ASSESSMENT OF EXPOSURE TO WHOLE BODY VIBRATION OF A FORKLIFT OPERATOR

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Abstract:*Operators of construction, agricultural and reloading machines are exposed to numerous negative effects, where the vibrations are in the group's most important. They are expressed by the operator to order the heavy reloading, construction and mining machinery. These are actually forced mechanical vibration body ie operating principle Whole body vibrations (WHV). The paper will be presented to forklift operator exposure to vibration of the whole body, with the observed two types LINDE H25T and Caterpillar D70. Many factors influence the occurrence of vibration fork and directly related to styles and moments that arise in the process of working on the engine, because the ways of suspension and chassis construction forklifts, seat of the vehicle type (mechanical or pneumatic), tire type, and quality of surface roughness interactions grounds and vehicles. The dominant influence of the size of their offices WHV forklifts, order the seat mechanical type. The paper discusses their effect to vibration. It was observed that during working hours at Linde forklift type equivalent to the value of the acceleration is very close and relatively small in all three directions, while the dominant type Catelpilar the Z direction. The paper also provided recommendations to reduce the impact of vibration or eliminate them.*

1. INTRODUCTION

During their daily work routine, operators of construction, agricultural, and transshipment equipment are exposed to numerous negative factors with complex adverse effects on human. Beside noise, dust, high temperature, and poor performance of commands, one of the significant negative factors is vibration. Workers especially exposed to vibration are drivers of heavy transport and agricultural vehicles, locomotives, and helicopters, operators of heavy construction machinery, as well as operators of mining and military equipment [1].

These are unavoidable mechanical vibrations during psycho-physical engagement of a man which affect the whole body, so these vibrations are usually called whole-body vibrations – WBV. These vibrations are transmitted through the lower part of the back, if a person sits while working; or through the feet if a person stands while working.

The exposure of heavy vehicles operators to the whole-body vibrations has been especially observed during the last 20-30 years, along with the development of heavy equipment. Since then, one has begun to perceive the correlation between the short- or long-term exposure of workers to the whole body vibrations caused by these machineries and certain more or less serious diseases [2]. Short-term exposure can cause discomfort in the human body, stomach and chest pain, shortness of breath, nausea, loss of balance, as well as decrease in performance of precise manipulation tasks. On the other hand, the long-term exposure may cause disorders of psychomotor, physiological and psychological systems of workers, as well as serious health issues, especially those related to spine.

Main sources of WBV are seats of industrial and agricultural vehicles, as well as platforms of heavy construction machines. Impact of other factors should not be forgotten, such as standing, (quality of) operative surfaces, vehicle design, vehicle speed, type of pneumatic, even the weight of operators. One of the most important factors is skill of a worker operating a forklift.

This paper will assess the exposure of a forklift operator to the whole body vibrations. The assessment is based on vibrations level of forklifts Linde H25T and Caterpillar D70. According to the assessment of exposure, an overview of measures will be given which could reduce the level of the whole-body vibrations that operators of the forklifts are exposed to.

2. FACTORS IMPACTING MAGNITUDE OF VIBRATIONS

The forklift is recognized as a vehicle with a risk due to the whole-body vibrations. The forklift is necessary equipment in production, transshipment and storing goods. It has been estimated that there are over 800,000 forklifts with more than 1.2 million operators in the USA only [3]. It is disturbing information that 100 workers die in accidents each year, and almost 20,000 get injured while operating forklifts [4]. Approximately 90,000 forklift operators in Great Britain work at increased risk [5].

In the European Union, correct implementation of preventive measures relating to workers' exposure to vibrations is regulated by Directive 2002/44/EC [6]. The whole-body vibrations are defined in more details by the international standard ISO 2631 [7], [8].

The whole-body vibrations are transmitted in three basic ways:

- Through the seat – they cause the whole body vibration of the operator;
- Through hand controls and steering wheel – they cause vibrations of the upper extremities;
- Through the bottom of the cabin and foot controls – they cause mostly local vibrations of the lower extremities of the operator.

Factors that impact occurrence of the vibrations of forklifts are many, and they are directly correlated with forces and momenta created by the working motor, due to the bottoming of the chassis and construction of the forklift, type of seat (mechanical of pneumatic), type of pneumatics, quality of a surface, i.e. interaction between a rough terrain and the vehicle, etc. [13]:

All these factors can be placed into two groups [9]:

1. Continuous – permanent impact factors such as motor type, tire type for forklifts, seat type, etc.
2. Transitory – sudden impact factors, such as moving over obstacles or rough terrain.

It is interesting that the ISO 2631 Standard takes only the effect of the continuous factors into consideration, while it does not deal with sudden factors. However, one has to pay attention to these factors, because these shakes are cause of back injuries in operators of heavy mobile equipment in 36% of cases [10].

Seats have significant impact on the magnitude of the whole-body vibrations. Seats of old forklifts are typically mechanical, with less possibility to isolate vibrations. According to forklifts manufacturers, new anti-vibrations, pneumatic seats can significantly reduce a vibration value [11]. Testing the forklift vibrations, according to EN13059, has shown that the values of the measured vibrations with new FLM80 seat (Figure 1) are three times smaller than the values with old mechanical seats.

Figure 1 FLM 80 seat

Also, impact of the vehicle speed on the magnitude of vibration should not be forgotten. Moving over an obstacle of $18mm$, a magnitude of vibration is increased 20% if the speed is increased for only $2\ km/h$, and it is even 75% increased if the speed is increased for $4\ km/h$ [11].

It is known that the effect of the surface on which the vehicle moves has also effect. Flat, smooth, clean surface, with all other conditions unchanged, produces five times less vibration than rough surfaces.

Impact of the mass of the operator in relation to the seat type is also interesting. For operator's mass under $85kg$, vibrations with mechanical seats are stronger than with pneumatic seats, but if the mass is above $116kg$ the value of vibrations with pneumatic seats is greater than with mechanical seats.

It is difficult to eliminate the presence of many factors that affect the occurrence of vibrations, which are transmitted through elastic, semi-elastic and rigid connectors to the driver's seat. It is, however, possible to reduce the intensity of vibrations with appropriate constructive solutions.

Last, but according to its impact on the magnitude of the whole-body vibrations possibly the first, is the behavior of the operator. Unskilled operators are not aware of the significance of speed and its impact on the vibrations, so they usually choose higher speed on a well maintained surface.

3. ASSESSING VIBRATION LEVEL

The whole-body vibration is measured in three mutually perpendicular directions, x, y, z. Health risk is not the same at all frequencies. For vibrations that are transmitted to the whole body in vehicles and on platforms, a measure filter of to $8Hz$ is used in the Z-direction, while filters of and $2Hz$ are used for measuring in the X- and Y-directions.

Since the health risk is not the same at all frequencies, the probability of health damage caused by exposure to vibrations at different frequencies is assessed by evaluation at different frequencies. According to frequency, there are two ways to evaluate the whole body vibrations. First, so called Wd weighting, is used for vibrations in two perpendicular axes, "x" and "y" (the values of measured accelerations awx and awy are multiplied by factor 1,4). The other, so called Wkweighting, is used for vibrations in the vertical "z"-axis (measured acceleration is not multiplied).

The level of exposure of workers depends on both the level of vibrations and duration of the exposure to vibrations.

The vibration level expressed as the effective acceleration level or root-mean-square is equal to average acceleration, measured on the seat while a person sits on it performing different tasks. Acceleration equivalent level (Aeq) is a constant value of acceleration which in a period of time (T)has the same energy value as the effective acceleration level.

Exposure of people to whole-body vibrations should be evaluated by the method given in ISO 2631-1:1997 standard, and the instruction for applying this method of measuring vibration on a work place is given in EN14253:2003 practical guidance.

According to the Directive 2002/44/EC, assessment of vibration level is done by two methods:

- Determining daily exposure level, A(8)–equivalent continuous acceleration over an eight-hour period
- Vibration dose value (VDV)–which is a cumulative dose.

In case of daily exposure to whole-body vibrations, there is an exposure limit value (ELV) which may not exceed $1{,}15\,m/s^2$ in professional conditions, and exposure action value (EAV) which is $0{,}5\,m/s^2$; if this value is exceeded, the employer are obliged to control risks that arise from vibrations. National regulations may have stricter demands.

Since the introduction of the Directive 2002/44/EC on protection against vibrations, all companies in Europe have been obliged to assess the risks of jobs that are exposed to vibrations.

In case of daily exposure$A(8) = 0{,}5\,m/s^2$, workers should be informed on risks due to exposure to vibrations. If $A(8) > 0{,}5\,m/s^2$, the measures of reducing vibrations must be carried out, and workers must be provided with preventive medical examinations. If $A(8) > 0{,}8\,m/s^2$(or $A(8) = 1{,}15\,m/s^2$, depending on national regulations), measures must be immediately carried out in order to avoid this excessive exposure, and workers have to take regular preventive health examinations.

In this paper, for assessing the exposure to the whole-body vibration, a daily exposure level will be determined.

4. DETERMINING LEVEL OF DAILY EXPOSURE TO THE WHOLE-BODY VIBRATIONS OF THE FORKLIFT OPERATOR

Assessing the level of daily exposure to vibrations of a forklift operator will be conducted by means of measured values of the vibration level on the seat of the forklift Linde H25T with the capacity of $2{,}5t$and Caterpillar D70, with the capacity of $6{,}5t$.

The measures are taken from the research *Whole-body vibration on construction, mining and quarrying machines*, prepared by Silsoe Research Institute, 2005. [12]

The vibration specification, beside basic data about the vehicle, offers data on the seat type, driver's weight, vehicle suspension, and pneumatics type, because these are important for the magnitude of vibrations.

4.1. Forklift Linde H25T

The period of working and measuring was 2h 50min, during which the operator had two breaks in duration of 10 minutes each. Driving surface was of a variable, but still good quality (Figure 2), and the operator had to spend few moments outside the vehicle in order to handle the cargo – concrete blocks.

Table 1

Model	H25T
Weight	$3890kg$
Capacity	$2500kg$
Power	$38kW$

Suspension	no suspension
Seat type	Grammer MSG85/721- mechanical
pneumatics	Continental 23×9-10
Driver's weight	$83kg$

For calculating the daily exposure level, it will be assumed that the worker had constantly the same task.

Figure 2. Condition of the driving surface

There was a good quality mechanical seat embedded in LINDE forklift – Grammer MSG85/721.

Measuring the vibration level was conducted by the Larson Davis HVM 100 instrument, which a measuring sensor PCB 356B40. The sensor was placed on the driver's seat (Figure 3).

Fig.3. 'Seat' accelerometer configuration incorporating operator presence switch (Grammer MSG 85/721)

Measured average vibrations values in all three axes, as well as the maximal values are given in Table 2 and Figures 4, 5, and 6

Table 2

Acceleration equivalent level - $Aeq\ m/s^2$ in three perpendicular directions		
awx (in x-axis)	awy (in y-axis)	awzin z-axis)
0,40	0,45	0,58
Maximal acceleration values(m/s^2) in three perpendicular directions		
X	Y	Z
4,31	4,72	21,70

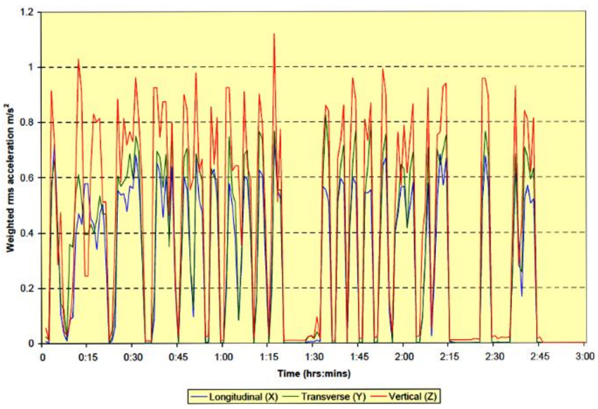

Figure. 4 Linde 2.5 tonne fork lift truck:- time histories of weighted 1-minute rms seat accelerations (X, Y and Z-axes)

The highest vibration values (maximal and equivalent) are measured in Z-axis at each moment of measuring. Frequency range of vibrations was from to $5Hz$.

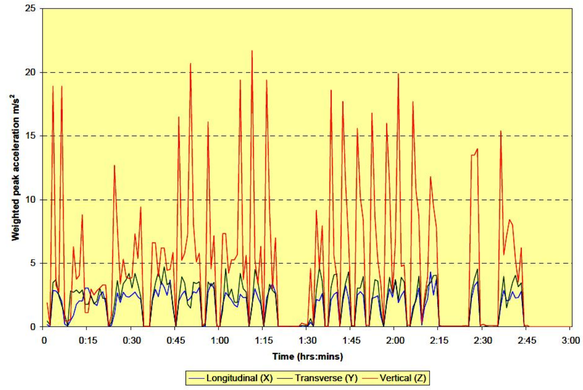

Figure 5 Linde 2.5 tonne fork lift truck:- time histories of weighted 1 minute peak seat accelerations (X, Y and Z-axes)

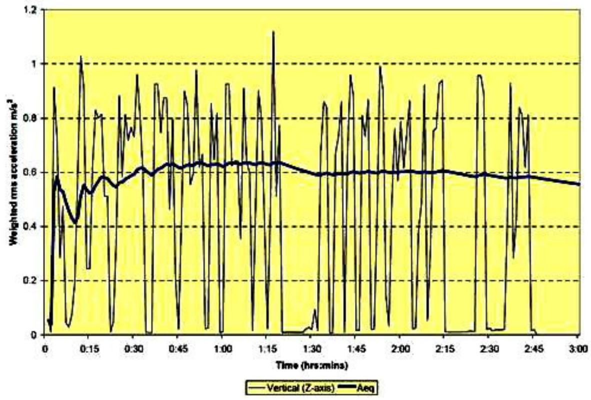

Figure 6 . Linde 2.5 tonne fork lift truck:- time history of weighted 1-minute rms seat accelerations (Z-axis) and equivalent continuous rms acceleration (Aeq).

The daily exposure level in all three axes is obtained from the equations:

$$Ax(8) = 1{,}4awx\left(T_{exp}/T_0\right)1/2 = 0{,}33\,m/s^2 \quad (1)$$

$$Ay(8) = 1{,}4awy\left(T_{exp}/T_0\right)1/2 = 0{,}37\,m/s^2 \quad (2)$$

$$Az(8) = 1{,}4awz\left(T_{exp}/T_0\right)1/2 = 0{,}34\,m/s^2 \quad (3)$$

Where

- $T_{exp}$is duration of daily exposure to vibrations
- T_0 is referent eight-hour exposure

4.2. Forklift Caterpillar D70

Duration of working and measuring the whole-body vibration was 3h 50min, and the operator left the vehicle once for $20min$. The driving surface had variable quality, from smooth to low quality surface (Figure 7). Table 3 presents some of the significant characteristics of this forklift.

Table 3

Model	D70
Weight	$9550kg$
Capacity	$6600kg$
Power	$69{,}9kW$
Suspension	No suspension
Pneumatics	Watts Kargo Model K2, 825×15
Driver's mass	$63{,}5kg$

Figure 7. Condition of the driving surface

A new mechanical seat was installed in the forklift Caterpillar for the purpose of measuring vibrations (Figure 8).

Measuring the level of vibrations was conducted by the Larson Daivs HVM 100 instrument, with the sensor PCB 356B40.

Fig.8. 'Seat' accelerometer configuration incorporating operator presence switch

The measured average vibration values in all three axes and maximal values are given in Table 4 and Figures 9, 10, and 11.

Table 4

Acceleration equivalent level - $Aeq\ m/s^2$ in three perpendicular directions		
awx (in x-axis)	awy (in y-axis)	awzin z-axis)
0.30	0.30	1.06
Maximal acceleration values (m/s^2)in three perpendicular directions		
X	Y	Z
4,59	5,12	15,90

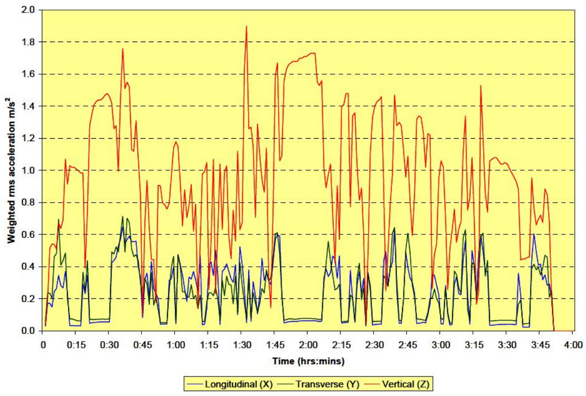

Figure. 9 CAT D70 6.5 tonne fork lift truck:- time histories of weighted 1-minute rms seat accelerations (X, Y and Z-axes)

The highest vibration values (maximal and equivalent) are measured in Z-axis at each moment of measuring. Frequency range of vibrations was from to $5Hz$.

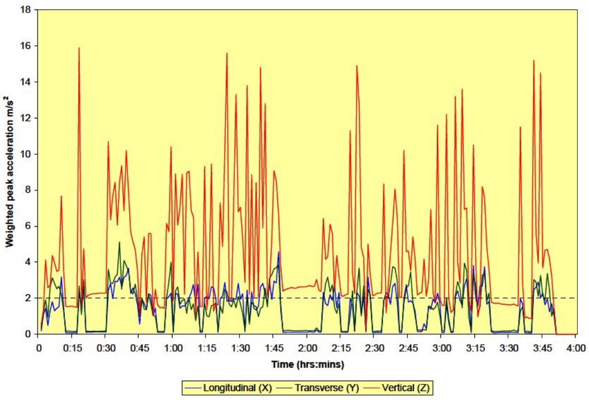

Figure 10. CAT D70 6.5 tonne fork lift truck:- time histories of weighted 1-minute peak seat accelerations (X, Y and Z-axes)

Daily exposure level in three axes is obtained from the equations:

$$Ax(8) = 1{,}4awx\left(T_{exp}/T_0\right)1/2 = 0{,}34\,m/s^2 \quad (4)$$

$$Ay(8) = 1{,}4awy\left(T_{exp}/T_0\right)1/2 = 0{,}29\,m/s^2 \quad (5)$$

$$Az(8) = 1{,}4awz\left(T_{exp}/T_0\right)1/2 = 0{,}73\,m/s^2 \quad (6)$$

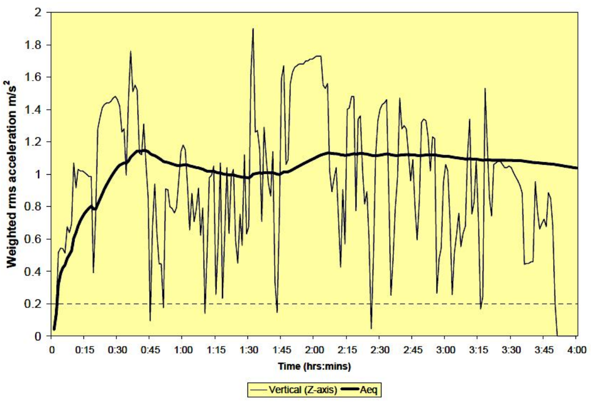

Figure 11 CAT D70 6.5 tonne fork lift truck:- time history of weighted 1-minute rms seat accelerations (Z-axis) and equivalent continuous rms acceleration (Aeq)

5. DISCUSSION

The highest values $Ax(8)$, $Ay(8)$ or $Az(8)$ is taken as a level of daily exposure to vibrations.

Both forklifts had their highest equivalent vibration values in vertical Z-direction, and the frequency range was from to $5Hz$.

The forklift Linde had its equivalent values in all three directions close one to another and relatively low, and it can be said that the good quality seat in this forklift reduced vibrations in Z-direction for more than 50%. The good quality driving surface and the adjusted speed had also impact on the level of the measured values of vibrations. The highest level of daily exposure to vibration was obtained in the Y-direction, and it measured $Ay(8) = 0{,}37\, m/s^2$. Since it was below the warning exposure value ($0{,}5\, m/s^2$), it wasn't necessary to conduct protective measures.

In the case of the forklift Caterpillar, the equivalent value was significantly higher in the Z-direction in relation to X and Ydirections (almost 4 times). Although there was a new seat installed in the vehicle, it didn't reduce the vibration in the Z-direction. A relatively poor driving surface had impact on the value of the measured vibrations. The highest calculated level of daily exposure was in the Z-direction and it was $Az(8) = 0{,}73\, m/s^2$. Since this value is higher than $0{,}5\, m/s^2$, after the measuring was done, the employer was obliged to conduct measures for reducing vibrations, and to provide the operators with preventive medical examinations.

Technical (engineering) solutions to minimize the effects of vibration on the forklift operator's body can be: improving the ergonomics of the cabin, the quality of the seats and safety profiles to optimize the position of the operator, the introduction of different suspension systems - suspension of depreciation vibration and improve the quality of the field to reduce vibration at the source.

Organizational measures may include rotation of employees i.e. reducing the time of exposure to vibration, making major break with activities which occur all over the vibration or the introduction of other working methods that require less exposure to vibration (e.g., an attempt to take on activities with the greatest values of vibration vehicle used without driver - automated guided vehicles).

One of the most significant organizational measures is better training and informing workers about the dangers of vibration modes and their influence is reduced or completely eliminated.

6. CONCLUSION

Forklifts are nowadays recognized as a risky means of transport in relation to the whole-body vibrations.

A large number of factors affect the magnitude of these vibrations. The type and design of vehicles (suspended chassis and cabin), quality of installed seats (normal or anti-vibration), and the type of tires are significant factors that leading manufacturers of these vehicles take into consideration while making new designs. On the other hand, quality of roads, speed of the vehicle, and cargo and driver's weight have significant impact on the vibration value. Quite frequently, however, one ignores the role of training of the operator and his knowledge of dangers of and safeguards against the whole-body vibrations.

There are numerous health consequences of exposure to high whole-body vibrations. That is way employers are obliged to conduct adequate measurements on their vehicles and to undertake adequate technical and organizational measure for reducing vibrations, in accordance with legal regulations.

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