WHOLE BODY VIBRATION MEASUREMENTS OF FORKLIFT TRUCK DRIVERS*

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ABSTRACT

Measurements of vibrations on the body of forklifts, driven by standing operators, were conducted to assess possibility of health hazards. The instrument used was a Larson-Davis HVM100 Digital Triaxial Vibration Meter, and the measured magnitudes were acceleration (m/s2) and Vibration Dose Value (m/s1.75). Measured values were assessed using the corresponding EU Directive. Even though, some of the values did exceed the recommended limits, it was found that, because of the limited use of the trucks (an average of 2 hr/day) the time-weighted averages were well below the action limit. Therefore it was concluded, that the measured vibrations did not constitute health hazard for the drivers.

SOMMAIRE

L'existence de risques pour la santé des ouvriers conduisant des chariots élévateurs à fourche en position debout a été examinée en mesurant les vibrations de ces machines. L'instrument utilisé pour mesurer ces vibrations était un Larson Davis HVM100 Digital Triaxial Vibration Meter. Les données d'amplitude recueillies étaient l'accélération (m/s2) et le VDV (la valeur de la dose des vibrations) en m/s1.75. Les résultats obtenus ont été comparés avec les valeurs recommandées par la Directive de l'Union Européenne. Même si certaines mesures surpassaient les limites recommandées, on a trouvé que les moyennes durées vs poids étaient inférieures aux limites prescrites puisque l'utilisation des chariots est limitée (une moyenne de deux heures par jour). On a conclu que les vibrations mesurées ne représentaient aucun risque pour la santé des conducteurs de chariots.

1. INTRODUCTION

There are some 8 to 10 million workers, in the United States alone, who are regularly exposed to occupational vibrations and there are many more in the rest of the world [1]. Although there are no published statistics, it can be assumed that the number of exposed workers is also large in Canada. The effects from those vibrations can include muscular fatigue, low-back pain, degraded circulatory functioning, and headaches [2, 3].

Depending on the type of work, there are two major occupational vibration exposures:

a) Whole Body Vibrations (WBV) that applies mainly to seated or standing operators of moving equipment such as tractors, farm vehicles, forklift trucks, etc, and
b) Hand-Arm Vibration (HAM), where the energy enters the body through the hands of the operator. This is the case of individuals who use regularly vibrating tools such as pneumatic pavement breakers, gasoline powered tools, chain saws, etc.

In some rare occasions, the operator may even be subjected to a combination of both types of vibrations. This will be the case of drivers of all-terrain vehicles or similar.

The reason the two types of vibrations are considered separately is because their effects on the human body are completely different as well as their measurements and assessment. Even within the WBV, there are two types of vibrations that are considered separately because of their effects as well the way they are assessed. They refer to the standing operator and to the seated one.

Depending of the type of forklift trucks, the operators work in a standing or seated position. The trucks that are the object of the present study are only operated by standing operators.

2. EXISTING STANDARDS

Several standards deal with whole body vibrations. All of the standards specify that measurement should be performed simultaneously in the three axes: x (front and back), y (sideways) and z (vertical). This is done using three separate accelerometers or one tri-axial acclerometer. Each signal is filtered in 1/3-Octave band in the low range of frequencies, between approximately 0.4 and 100 Hz (the ISO standard) simultaneously. A weighting factor is then applied, that is different for each one of the three signals.

8-hr Daily Exposure	Acceleration	VDV
Limit Value	1.15 m/s^2	21 m/s$^{1.75}$
Action Value	0.5 m/s^2	9.1 m/s$^{1.75}$

Table 1. Whole-Body Vibration Values (EU Directive 2002/44/EC)

The standard that Occupational Hygienists usually consult is the American Conference of Governmental Industrial Hygienists (ACGIHs) Threshold Limit Values (TLVs) 4]. It specifies the maximum accelerations a person can be exposed to for a given length of time. In other words, the measured accelerations in each direction are compared to a set of accelerations values between 0.4 and 80 Hz, for exposures between 1 minute and 24 hours. Those limits have been adapted from the 1985 version of the ISO Standard 2631, (superseded by the ISO Standard 2631-1:1997 [5]). The British Standard BS 6841 [6], similar to the ISO Standard 2631 – 1:1997.

The latest ISO whole-body vibrations standard, ISO 2631-1:1997, deals with three situations: health, comfort and perception. When dealing with health, it states: "It applies primarily to seated persons, since the effects of vibration on the health of persons standing, reclining or recumbent are not known."

As mentioned above, the output from the three accelerometer's signals are filtered in 1/3- Octave bands. They are combined and treated in two different manners depending of the nature of the signals. If the signals is of a relatively low crest factor the weighted r.m.s. values are reported as m/s^2. In the presence of high crest factors, occasional shocks, transient vibrations, etc. signals are treated differently and results are presented as Vibration Dose Value (VDV), in m/s$^{1.75}$. The crest factor is defined as the modulus of the ratio of the maximum instantaneous peak value of the acceleration signal to its root-mean-square (r.m.s.) value.

The easiest to use document regarding the assessment of the vibration is the European Directive 2002/44/EC [7]. It establishes two values: the Action Value, above which the employer should implement a program of technical and administrative measures, intended to reduce or eliminate the exposure to mechanical vibrations. The second set of limits is the Limit Value above which no worker should be exposed. Both values are provided for exposure of 8 hr/day.

Table 1 shows the Limit and the Action values as per the Directive.

3. MATERIALS AND METHODS

3.1 Forklift trucks and operations

Measurements were performed in a medium sized paint-manufacturing factory that has eight truck-loading bays for the receiving and shipment of materials.

The forklift trucks (Figure 1) used in the facility are designed to work in narrow aisles between storage facilities and to load trucks and trailers. They are electric driven (because of the requirements in a potentially explosive environment). They are narrow and their wheelbase is relatively short. The driver is standing all the time, since there is no seat for him. The wheels of the trucks are lined with hard rubber and have small diameter. That accentuates the vibration caused while driving over loading ramps and imperfections and bumps of the floor that are transmitted to the driver.

The trucks are used for:

a) Unloading of raw materials and supplies from trucks. To do so, they have to enter the body of the truck or trailer through a loading ramp.
b) Loading of the finished products, drums or pallets, or both on the trucks.
c) Moving totes (large drums) between locations in the plant and storage areas.
d) Staging raw materials for production runs.

3.2 Instrumentation

The instrument used was a Larson Davis Mod HVM 100, equipped with a PCB triaxial accelerometer. It was calibrated in the factory. Larson Davis Blaze 4.11 software was used to calibrate the instrument in the field and to retrieve the measured data.

The instrument was mounted on the frame of the truck (Figure 2). The accelerometer was attached to the frame right next to the operator using a magnet. The vibrations transmitted to the operator are thus measured without attenuation. Care was taken to have the proper orientation of the accelerometer (Z – up, X – front to back and Y – sideways).

The instrument is equipped with the filters needed to measure the acceleration according to the above-mentioned standards so the results are provided with the proper weightings. Using the software, one can also obtain the history of

Figure 1. View of one of the forklift trucks used in the facility

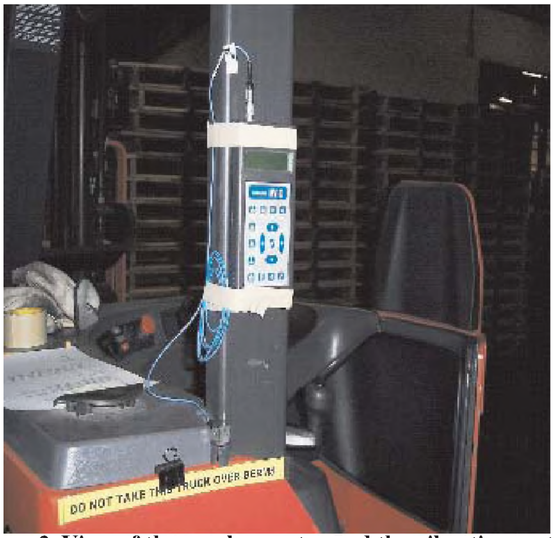

Figure 2. View of the accelerometer and the vibration meter attached to the body of the truck.

the individual accelerations (X, Y, Z) RMS, as well as their peak values. Also, the software calculates the VDV values as explained above.

3.3 Procedures

Before each run, the instrument was calibrated using the software and attached to the truck under test. Then, the driver was allowed to perform his normal activities for approximately 20 m. At the end of this period, the information from the instrument was downloaded into the computer using the same software.

Samples were taken of all the major activities involving forklift trucks in this facility.

3.4 Measurement Results

The results of the measurements are shown in Table 2. The table also lists the duration of the test, the test's number and the acceleration in each direction as well as the calculated total acceleration ("Sum") and the Vibration Dose Value ("VDV").

Run Name	Duration min	X m/s^2	Y m/s^2	Z m/s^2	Sum m/s^2	VDV $m/s^{1.75}$	Truck No
Test 1	10:00	0.404	0.344	0.653	0.839	9.02	PR58
Test 2	22:02	0.439	0.379	0.58	0.849	9.39	PR41
Test 3	9:56	0.386	0.332	0.583	0.771	8.23	PR58
Test 4	18:26	0.758	0.476	1.14	1.45	17.6	PR58
Test 5	14:00	0.544	0.53	0.754	1.07	8.8	PR39
Test 6	13:43	0.444	0.342	0.473	0.731	8.62	PR43
Test 7	23:24	0.422	0.291	0.409	0.653	9.4	PR43
Test 8	21:53	0.553	0.347	0.843	1.06	15.8	PR58
Test 9	20:56	0.299	0.277	0.324	0.519	6.5	PR38
Test 10	14:55	0.501	0.351	0.545	0.816	11	PR45
Test 11	44:31	0.398	0.357	0.492	0.725	9.77	PR42

Table 2. Summary of Acceleration Measurement Results

4 ANALYSIS OF THE RESULTS

4.1 General Observations

As expected, the largest acceleration levels are observed in the Z direction. This corresponds to the vertical motion caused by the vibrations due to the floor irregularities.

The second dominant vibration levels are the X-component. The forklift truck, shown in Figure 1, has a large width between the front and the rear wheels. This causes large oscillations of the truck body in the front-to-back (X) direction. Finally, because of the narrow body of the truck, it is obvious that the oscillations in the lateral (Y) direction are small.

4.2 Risk Assessment

A comparison between the values of both SUM and VDV columns in Table 1 to the measured results in Table 2, shows that some of the vibration levels exceed the Action Values.

The ISO Standard 2631-1:1997 specifies that in the case that a worker is exposed to more than one type of vibration during the workday, or if the exposure duration is shorter than 8 hs, the daily exposure should be calculated using the formula:

$$a = [(1/t_s)\ (\Sigma(a_i)^2\ t_i)]^{1/2} \qquad (1)$$

Where:

a is the resulting acceleration
t_s is the duration of each portion of the shift
$(a_i)^2$ are the individual accelerations, and
t_i are the individual durations.

The average usage duration of the trucks, for the current study, was 2 hr/day. So, the results were corrected using Formula (1). The final results with the corrected exposures are shown in Table 3.

4.2 VDV or SUM?

To determine which descriptor, VDV or SUM, to use, two tables, Table 4 and Table 5 were prepared. Table 4 shows the results where the tests were ordered in descending VDV values, while in Table 5, the test were orederd in descending SUM values.

Analysis of the two tables show that there is no clear relation between the two indices. Tests that are on the top of one table are not at the top of the other, nor the middle positions of both tables are consistent. Therefore, both results were examined and found to be below the recommended limits.

5 CONCLUSION

An assessment of the health risk of forklift truck drivers was performed by measuring the vibrations of the truck body.

Run Name	Sum Measured m/s^2	Sum 8 hr TWA m/s^2	VDV Measured $m/s^{1.75}$	VDV 8 hr TWA $m/s^{1.75}$
Test 1	0.839	0.42	9.02	4.5
Test 2	0.849	0.42	9.39	4.7
Test 3	0.771	0.39	8.23	4.1
Test 4	1.45	0.73	17.6	8.8
Test 5	1.07	0.54	8.8	4.4
Test 6	0.731	0.37	8.62	4.3
Test 7	0.653	0.33	9.4	4.7
Test 8	1.06	0.53	15.8	7.9
Test 9	0.519	0.26	6.5	3.3
Test 10	0.816	0.41	11	5.5
Test 11	0.725	0.36	9.77	4.9
Guideline (EU)		**1.15**		**21**

Table 3. Measured and Corrected Acceleration Values

Tests were conducted on six trucks resulting in 11 runs in total. Results show that workers are not at risk while driving the trucks.

6 REFERENCES

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4 American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs) and Biological Exposure Indices (BEIs), pp. 126-133, ACGIH, Cincinnati, OH (2002) (124-131).

5 International Standards Organization: Evaluation of Human Exposure to Whole-Body Vibration, ISO 2631-1. ISO, Geneva (1997).

6 British Standard Institute: Measurement and Evaluation of Hyman exposure to Whole-Body Mechanical Vibration and Repeated Shock, BS 6841. BSI, London (1987)

7 Directive 2002/44/EC of the European Parliament and of the Council, June 2002. Official Journal of the European Communities,L177/13-19 (6.7.2002).

Run Name	Sum m/s^2	VDV $m/s^{1.75}$	Truck No
Test 4	1.45	17.6	PR58
Test 8	1.06	15.8	PR58
Test 10	0.816	11	PR45
Test 11	0.725	9.77	PR42
Test 7	0.653	9.4	PR43
Test 2	0.849	9.39	PR41
Test 1	0.839	9.02	PR58
Test 5	1.07	8.8	PR39
Test 6	0.731	8.62	PR43
Test 3	0.771	8.23	PR58
Test 9	0.519	6.5	PR38

Table 4. Accelerations by Descending VDV Results

Run Name	Sum m/s^2	VDV $m/s^{1.75}$	Truck No
Test 4	1.45	17.6	PR58
Test 5	1.07	8.8	PR39
Test 8	1.06	15.8	PR58
Test 2	0.849	9.39	PR41
Test 1	0.839	9.02	PR58
Test 10	0.816	11	PR45
Test 3	0.771	8.23	PR58
Test 6	0.731	8.62	PR43
Test 11	0.725	9.77	PR42
Test 7	0.653	9.4	PR43
Test 9	0.519	6.5	PR38

Table 5. Accelerations by Descending SUM Results