.02	OY32	3	12	8902.32
OS22	0	2	50788.61	OY22	0	1	213229.24	OG32	2	9	9597.35
EK32	1	2	51647.18	OG11	0	1	213494.70	LA22	3	12	9655.86
ON32	0	2	52706.38	OG41	0	1	217464.46	OS21	2	8	10209.67
OG42	0	1	52934.51	OS41	0	0	236271.69	ON12	3	11	10587.96
OG41	0	1	53989.64	OS12	0	1	242379.32	OY31	2	6	11777.29
OS11	0	1	55775.00	OS11	0	0	253589.49	OG21	2	8	11977.02
OG32	0	1	59763.29	OS21	0	1	257273.52	LA11	2	6	13906.78
OG31	0	1	60941.65	LA42	0	0	262661.78	EK32	2	6	14201.34
ON31	0	1	76894.83	OY11	0	0	268332.72	ON21	2	9	14214.45
EK42	0	1	81440.22	OS32	0	0	288834.03	EK21	1	6	17983.19
OS31	0	1	89528.84	OS31	0	0	367142.07	EK31	1	5	22283.53

4. CONCLUSIONS

All the machine average exposure points were well above 400 points and the least average WVAMs for all CMs and PMs and average MVAMs for BMs are more than the daily EAV and ELV. Thus, the study concluded that the contributing factors responsible for the high values of the exposure analysis experienced by workers were; poor machine damping, use of old and obsolete machines, poor working conditions, and general negligence by workers to

the use of the required personal protective equipment, lack of proper working tools, worker's carelessness and lack of required training.

It is hereby recommended that working tools should be provided, vibration damper should be installed, use of personal protective equipment should be encouraged, workers should be given adequate training, new, the workers' exposure time should be reduced, new and modern machines should be procured and workers attitude to occupational safety should improve.

ACKNOWLEDGMENT

This is to acknowledge the Tertiary Education Trust Fund (TETFUND) as the sole sponsor of this research work through the Institutional Based Research (IBR) grant (Ladoke Akintola University of Technology, Ogbomoso, Nigeria) (2016).

REFERENCES

- [1] M.J. Griffin. Negligent Exposures to Hand-Transmitted Vibration. *International Archives of Occupational and Environmental Health*, 81, (5); (2007), 645 – 659.
- [2] M. Bovenzi. Health Risks from Occupational Exposures to Mechanical Vibration. *La Medicina del Lavoro*, 97, (3); (2006), 535 – 541.
- [3] R. Wolfgang, R. Burgess-Limerick. Whole-Body Vibration Exposure of Haul Truck Drivers at a Surface Coal Mine. *Applied Ergonomics*, 45, (6); (2014), 1700 – 1704.
- [4] United States Bureau of Labor and Statistics (2015). Non-Fatal Occupational Injuries and Illnesses Requiring Days Away from Work. <https://www.bls.gov/news.release/osh2.toc.html>. Accessed on April 22, 2020.
- [5] X. Zhao, C. Schindler. Evaluation of Whole Body Vibration Exposure Experienced by Operators of a Compact Wheel Loader According to ISO 26311:1997 and ISO 2631-5:2004. *International Journal of Industrial Ergonomics*, 44, (6); (2014), 840 – 850.
- [6] K.A. Zinck. The Evaluation of Human Vibration Measurements and the Effectiveness of Different Vibration Reduction Strategies in a Sawmill. *Being a Conference Paper Presented at the Worker's Compensation Board, United Kingdom*, (2000), 9 – 12.
- [7] O.A. Orelaja, X. Wang, D.S. Ibrahim, U. Sharif, U. Evaluation of Health Risk Level of Hand-Arm and Whole-Body Vibrations on the Technical Operators and Equipment in a Tobacco-Producing Company in Nigeria. *Journal of Healthcare Engineering*, (2019), 20 - 31.
- [8] H.S. Seidel. Selected Health Risks Caused by Long-Term, Whole-Body Vibration. *American Journal of Industrial Medicine*, (23); (1993), 589 - 604.
- [9] M.A. Bovenzi, A.C. Zadini, A.O. Franzinelli, F.M. Borgogni. Occupational Musculoskeletal Disorders in the Neck and Upper Limbs of Forestry Workers Exposed to Hand-arm Vibration. *International Journal of Health and Ergonomics*, (34), (1991), 547 - 562.
- [10] N.J. Mansfield. Human Response to Vibration. *New York, CRC Press, Boca Raton, FL, USA*, (28); (2004), 23 – 32.
- [11] European Union Parliament. Directive 98/37/EC of the European Parliament Council on the Approximation of the Laws of the Member States Relating to Machinery. *OJL 207*, (1998), 64 - 75.
- [12] International Organization for Standardization (ISO). Mechanical Vibration and Shock - Evaluation of Human Exposure to Whole-body Vibration-part 1. *International Organization for Standardization*. (1997), ISO 2631-1.
- [13] D.G. Wilder. The Biomechanics of Vibration and Low Back Pain. *American Journal of Industrial Medicine*, (23); (1993), 577 - 588.

- [14] Federal Environmental protection Agency (FEPA). Interim Guidelines and Standards for Industrial Effluents, Gaseous Emissions, and Hazardous Wastes in Nigeria. *Federal Environmental Protection Agency*. (1991), 52 – 53.
- [15] Environmental Protection Authority. Wood Processing Works. Environmental Protection Authority. (2002), Available online: <http://www.epa.org>. Accessed on March 31, 2020.
- [16] L.G. Punnett, J.S. Park, L. Punnett. Work Routinization and Implications for Ergonomic Exposure Assessment. *Ergonomics*, 49, (1); (2006), 12 – 27.
- [17] International Organization for Standardization (ISO). Mechanical Vibration and Shock Evaluation of Human Exposure to Whole-Body Vibration. Part 5: Method for Vibration Containing Multiple Shocks. *International Organization for Standardization, Geneva, Switzerland*, (2004), 2631 - 2635.
- [18] H. Jahncke, S. Hygge, S.E. Mathiassen, D. Hallman, S. Mixter, E. Lyskov. Variation at Work: Alternations between Physically and Mentally Demanding Tasks in Blue-Collar Occupations. *Ergonomics*, 60, (9); (2017), 1218 – 1227.
- [19] Health and Safety Executives (HSE) (2005).Hand-arm vibration exposure calculator, available online: <http://www.hse.gov.uk/vibration/hav.xls>.
- [20] Health and Safety Executive (HSE) (2019) Vibration: Employers' responsibilities-legal duties; Vibration Levels.
<https://www.hse.gov.uk/vibration/hav/advicetoemployers/responsibilities.htm>