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STUDY OF THE HUMAN WHOLE-BODY VIBRATION TRANSMISSION (CASE STUDY)

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Abstract: *The objective of this research is to present the results of an experimental study on the transmission of vertical vibration, generated by a motor pump of a thermal power plant, to the human body. Therefore, the causes and consequences of this situation were studied with the "bowtie" method, which involved carrying out a series of specific measurements, used in two applications: the exposure assessment method (points method) and the monitoring method. The results obtained show that human error, aging, imbalance, and electrical error are the causes of vibrations that have a great impact on the human body, depending on the bowtie method. In addition, the two applications proved that the hazardous vibrations are those according to the x and z axis.*

Key words*: Bowtie, points method, monitoring, vibration transmission, WHB*

1. INTRODUCTION

In the industry, many factors contribute to the failure of systems like the human error which can cause a major risk[1], this error can be caused by the environment of the work that generate discomfort, among its causes it found the noise and vibrations for example[2][3], this situation exists in several fields agriculture, transport, constructions, mining, industries … etc. [4] Where the workers are being subject to vibrations and shocks that attack the human body and cause damage.

Generally, these vibrations divided into two categories: the first is WHB "Whole Body Vibration" and the second is HAV "Hand Arm Vibrations" [5,6]

These vibrations not only cause discomfort, but they also cause many different health problems [7], like "white finger" disease (VWF) or "hand-arm vibration syndrome", that attacks the nerves [8,9] and « Carpal Tunnel Syndrome » [10]. These health problems are not considered by medicine to be diseases caused by vibrations, but rather by other factors [6]. Thus, the major of them excluded from professional diseases.

The difference in health hazards is due to the frequency of exposure [11], as the human body is very affected by low-frequency vibrations, and this is due to the low frequency of "the human body natural resonance"[12], in contrast, the high frequency with a low amplitude is considered a good vibration and is used in the clinical treatment of osteoporosis and increased muscle activation during exercise[13,14].

For that many models of the human body [7,15,16][17] and experimental studies [18,19] are proposed.

The causes of industrial vibrations vary, they might be: the unbalance[20], the misalignment[21]…etc.

This work proposes an analytical study of an Algerian case in which workers are exposed to industrial vibrations; the case study tacked from the SONELGAZ SPE Algerian thermal power plant.

The rest of the paper is ordered as follows: section 2''Methods and Material'' that describes the plant, the materials and methods used in this work. ''Results and Discussion'' like section 3 where it discusses the results. Finally, ''Conclusion''.

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2. INFORMATION. METHODS AND MATERIAL

The case of this work located in SONELGAZ Annaba is a thermal power plant which contains two motor pumps alimentary A and B (figure 1), one of them is in service (pump A) with a generation of high levels of vibration, and the second (pump B) under maintenance with the presence of 4 workers at least in this area that exposed to these vibrations for a period of 08h/days (figure 2).

We need firstly to know the causes and consequences of these vibrations for that the method bowtie was used.

After that, we must take regular readings of vibrations that are made by a "VIBROTEST 60" (figure 3) according to "vibration direction for the whole body", where the acceleration values must be presented in 3 directions X, Y, and Z (figure 4). Finally, the vibrations are evaluated in two ways: Daily exposure method and daily monitoring.

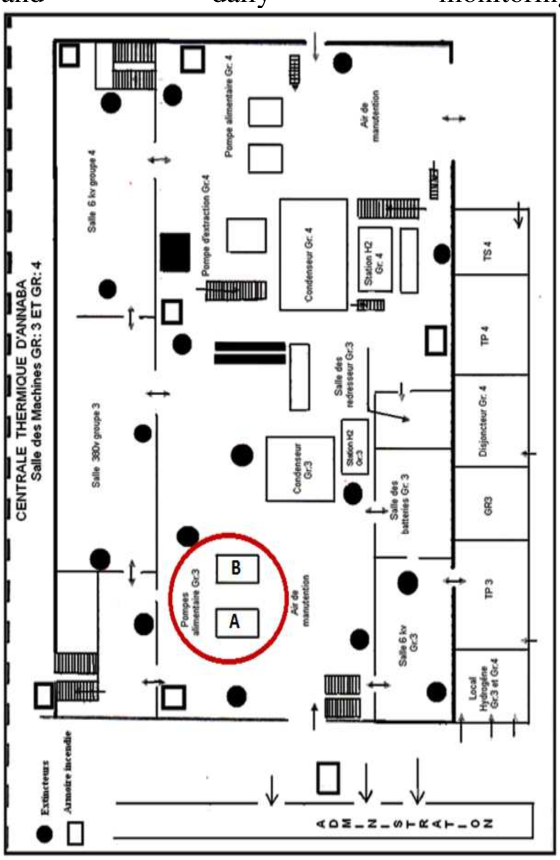


Fig. 1. Pump location.

Fig. 2. Presence of employers on the site rounds.

Fig. 3. The components of VIBROTEST 60 with vibration sensors [22].

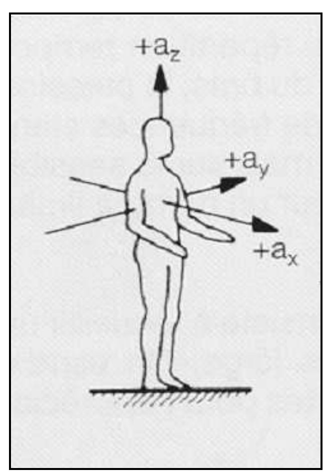


Fig. 4. Vibration direction for the whole body.

2.1 Vibrations causes and consequences:

To define the causes and consequences of vibration generated it must be used the bowtie method that is a qualitative method, it based on the combination of tow arborescence methods fault tree and Etree with mention of safety barriers on each side (figure 5). [23,24]

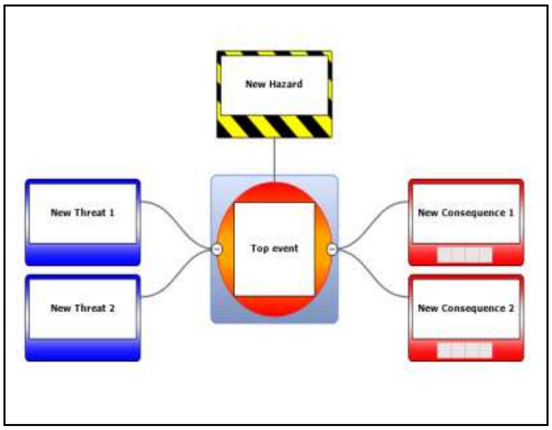


Fig. 5. Bowtie diagram.

2.2 Daily exposure Method:

This method presented below is actually the most practical because its results are objective and easy to read. Entire body vibration management can be performed through the exposure point system; the points are then accumulated for a specific worker until the amount of exposure points for P_E corresponding to the working day is obtained. Then it projected in the graph where: the green points signified that the risk is acceptable (less than 100 points), orange points mean a manageable risk; preventive actions are needed to eliminate or reduce the risk of exposure between 100 and 529 points, finally the Red points which are more than 529 points: the points of unacceptable risk according to the regulations it is necessary to act immediately.[11]

To calculate the number (PE) of points corresponding to the duration T, in hours, the following formula is applied:

$$P_E = \left(\frac{k \times aweq}{0.5}\right)^2 \times \frac{T}{8hours} \times 100 \qquad (1)$$

With:

aweq : the equivalent amplitude of vibration,

k : the orientation weighting factor (1.4 for x and y, 1 for z).

T : The vibration exposure time, h ;

Table 1

Points method in the case of total body vibrations.

Accélération (m/s²) \ Durée réelle d'exposition (h)	0.5	1	2	3	4	5	6	7	8	9	10
2	100	200	400	600	800	1000	1200	1400	1600	1800	2000
1.9	90	181	361	542	722	903	1083	1264	1444	1625	1805
1.8	81	162	324	486	648	810	972	1134	1296	1458	1620
1.7	72	145	289	434	578	723	867	1012	1156	1301	1445
1.6	64	128	256	384	512	640	768	896	1024	1152	1280
1.5	56	113	225	338	450	563	675	788	900	1013	1125
1.4	49	98	196	294	392	490	588	686	784	882	980
1.3	42	85	169	254	338	423	507	592	676	761	845
1.2	36	72	144	216	288	360	432	504	576	648	720
1.15	33	66	132	198	265	331	397	463	529	595	661
1	25	50	100	150	200	250	300	350	400	450	500
0.9	20	41	81	122	162	203	243	284	324	365	405
0.8	16	32	64	96	128	160	192	224	256	288	320
0.7	12	25	49	74	98	123	147	172	196	221	245
0.6	9	18	36	54	72	90	108	126	144	162	180
0.5	6	13	25	38	50	63	75	88	100	113	125
0.4	4	8	16	24	32	40	48	56	64	72	80
0.3	2	5	9	14	18	23	27	32	36	41	45
0.2	1	2	4	6	8	10	12	14	16	18	20

2.3 Monitoring vibration indicator method:

Total vibration measurement will qualify, compared with previous criteria or measures, the overall condition of the person or the system. This surveillance technique includes tracking the evolution of one or more markers over time (displacement, speed, acceleration). The mechanical pulse is recognized by a vibration sensor, located on the surface of the person's vibration or fixed on the system bearings, which enables the mechanical signal to be transformed into an electric signal which is redirected to the vibration meter to measure the signal and show the total value [25,26]. There are two different ways to monitor:

a-continuous, or online,

b- Periodic in the form of rounds more or less spaced in time.

The evolution over time of a vibration indicator is represented by a curve called a trend curve [figure 6]. The measurement result is compared with previous measurements and with predefined thresholds [27]table 2.[28]

Table 2

The limit values of total body vibration.

Exposure time	Action values	Exposure limit values
8 hours	0.5 ms^{-2}	1.15 ms^{-2}

To determine health risks, a factor K is multiplied by each acceleration corresponding to each direction. The factor K is equivalent to 1.4 for two horizontal axes.

This weighting is due to a higher susceptibility of the human to horizontal accelerations than vertical ones. (ISO2631)[29]

Where the body vibrations, a_G will be

$$a_G = \sqrt{a_X^2 + a_Y^2 + a_Z^2} \qquad (2)$$

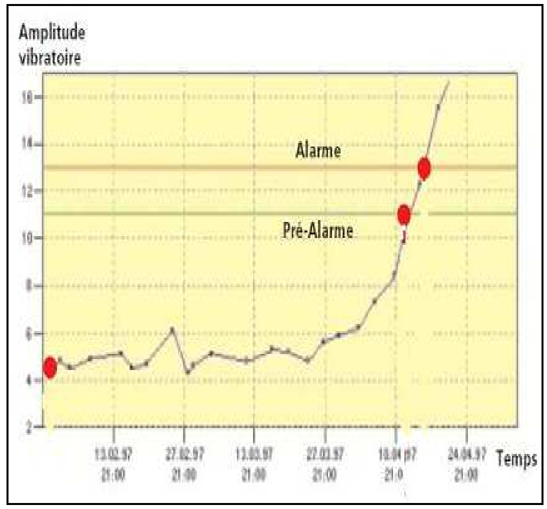


Fig. 6. Trend curve.

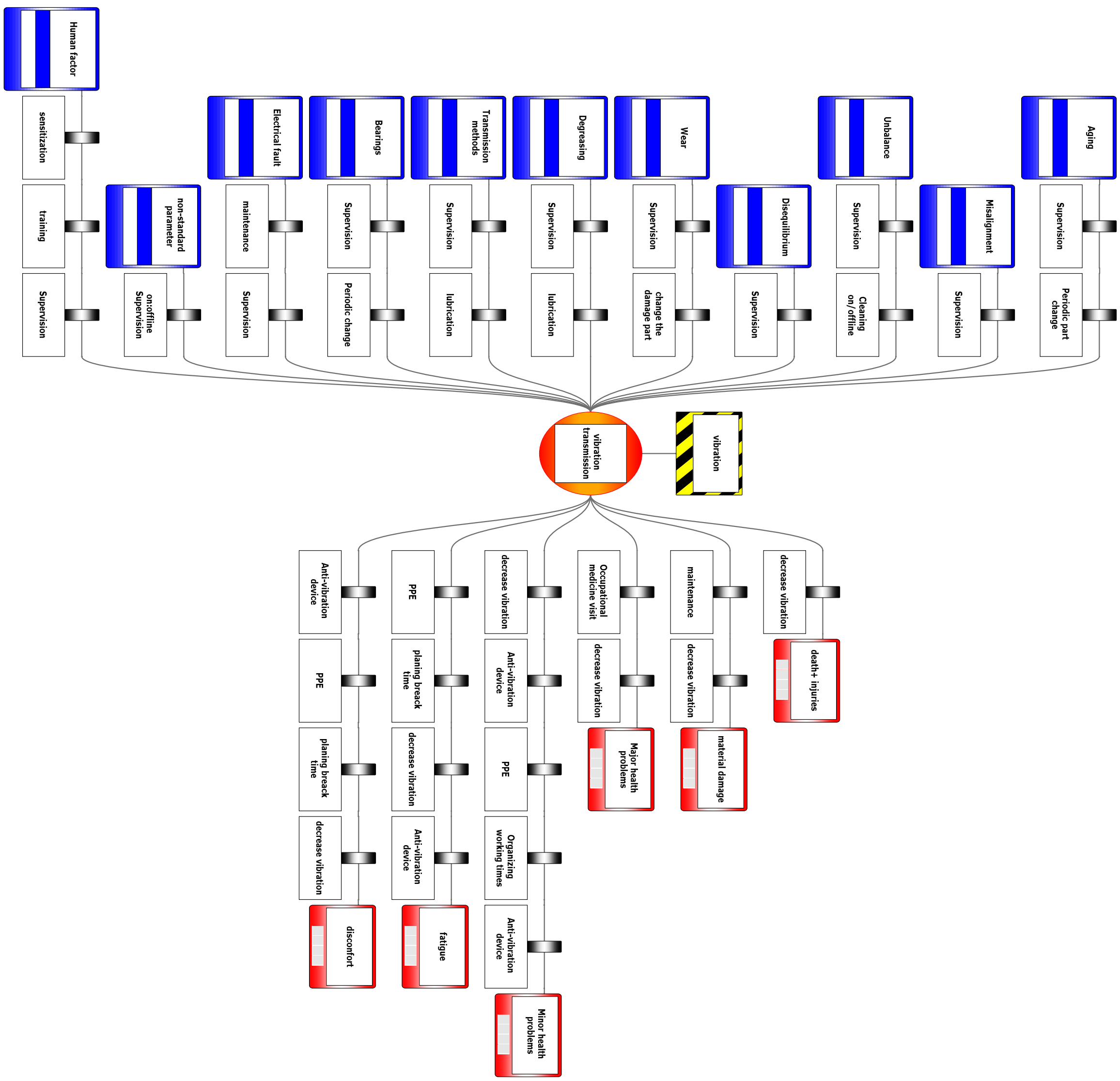


Fig.7. causes and consequences of vibrations transmissions

3. RESULTS AND DISCUSSIONS

3.1 Causes and consequences of vibrations

The Figure below **(Fig.7)** shows the causes and consequences of industrial vibrations and barriers proposed.

From the figure 7 it observed that the vibration can be caused by many factors like hardware origin as unbalance, misalignment and electrical default or by human error which is the mean cause, those results converge with literature[1,20,21,30].

For the consequences it found that varied between discomfort, injuries and death

3.2 Exposure assessment (the points method):

For this application we need a worker exposed to several sources of vibration during a working day, we have requested as a sample an operator exposed to vibrations produced by a lathe, a milling machine, and pumps alimentary.

The vibrations transmitted to this person are grouped in Table 3,

Table 3

Transmitted vibration values.

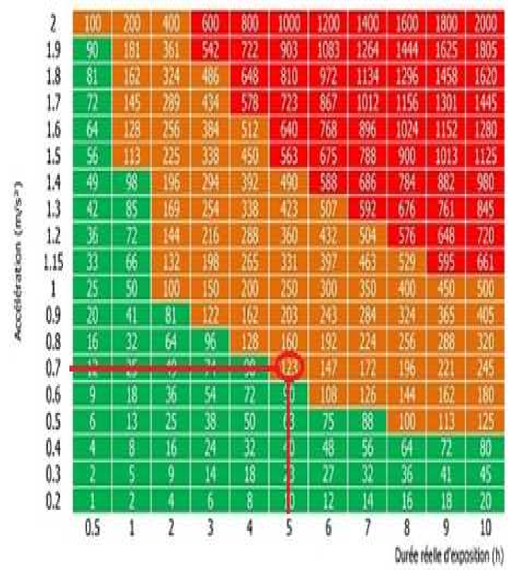
Machine / Axes	Tower (1 hour)		Milling machine (1 hour)		**Pump (5 hours)**	
	measure	weight	measure	weight	measure	weight
Axe X : m/s²	0.789	1,104	1.103	1,544	0.955	1,337
Axes-Y : m/s²	0.318	0,445	1.096	1,534	0.681	0,953
Axe Z : m/s²	0.632	0,632	0.512	0,512	1.242	1,242

- Example of how to use the illustration table :

According to the value measured in the direction of the Y axis of the pump equals 0.681 m/s2 for the duration of 5 hours the table shows an equal number of points 123 points (table 4).

Table 4

Exploitation example



Accélération (m/s²)	0.5	1	2	3	4	5	6	7	8	9	10
2	100	200	400	600	800	1000	1200	1400	1600	1800	2000
1.9	90	181	361	542	722	903	1083	1264	1444	1625	1805
1.8	81	162	324	486	648	810	972	1134	1296	1458	1620
1.7	72	145	289	434	578	723	867	1012	1156	1301	1445
1.6	64	128	256	384	512	640	768	896	1024	1152	1280
1.5	56	113	225	338	450	563	675	788	900	1013	1125
1.4	49	98	196	294	392	490	588	686	784	882	980
1.3	42	85	169	254	338	423	507	592	676	761	845
1.2	36	72	144	216	288	360	432	504	576	648	720
1.15	33	66	132	198	265	331	397	463	529	595	661
1	25	50	100	150	200	250	300	350	400	450	500
0.9	20	41	81	122	162	203	243	284	324	365	405
0.8	16	32	64	96	128	160	192	224	256	288	320
0.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	123	147	172	196	221	245
0.6	9	18	36	54	72	[illegible]	108	126	144	162	180
0.5	6	13	25	38	50	[illegible]	75	88	100	113	125
0.4	4	8	16	24	32	[illegible]	48	56	64	72	80
0.3	2	5	9	14	18	[illegible]	27	32	36	41	45
0.2	1	2	4	6	8	10	12	14	16	18	20

Example of the points number calculation:

According to the equation (1), the value of the acceleration in the X axis the direction of the milling machine which is equal to 1.103m/s², the points number will be :

Pc=((1,4×1,103)/0,5)^2×(1/8)×100=119,2≅ 119points

points Number illustrated and calculated in Table 5:

Table 5

Exposure assessment.

Tour (1 hour)			**Milling machine (1 hour)**			**Pump (5 hour)**			**Sum of points during eight hours, A(8)**	
Axe X : 0.789 m/s²	P_T	66	Axe X : 1.103 m/s²	P_F	113	Axe X : 0.955m/s²	P_P	423	A(8)	602
	P_c	61		P_c	119		P_c	447	$A_{Pc}(8)$	627
Axe Y : 0.318 m/s²	P_T	8	Axes-Y : 1.096 m/s²	P_F	113	Axe Y : 0.681m/s²	P_P	203	A(8)	324
	P_c	10		P_c	118		P_c	227	$A_{Pc}(8)$	355
Axe Z : 0.632 m/s²	P_T	18	Axe Z : 0.51 m/s²	P_F	13	Axe Z : 1.242m/s²	P_P	360	A(8)	391
	P_c	20		P_c	13		P_c	386	$A_{Pc}(8)$	419

Where:

P- Number of points illustrated according to table n°4.

Pc- is the number of points calculated from formula (1)

A(8)- The total of the points shown A(8)= PT+PF+PP;

A_{Pc}(8)- The total of the points calculated APc(8)= PTC+PFC+PPC.

For the lathe, all points of the three axes are below the exposure action value which is 100 points.

The same applies to Z axis of the milling machine, but the X and Y axis points exceed the exposure action value, but still remain below the exposure limit value of 529 points.

But for the pump we find that all the points of the three axes are greater than 100 points, so the action value is exceeded and they remain below 529 points "the exposure limits value”.

Then, adding the points of each axis gives:

Exceeding the exposure limit value along the X axis A(8)= 602>529 points "non-standard value".

The action limit values along the Y and Z axes are exceeded but remains below the exposure limit value.

3.3 Monitor a worker exposed to vibration :

For this application, we chose a mechanic exposed to a single source of vibration in his day (the vibration transmitted from the pump) for eight hours, so we took acceleration measurements at different dates, weighted these measurements and calculated their overall Ag levels (according to formula (2)), we then compared these values with the thresholds (Table 6) and plotted the trend lines (Figures 6, 7 and 8).

Table 6

Vibration transmission in 3 axes.

dates	**axes**	**measured vibration level (m/s^2)**	**weighted vibration level (m/s^2)**	**weighted overall level (Ag) (m/s^2)**
15/04	X	0,535	0,749	1,606
	Y	0,587	0,8218	
	Z	1,16	1,16	
17/04	X	0,625	0,875	1,781
	Y	0,605	0,847	
	Z	1,30	1,30	
19/04	X	0,867	1,2138	2,167
	Y	0,647	0,9058	
	Z	1,55	1,55	

Trend curves

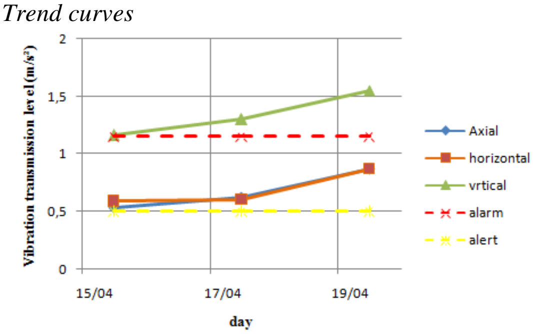


Fig. 6. Trend curve followed without weighting.

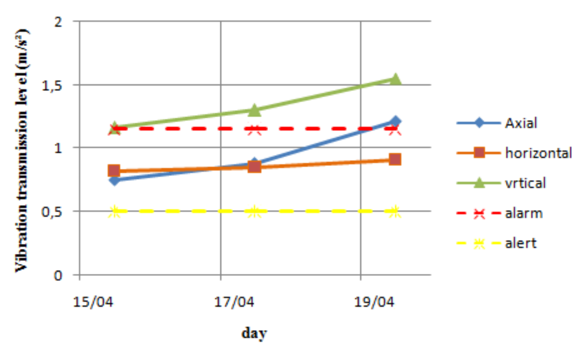


Fig. 7. Monitoring trend curves with weighting.

According to this trend curve, there is an increase in vibrations at axis (z) level with exceeding of action value (alert) for each X and Y axes.

This curve shows that there was a hidden danger and that this signalled by exceeding the limit value for the weighted level of the X axis values.

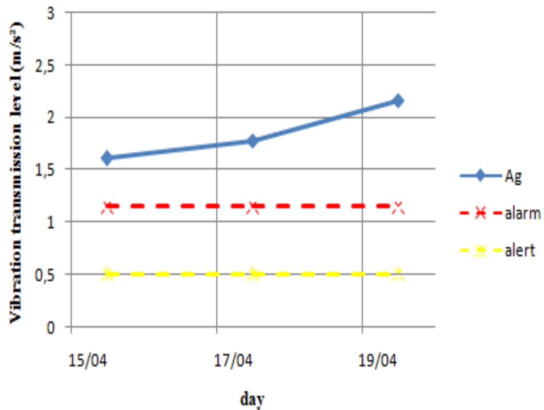


Fig. 8. Overall level monitoring trend curve Ag

Exceeding the thresholds is frank in this curve so the situation has been dangerous and it needs corrective actions.

The curves (figure6, 7, and 8) deduced in the experimental part II and weighted according to the standard (ISO 2631) show that the intolerable nuisance parametric surpluses follow the Z and X axes, which depend on the vibration nature of the source (alimentary pump).

4 METHOD COMPARISON

The idea of this comparison centred on the field of use, the input factors (acceleration level, duration...) for each of these methods, and this is summarized in the following table (table7):

Table 7

Methods comparison.

	BE AFFECTED BY		INCOMING FACTORS			
	person	machine	Acceleration level	frequency	duration	the body part that receives vibrations
M I	+	-	+	-	+	+
M II	+	+	+	-	-	+

5 CONCLUSION

This work proposes a study of whole-body vibration transmission. For that, this study started with the analysis of the causes and consequences of vibration, and as a result, it observed that among the causes the human error, the aging, the unbalance, the electrical fault were found; however, the consequences varied between death and discomfort.

So the evaluation of vibration transmission in the whole body is very important, for those 2 applications in the case study were applied. The first one is the Daily exposure Method applied to a worker who has three tasks in the day; and for the second is the monitoring vibration indicator method for a worker has done the same task in 8 hours. It is noted that both cases suffer from a high vibration level therefore the working conditions have been severe, so it is necessary to find quick solutions aimed at prevention (to reduce the risk we take by the proposal the integration of mobile insulators). Finally, the comparison of the two evaluation methods shown that they both have advantages and inconvenient.

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STUDIUL TRANSMISIEI VIBRĂRII ÎNTREGUL CORP UMAN (STUDIU DE CAZ)

Rezumat: Obiectivul acestei cercetări este de a prezenta rezultatele unui studiu experimental privind transmiterea vibrațiilor verticale, generate de o pompă cu motor a unei centrale termice, către corpul uman. Prin urmare, cauzele și consecințele acestei situații au fost studiate prin utilizarea metodei ”papion”, care presupune efectuarea unei serii de măsurători specifice, utilizate în două aplicații: metoda de evaluare a expunerii (metoda punctelor) și metoda de monitorizare.Rezultatele obținute arată că eroarea umană, îmbătrânirea, dezechilibrul și eroarea electrică sunt cauzele

vibrațiilor care au un impact puternic asupra corpului uman, în funcție de metoda ”papion” aplicată. În plus, cele două aplicații au dovedit că vibrațiile periculoase sunt cele conform axelor x și z.
Cuvinte cheie: metoda papion - metoda punctelor- monitorizare- transmiterea vibrațiilor- WHB

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