MEASUREMENT AND EVALUATION OF VIBRATION LEVELS ON FORKLIFT TRUCK DRIVERS

Cristiano Zucco, c.zucco@terra.com.br, zucco@linckmaquinas.com.br
Linck S.A. Equipamentos Rodoviários e Industriais, Av. das Industrias, 500 - Km 106,5 da BR290, CEP:92900-000, Eldorado do Sul, RS, Brazil. Tel.(+55 51) 2125-3362, Fax.: (+55 51) 2125-4545.
Herbert Martins Gomes, herbert@mecanica.ufrgs.br
UFRGS, Federal University of Rio Grande do Sul, Post Graduate Program in Mechanical Engineering, Porto Alegre, Rio Grande do Sul, Brazil. Tel.: (+55 51) 3308-3681.

Abstract. *This paper shows a whole-body vibration study in forklift trucks drivers working in different situations, comparing two kinds of tires, pneumatic and super elastic (massive); two types of floor, regular paving stone and smooth asphalt, and two load conditions, load-free or full loaded in equivalent speeds. The vibration was measured in three orthogonal axis, x, y and z, and then calculated a weighted root-mean-square acceleration to face the results against ISO 2631-1:1997 standard. The main goal of this paper was to measure and compare the human whole-body vibration in forklift trucks operators, who are exposed to such repetitive load and complain about discomfort on their spines during this kind of machine operation. In general, it was possible to verify that the use of pneumatic tires resulted in lower values of equivalent acceleration. In this case, the super elastic tires showed results with higher acceleration magnitude.*

Keywords: *vibration in forklift trucks, whole body acceleration measurements, experimental measurements.*

1. INTRODUCTION

Accordingly to Vendrame (2003), vibration is a word that is usually used to refer to oscillatory movements of bodies around an equilibrium position. Regarding human vibration, it is common to consider all the harmonic oscillations and displacements caused by vibrating parts that are in contact with the body and that move it from it rest position. Vibration is also a harmful agent which is present at several labor activities nowadays. Chemical, forest, mining automotive industry is some examples of activities where vibration can be present and act as a harmful factor subjecting workers, for example, to localize vibrations (also known as hand-arm vibrations) and to whole body vibration. Each part of our body vibrates based on a set of characteristic frequencies; when external vibration excites the body and matches those characteristic frequencies, the resonance effect takes place and there is an amplification of vibration. As described previously, it is usual to separate two main vibration source categories for human beings: those that involves whole body vibration and those that involves just some human limbs, such as, hand-arm segment. The transmitted vibrations are generally low frequency, high amplitude accelerations. They are in the 1 to 80 Hz frequency range, specifically in the 1 to 20 Hz range. The motion sickness is also treated as wholly body vibration and it acts in the frequency range of 0.1 to 0.63 Hz. Such vibrations are more critical to activities related to transportations systems. Vibrations that reach the hand-arm segment (localized vibrations) are frequently studied and occur in the 6.3 to 1250 Hz range. This source of vibration can be found in drill excavation and wood extraction industry. The main sources of occupational exposure to vibrations are mainly related to, automotive passengers and drivers, lifters, stairway, as well as on tall buildings, including offshore platforms.. These vibrations sources may represent potential risk as they may affect the labor activities. According to Donald Wasserman *apud* Vendrame (2003), there are more than 2 million workers exposed to hand-arm vibration risks in the United States and this number is greater than the rest of the world. Most of these workers are users of hand-tool like pneumatics hammers, hydraulic and combustion machines. Such tools are regularly used on a variety of industrial activities including construction, forest industry, railway transportation, automotive maintenance, etc. According to Vendrame (2003), in 1918, an American physician labor, Alice Hamilton, produced the first medical studies on an Indiana quarry in the EUA, where works were using manual pneumatic vibration tool. Since there, she has been considered the pioneer in the medical researches on hand-arm vibrations. It was shown the relation between the regular uses of vibration electric tools to the irreversible and weakens medical disease mistakenly known as Raynaud Syndrome or with white finger disease, nowadays known as had-arm vibration syndrome. In general, the vibration transmission happens through some support surface. The evaluation of the exposure levels is accomplished based on the daily exposure expressed as weighted acceleration to 8 labor hours (working journey). In this work, the movement transmitted to the whole human body will happen through the forklift seat, for a seated driver. This vibration input can occur by the feet or back. The evaluation of vibration is accomplished by the Basic Method using the higher value for weighted r.m.s. (*root mean square*) acceleration on one of the three axis, expressed in m/s^2 that are measured according to three orthogonal vibration axis x, y e z of the body support surface (forklift seat). In order to manage the vibration risks, in the last years, there was an increase in the power and speed of industrial machines used to move or transport loads. Therefore a large number of machines present higher vibration levels transmitted to the drivers/passengers, and conversely the number of people affected by harmful vibrations. So, nowadays the study of such kind of problems has attracted attention for many researchers. The industrial machinery used, for example, in the paving industry, exposes the human body to mechanical vibration, which can affects the comfort, work efficiency, healthy and safety. However there are other factors that may cause vibration in the same way. Experimental and investigative tests have provided some answers to the problem of whole body vibration transmission. However, it is still difficult to separate the health effects from those only related to vibration. On actual situations, there are so many factors that this can become a hard task. The bad position, genetic inheritance and the sum of these factors can lead to cervical, abdominal and digestive injuries, urinary difficulties, visual disorders, headache and insomnia (Griffin, 1990). This paper intends to evaluate the vibration exposure levels in forklift drivers who are exposed on the day-by-day labor journey to such vibrations and then compare with the limits indicated by ISO 2631-1:1997, Mechanical Vibration and Shock – Evaluation of Human Exposure to Whole Body Vibration – Part 1: General Requirements. It wants to compare the transmitted vibration amplitude in the longitudinal axis (z axis) that might lead to the cervical and lumbar injuries to those values indicated by the Standard. Based on the measured data it is intended to nominate some improvements in the machine and the way it is operated.

2. BRIEF BIBLIOGRAPHICAL REVIEW

Due to variety of conditions and effects of the exposure of humans to vibration and due to lack of reliable data, this paper will be based on the ISO 2631-1:1997 Standards (this Standard is indicated by the NR-15 (Brazilian Regulation Standard), 8th annex, for evaluation of unhealthy vibrations) as guide for human exposure to wholly body vibration. Therefore, it is expected that this International Standard shows if any measured condition is within regular ranges. As an recent Standard it is expected that any case of harmful vibration be noticed and reported to gather more information and update the knowledge of human vibration. Generally speaking, there are three ways for human exposure o vibration: (a) Transmitted vibrations, both to whole body and limbs; (b) Transmitted vibration to whole body only by support surfaces; (c) Applied vibrations to specific parts of the body: head, ar.m.s., legs, hands, etc.

This paper will deal with the second type o transmitted vibration, particularly to support surfaces for seated humans. The analysis of the whole body involves the evaluation of the risk associated to the exposure to vibration. The International Standard ISO 2631:1997 describes the methods to evaluate the vibration related to human health, its interference with labor activities, discomfort and the possibility of motion sickness. This International Standard specifies the direction, location and duration of the measurements, requirements of the used equipments as methods to evaluation and acceleration measurements. According to the published article in September 2003, the WCB engineering company was invited to participate in ergonomic study to evaluate hand vibrations on bus drivers transmitted by steering wheel (HAV-Hand Arm Vibration) and whole body vibration (WBV-Whole Body Vibration), operating in normal conditions. It was concluded that both measurements were within the Standard limits. Therefore, in this case, these bus drivers were not exposed to any vibration risk. Filho *et al.* (2003) presented a paper where the vertical vibrations on agricultural tractors in the seat's driver, operating with plow and three service speeds. It was concluded that the acceleration levels on the seat were considerable lower than the levels measured on the base of the seat for the three investigated speeds, and the third gear presented the higher levels of vibration. However, the weighted acceleration levels were beyond ISO 2631-1:1997 Standard limits for a work day (8 hours). Brandão (2008) measured the vertical vibration on forklift trucks aiming at the comparisons for truck driver vibrations who complained about the use of super elastic tires (they frequently generated lumbar column fatigue). Finally they concluded that the truck drivers when exposed to vibrations generated by pneumatic tires equipped trucks were exposed to higher level of vibration and therefore this condition were more harmful to health compared to super elastic tires. It was noticed that for the consulted literature there are some controversies if some equipments presents or not risk to human health. In fact, this will depend on operational conditions and technical characteristics of these machines as well. Another important item is related to the exposure to vibration, driver's biometric characteristics. It was concluded that in each case, independently of the used equipment or the exposure time a critic appraisal should be done, based on the measurements, in order to precisely evaluate the risks to the vibrations

2.1. Problems related to vibration

Known as repetitive strain injury in Brazil (LER-Lesão por esforço repetitivo) and Work Related Musculoskeletal Disorders (DORT-disturbios osteomusculares relacionados ao trabalho) the incidence of these kind of disorders have presented a significant increase in the last years, according to official statistics of government offices related to worker health. This has been pointed as the most common cause of absence in the job and they represent the most reported work disorder for the Brazilian Social Security System (Ferreira Junior, 2000). Among the several types of diseases, the DORT, and specifically the low-back-pain is the main cause of inability of shirt and long term in the workers. This disorder affects about 80% of the population of workers. Some studies have shown a positive correlation between whole body vibration and pain, which leads to loss of day-to-day tasks and consequently reducing the worker's performance since it affects directly it's vertebral column. See Figure 1(a).

The association of bad posture and oscillatory movements may lead to low-back-pain and this is the start of a disease that if not treated may evolve to a lumbar hernia in which a tear in the outer, fibrous ring (*annulus fibrosus*) of an intervertebral disc (*discus intervertebralis*) allows the soft, central portion (*nucleus pulposus*) to bulge out. When a vibratory movement occurs, a contraction in the back muscles happens (in the attempt of the body to maintain posture) which cause a conflict between the nervous and the disc since they fill the same place. So, a curvature may occur in the disc which presses the medulla causing pain. As time goes on, vertebral degeneracy may occur, worsen the problem and pain. Figure 1(a) and (b) shows, in detail, the parts of the vertebral human column which are responsible to pain. As stated previously, vibrations that are transmitted to human body are classified in two groups, according to the reached area: whole body, low frequency and large amplitude vibrations in the 1 to 80 Hz range and the hand-arm system, which reaches just parts of body as limbs, in the frequency range of 6.3 to 1250 Hz. The vibration may cause adverse effects to health, in the activities related to machine operation, comfort or even cause motion sickness. Severe and continued exposures to vibration may lead harm to the body.

a) b)

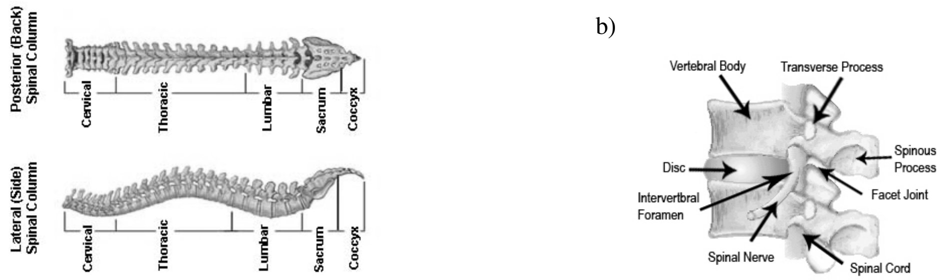


Figure 1. (a)Human vertebral column,(b)column detail.

The body parts more sensitive to vibration depend on the magnitude, distribution in the body, frequency, duration and direction of vibration. Based on epidemic research, biodynamical models are presented relating the vibration intensity with the harm they may cause and also mechanical properties of tissues and bones of human body. Therefore administrative controls may be accomplished in order to avoid those harmful effects. The training is an important aspect in the prevention to future problems related to vibration exposure. Drivers should be informed about human vibration, health and other effects related to vibration exposure and the different methods used to mitigate. Bad posture is only one of the causes of low-back-pain, so the drivers should be trained to keep a straight posture in order to minimize the risks of the vibration transmission. In the case of seated workers, straight posture may lead to well-being at the end of the day. The maintenance of the seat is crucial even in seats prepared with suspension systems since they have a limited service life when compared to vehicle service life. The training should guide the vehicle driver on how operate with suitable velocity and avoid bumps and other obstacles. The health surveillance may happen through medical assistance or therapeutics that should be taken by the worker frequently. It is important to visit a professional not only when symptoms are present but periodically. When some pain or uneasy show up this means that the injury is on advanced level of commitment. It is advised take some initial exams in order to identify initial column, heart or intestinal disorders, since these problems can be exaggerated by transmitted vibration to the body. Habitual exams when hiring drivers are important since the may identify if some of these problems are progressing or a new one is developing.

2.2. Whole body vibration related to heavy machinery

Over the years whole-body vibration has mainly been associated with transport. This can be the transport of people, goods or materials and transmitted through the tractors used in forestry and agriculture, trucks, cranes, forklifts, among others construction equipments. In research conducted on the occupational exposure to vibration and published by Rui Melo (1993), you can see the percentage occupied by each machine on vibration when compared to others machineries, as shown in Figure 2.

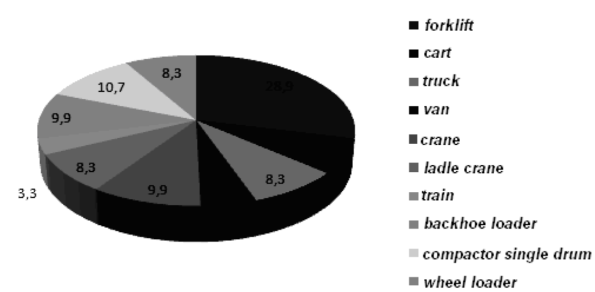


Figure 2. R.m.s. acceleration for each machinery type (Directive 2002/44/EC).

Among the surveyed machines, which have some industrial application, construction or services in general, two stands out by the high rate of vibration: forklifts and compaction rollers. The forklift trucks are responsible for 28.9% of effective value of acceleration, which is directly responsible for the vibration transmitted to the person, while compaction rollers contribute with 10.7%.

2.3. Duration, direction and place of measurements

The duration of measurements should be long enough to be representative in a statistical sense and to ensure that the vibration measured is typical for the exposures which are being assessed. When deciding on the duration of measurements, it is important to analyze all the tasks that are being undertaken and any additional conditions that may affect the duration. Very often a complete exposure consists of several periods with different characteristics. To fully assess the exposure, separated analyses of those periods may be required. Each time, the duration of measurements should be recorded in the final assessment report. Once all the measurements are carried out, the results need to be analyzed in accordance with an approved procedure to be later compared with the exposure standards. Axial vibrations transmitted to man should be measured in appropriate directions orthogonal to a coordinated system, which origin is at the geometric center of the surface of contact. The terminology commonly used in the biodynamic system relates to the coordinated human skeleton in normal anatomic position. Accelerations in the feet and buttocks are designated $\pm a_z$; accelerations in the front and rear axle (*anteroposterior* or chest / back), $\pm a_x$, and the lateral axis (right to left), $\pm a_y$, as shown in Figure 3:

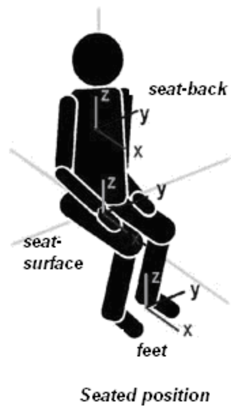


Figure 3. Orthogonal axis definitions for acceleration measurements (ISO-2631, 1997).

After selecting the most appropriate instrumentation for the measurements, the next step is to consider the location for the selection of measurements. This is very important to remember, because the vibration transmitted to the body should be measured on a point of application of the body. For a seated person, the entry point would be the seat, the backrest of the back and feet. The decision to use the orientation of the instrumentation, the location most appropriate to adjust the duration and accelerometer measurements to represent a typical measurement, ensure the overall quality of data collected and therefore the results.

2.4. Evaluation of human body exposure levels to vibration

The ISO 2631-1:1997 uses acceleration as the primary measure for analysis of vibration. In some cases, where the vibration and frequency are very low, measurements can be made in speed and turned into acceleration. It is known that each part of the body has a resonance frequency, reacting therefore differently to each vibration input. As a result, different weighting factors in frequencies are used, depending on the direction of transmission of vibration to the body, as shown in the curves shown in Figure 4(a). The idea of these curves is the weighting function as a filter, to let go only the interested acceleration that affects certain part of the human body. Figure 4(b), as reported by ISO 2631-1:1997, shows situations where the frequencies are considered for each direction. This study emphasizes the problem in health, therefore, takes into account the factors of weight Wk for z axis vertical vibration in a range of between 4 to 13 Hz and vibration factor W_d to the axle x and y to with 0.5 at 2 Hz range . As health related, is also taken into account the additional factor W_c. However, this is not addressed, because the measurements were taken only for the seat and not the back, without any prejudice to the results.

2.5 Application of the weightings and assessment of Basic Method

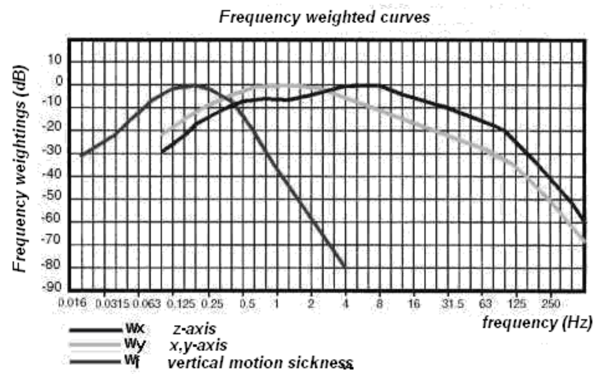
The ISO Standard requires that the evaluation includes measurements of weighted r.m.s. acceleration, which is expressed in m/s^2 for translational vibration and rad/s^2 to rotational vibration. Typically, it incorporates a weighted acceleration in the design of equipment to be used. This equipment has circuitry or software that apply the Fourier

Transform of the signal of the acceleration (in dB) and thus apply the weighting curves as indicated above. As already mentioned, it is used for the vertical vibration in the z axis for the seat, the weighted acceleration Wk, which has greater sensitivity in the range between 4 to 13 Hz for the vibration unlike the horizontal x and y axis, the weighted acceleration W_d have greater sensitivity in the range between 0.5 to 2 Hz. The basic evaluation method is the weighted r.m.s. acceleration method. This method accounts for the frequency content and is expressed as equation 1:

$$a_{rms} = \sqrt{\frac{1}{T}\int_0^T a_w^{\,2}(t)dt} \tag{1}$$

where $a_{r.m.s.}$ is the weighted acceleration (m/s^2) r.m.s., T is duration of the measurement (s), a_w is the weighted acceleration already weighted by the curves previously indicated. The ISO Standard recommends several methods of calculation of weighted acceleration $a_w(t)$ depending on the characteristics of vibration. For those types of vibrations containing shocks, when the crest factor is more than 9, it is recommended to use additional evaluation methods like the running r.m.s. or the Fourth Power Vibration Dose Method. If the crest factor is below or equal to 9, the basic evaluation method is normally sufficient. Crest Factor is the ratio between the maximum acceleration value divided by the measured r.m.s. acceleration ($F=a_{max}/a_{r.m.s.}$). If the acceleration in one axis is larger than the two others, the standard allows using only the higher vibration r.m.s. value.

a)



b)

Weighting Factor in frequency	Healthy	Comfort	Perception	Motion Sickness
W_c	X axis, Back rest	X axis, Back rest	X axis, Back rest	-
W_e	-	x, y and z axis, Seat surface	x, y and z axis, Seat surface	-
W_j	-	lie	lie	-

Frequency	Healthy	Comfort	Perception	Motion sickness
W_k	Z axis, seat surface	Z axis, seat surface Z axis, stand	Z axis, seat surface Z axis, stand	-
		lie (except head) x, y and z axis, feet (seated)	lie	
W_d	X axis, seat surface Y axis, seat surface	X axis, seat surface Y axis, seat surface x and y lie	X axis, seat surface Y axis, seat surface x and y lie	-
		y and z axis, back	-	
W_f	-	-	-	vertical

Figure 4. (a)Weighting curves to measured accelerations, (b) weighting Factors as function of acceleration direction and supplementary weighting factors (ISO 2631-1:1997).

If the r.m.s. vibration levels are similar, the standard recommends that you use the vector combination of the three r.m.s. accelerations, i.e.

$$a_{rms} = \sqrt{k_x a_{rms,x}^{\;2} + k_y a_{rms,y}^{\;2} + k_z a_{rms,z}^{\;2}} \tag{2}$$

where is the r.m.s. acceleration value (m/s^2) on the *x* axis and k_x is a multiplicative factor that takes into account the importance of acceleration and statistical knowledge about the risks to health (using the curve Wd, the factors are $k_x = k_y = 1{,}4 \quad e \quad k_z = 1$). Another method, more sensitive to peak accelerations that the r.m.s. value of the method, uses a power similar to the fourth order method to measure the r.m.s. value, as shown in Equation 3.

$$VDV = \sqrt[4]{\int_0^T a_w(t)^4 dt} \tag{3}$$

where VDV is the Vibration Dose Value (m/s^{1,75}) corresponding to instantaneous weighted acceleration a_w (m/s^2). If exists more than one exposure to vibration in a day, the final value of the VDV is given by:

$$VDV = \sum_{i=1}^{n} \sqrt[4]{VDV_i^4} \tag{4}$$

where n is the number of cases of exposure to vibration. Apparently, the second method could be considered more conservative because it takes more account of the acceleration peak values, but different curves of vibration limits are adopted in this case, making the two methods practically equal to the exposure time for 4h or 8h. In this paper, only the first method will be used to assess the risk of vibration to healthy.

In order to find the healthy problems associated to vibration, the weighted acceleration r.m.s. should be evaluated to periodic vibrations as for non-periodic vibrations in a wide range of frequencies. Such vibration is transmitted to the driver seat and then to the wholly body since the frequency range are about 0,5 to 80 Hz. For seated persons, the multiplicative factor "k" should be included. For x and y axis it is recommended to use W_d curves and k=1,4; for z axis, it is recommended to use W_k curve and k=1.

In order to evaluate the effects for healthy, two relations can be used to evaluate the equivalent vibration value for different exposure times. These equations allow the evaluation of an equivalent weighted acceleration a_{w2} for a desired time of exposure T_2 given a measured weighted acceleration a_{w1} for an exposure time of T_1

$$a_{w1}\sqrt{T_1} = a_{w2}\sqrt{T_2} \quad \text{and} \quad a_{w1}\sqrt[4]{T_1} = a_{w2}\sqrt[4]{T_2} \tag{5}$$

Each equation should be used regarding the vibration evaluation model (first equation for r.m.s. acceleration and equation 2 for VDV Method). Figure 5 represents the two equations. The region between the dashed lines refers to warning zones and indicates that the vibration levels deserves attention and should be mitigated. For the positions below the dashed lines, which are referred as VAE (Vibration Action Exposure), the effects to healthy are not clearly demonstrated by the literature and theoretically are safe vibrations. Above the outer dashed line (for each equation), which is referred as VLE (vibration Limit Exposure), there is a highly probable risk to harmful vibration to healthy. It is clear from the Figure that for exposure times of 4 h and 8h both equations are similar.

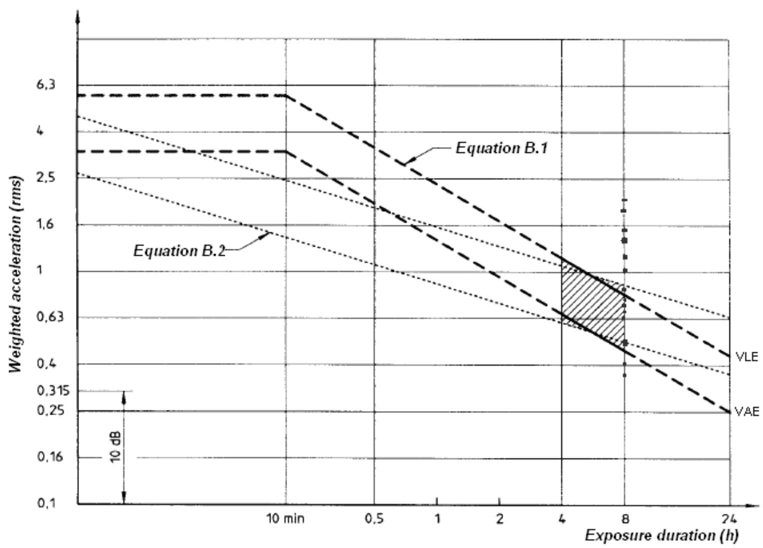


Figure 5. Weighted acceleration curves x exposure time, ISO 2631-1:1997 (lower curve –action limit to vibration, upper curve- exposure limit to vibrations).

3. INSTRUMENTATION

A transducer is a device that transfers and transforms one measure variable into another. Modern measurements use transducers which transform mechanical vibrations into electrical energy. The most suitable transducer to measure vibrations in the human body is the accelerometer. It produces an electrical output that is proportional to the sensed acceleration. The most common types of accelerometers are the piezoelectric, piezoresistive and capacitive. In order to measure, the choice of the right equipment is important. It should be taken into account the total time of measurements, the sampling frequency rate, number o channels. Once measured, the accelerations should be processed in order to apply the standard filters in accordance to the directions of measurements. The vibration is measured usually by accelerometers embedded on devices that are ergonomic aiming not to cause changes in the seat, the way the operator uses the machine or his attitude. The device is allocated in order to follow the contour of the seat. It contains a tri-axis accelerometer for simultaneously measurements in tree direction. A very important detail that should be verified is related to the alignment of the device in the right axis, following ISSO 2631 specifications.

3.2 Data acquisition program

It was used a vibration dosimeter VI-400, S/N 12430 made by Quest Technology Inc., to acquire acceleration. In order to set up the dosimeter to receive information from accelerometer it was used the Quest Suit PRO VI software, which offers the possibility to use pre-set values. Before any measurement, it was selected three measurements channels x, y and z. The software allows adjusting to record all the measured signals. It as selected and integration time referred to an exposure time of 8h. The "k" factors were set accordingly. k_x=1,4 for x-acceleration, k_y=1,4 for y-acceleration and k_z=1,0 for z-acceleration. All the data are saved and then exported to the dosimeter by USB cable. In this study it was used accelerometer with x-sensitivity 100 mV/g, y-sensitivity 98,3 mV/g and z-sensitivity 101,4 mV/g, and the seat pad was positioned in the interface of the seat and the driver, in such a way the operation of the vehicle was not modified nor his posture while driving.

It was used two identical forklifts but with different tires. It was analyzed the acceleration in the three axis and than calculated the weighted acceleration which was confronted with the limits indicated in the ISO 2631-1 Standard. The measurements were achieved with the drivers seated since the body stress affects the transmission of the vibration through the seat. The procedure was executed in service conditions of use, as recommended by ISO 2631 Standard.

4. VEHICLES USED IN THE TESTS

The vehicles used in the tests were identical. Figure 6 shows the forklift used in the tests. The vehicle presents the following features. Forklift by Clark, model CMP25L, 2,5 ton capacity, Mitsubishi 4G64 engine, GLP fuel, with forks and retracted side supports, DLG, Clark transmission TA18, triplex turret (3 stages) 189" and forks with 1070mm.

One of the vehicles was equipped with pneumatic tires and the other with solid tires (superelastic). The tire specifications are presented on Table 1.

Table 1. Tire specifications.

Model	Specification	Specification	Pressure	Pressure
	Front	Rear	Front	Rear
BKT PL801 (forklift 1)	700x12	650x10	4,8 bar (69 psi)	5 bar (74 psi)
Master Solid Monomtic (forklift 2)	700x12	650x10	Solid	

5. FORKLIFT MEASUREMENTS PROCEDURE

The first step was to make a mock test in order to collect initial parameters necessary for better measurements and fix problems related to the position of the instrumentation. It was choose two types of pavements for comparisons. Pavement 1 means block pavement and pavement 2 means smooth asphalt. Each pavement condition was accomplished with pneumatic and solid tires. Another variable analyzed was the load condition using a comparative load of 1.000 kg. It was adopted an acronym for each measured configuration, taking into account the elected pavement, load condition and tire model. Each driver was individually interviewed and asked for personal opinion about the vehicle operation in such conditions. Both drivers complained about the vehicle operation on block pavements, unload condition and solid tires, they pleaded this conditions would be harmful for their healthy. This was later confirmed by the measurements. The driver's characteristics are listed in Table 2:

Table 2. Driver's characteristics.

Driver	Weight (kg)	Age (years)	height (m)	IMC
A	75	29	1,79	23,41
B	90	26	1,80	27,78

As stated previously, the measurements were performed in order to reproduce service conditions. Thus, it was recommended to the drivers to operate as a normal day-to-day condition in order to minimize uncertainties, as recommended by good practice of unhealthy condition measurement. The acquisition was accomplished for a total time of 60s and a sampling rate of 50 kHz far from the lower limit for aliasing. This high sample rate is due to the use of the dosimeter as a sound dosimeter for acoustical measurements.

6. RESULTS

The measurements results are presented through tables. In order not to became repetitive and tiresome, it will be emphasized only the extreme results, those which present maximum and minimum results for acceleration measured in the operation of the forklifts, or in other words, the most harmful and less harmful vibrations for the drivers. The computations were made aiming the equivalent acceleration for 8h daily work journey and using the second Equation (5). In order to have limit references for harmful vibration it is used two limit values (vibration action limit and vibration limit exposure). Using the previously equations indicated by ISO 2631-1, the lower limit used was VAE= 0.5045 m/s^2 and the upper limit used was VLE= 0.8291 m/s^2 for 8h exposure time.

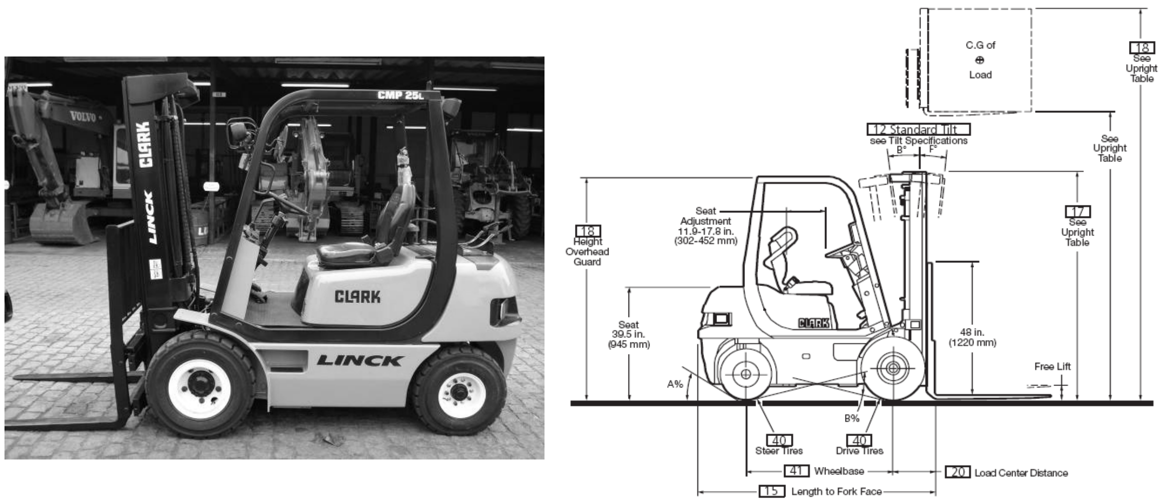


Figure 6. Clark Forklift Model CMP25L.

As indicated by Table 3, the acquired vibrations for block pavement and solid tires are relatively higher than those with pneumatic tires. In the unload condition, the most harmful condition for both drivers, the vibration affects considerably driver column (VLE) if driver A exposes to more than 1h 24min and for driver B more than 1h47min, as indicated by Table 3.

Table 3. Measurements on block pavement and solid tires.

Measurement	Driver	Load	x	y	z	r.m.s.	Time to VAE	Time to VLE
VIB10	A	Without	0.6202	0.4814	1.6199	1.9576	00:31	01:24
VIB11	B	Without	0.6102	0.6599	1.1967	1.7366	00:39	01:47
VIB12	B	With	0.4217	0.4227	0.9817	1.2894	01:12	03:14
VIB13	A	With	0.378	0.3728	0.7534	1.0583	01:47	04:48

On the other hand, for load condition operation, the driver might be exposed to longer times. Driver A will have harmful effects(VLE) with exposure times more than 4h48min while driver B has a limit of 3h14min of exposure. These exposure times are considered low values when compared with a daily 8h work journey,

The second situation referrers to smooth asphalt pavement and the use of pneumatic tires, Table 4. This condition showed less harmful to healthy than the previous situation (block pavement). In this case, the less harmful situation, loaded, the drivers would be exposed for such vibrations for more than 24h.

However, in the unloaded condition, driver A would be exposed to a limit of 15h32min, while driver B would be exposed to a limit of 16h27min as can be noticed in the Table 7. Therefore, when the two conditions are faced , it is evident that the smooth asphalt pavement with pneumatic tires and loaded presents less harmful vibrations to driver healthy and thus the driver would not suffer injuries and would work the full journey without the .

Table 4. Measurements on smooth asphalt pavement and pneumatic tires.

Measurement	Driver	Load	x	y	z	r.m.s.	Time to VAE	Time to VLE
VIB29	B	With	0.1669	0.1545	0.1941	0.3729	14:22	>24
VIB31	A	With	0.165	0.2339	0.2133	0.454	09:42	>24
VIB30	B	Without	0.1892	0.2732	0.3323	0.5718	06:07	16:27
VIB32	A	Without	0.1732	0.2822	0.3474	0.5824	05:54	15:32

The full records of the measurements are presented in the following Tables 5 and Table 6 and confirm what was noticed previously.

Table 5. Measurements on Block pavement and pneumatic tires.

Measurement	Driver	load	x	y	z	r.m.s.	Time to VAE	Time to VLE
VIB6	A	Without	0.4421	0.5041	1.1429	1.4789	00:54	02:27
VIB7	B	Without	0.5761	0.6159	1.0316	1.5678	00:48	02:11
VIB8	B	With	0.3436	0.3323	0.5099	0.8413	02:49	07:36
VIB9	A	with	0.2591	0.2894	0.4989	0.738	03:40	09:52

Table 6. Measurements on smooth asphalt and solid tires.

Measurement	Driver	Load	x	y	z	r.m.s.	Time to VAE	Time to VLE
VIB29	B	With	0.2048	0.1965	0.3737	0.5715	04:07	09:17
VIB31	A	With	0.2003	0.2609	0.3221	0.6334	05:00	10:24
VIB30	B	Without	0.2407	0.2927	0.3855	0.7569	06:40	11:30
VIB32	A	Without	0.2654	0.3013	0.471	0.651	08:16	11:33

7. CONCLUSION

Preventing the exposure to vibration transmitted to whole body means reduce severe vibrations and potential harmful effects. This can be reached by several ways, such as simple action but effective that applied in the right way may result on notable improvement. Aiming at the healthy care, reducing the transmission of vibration to the body and the exposure time, as well, may reduce harm probability. Another simple solution was to use a suspension system with dashpots on both wheels and seat. As the forklifts are machines that were designed for indoor tasks and on smooth pavement condition it would be predictable that the operation in situations different from those might generate adverse vibrations. Some design modifications may improve driver comfort, vehicle service life, since less vibration may reduce wearing.

Analyzing the results, it was concluded that some forklift drivers in certain conditions are exposed to vibration values above ISO 2631 Standard limits recommendations (in this work, most of the cases) for a daily 8h work journey.

It can be noticed that 43.5% of measurements are above VLE limit, which is a harmful condition with high level of probability of injury. Measurements between VAE and VLE limits, which is a zone considered potentially harmful, represents 44% of the measurements. 12.5% of the measurements presented equivalent measurements VAE limit for the second equation and theoretically, drivers subjected to such vibrations will not present any healthy effects during his work life.

The second remarkable conclusion is that the operation with solid tires presents values of vibration higher than pneumatic tires for any type of pavement. This probably is due to the fact that impact absorbed by the tire is largely transmitted to the driver since here is no suspension system. On the other hand, the pneumatic tires absorb part of the vibration as a dashpot.

At last but not at least is that in the loaded condition the vibrations are less intense. This can be explained by the fact that forklift center of gravity (CG) shifts accordingly with the load in the fork. This shift occurs in the triangle sketched in Figure 7. This triangle is called Stability Zone. As the forklift is loaded the Center of gravity shifts ahead from line 1 to line 3, becoming more stable as can be seen by the Figure 7. Otherwise, it shifts backwards to line 2 becoming instable and more susceptible to vibrations.

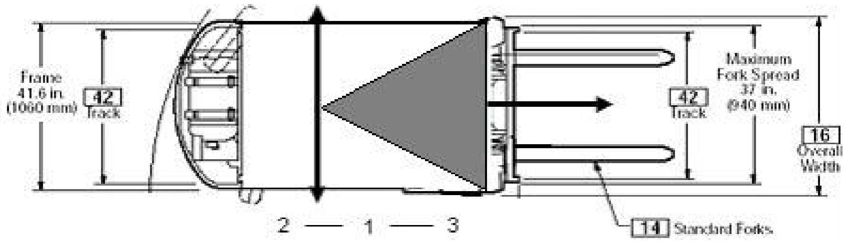


Figure 7. Forklift stability zone (gray triangle).

Despite the disadvantages of the pneumatic tires (need of frequently calibration, chance to be perforated, less time to wear, lower load capacity) when compared with the solid one, this type of tire offers better benefits regarding healthy, comfort in operation and this should be taken into account when choosing forklifts trucks.

8. ACKNOWLEDGEMENTS

The author acknowledges the CNPq financial support to this research.

9. REFERENCES

Brandão, J. G. T., Tomazini, J. E., Amann, B. O., 2008, "Análise de Vibrações em assentos de empilhadeira" (in Portuguese), In: Proceedings of the 7th Brazilian Conference on Dynamics, Control and Applications, DINCON.

Clark, 2007, "Catálogo Informativo das Empilhadeiras Clark", <http://www.clarkempilhadeiras.com.br>(in Portuguese). Accessed on 12/09/2008.

Directive 2002/44/EC, 2006, Guide to good practice on whole body vibration, Version 6.7, 65p.,12/06/2006.

Ferreira Jr., M., 2000, "Saúde no trabalho: temas básicos para o profissional que cuida da saúde dos trabalhadores"(in Portuguese), São Paulo,Roca Ed., 357p.

Filho, P. F., Fernandes, H. C., Queiroz, D. M., Souza, A. P., Camilo, A. J., 2003, "Avaliação dos Níveis de Vibração Vertical no Assento de um Trator Agrícola de Pneus Utilizando um Sistema de Aquisição Automática de Dados", (in Portuguese), Revista Árvore, vol.27, no.6, Viçosa.

Griffin, M. J., 1990, Handbok of Human Vibration, London, Academic Press.

ISO 2631-1:1997, "Mechanical Vibration and Shock – Evaluation of Human Exposure to Whole Body Vibration – Part 1: General Requirements".

ISO 5349-1/2:2001, "Mechanical vibration – Measurement and evaluation of human exposure to hand-transmitted vibration – Part 1: General requirements". Part 2: Practical Guidance for measurement at the workplace".

ISO 8041:2005, "Human response to vibration - Measuring instrumentation".

Melo, R., 1993, "Health and Safety Executive", HS(G) 150, United Kingdom, 58p.

NR 15, 2001, "Norma Regulamentadora do Ministério do Trabalho e Emprego" >(in Portuguese), Anexo 8.

Occupational Health and Safety Regulation, 1998, "Worker's Compensation Board of British Columbia", Contry regulation.

Quest-technology, 2008, "Vibration monitors and Real-time vibration Analyzers", VI-400 PRO, 203p.

Vendrame, A. C., 2008, "Exposição ocupacional à vibrações" (in Portuguese), <http://www.vendrame.com.br/downloads/>, Accessed on 12/09/2008.

10. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.