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WHOLE-BODY VIBRATION EMISSION AND MOBILE MACHINERY

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1. INTRODUCTION

1.1 Why Do Emission Testing?

The EU Machinery Directive places duties on manufacturers and suppliers regarding the levels of whole-body vibration produced by their machinery. One requirement is that suppliers of machinery provide information on the whole-body vibration emissions of their machines. Where the emission level exceeds 0.5 m/s^2 the actual level must be reported in the machine's instruction manual.

The philosophy behind the requirement to declare whole-body vibration emission levels is to assist workplace occupiers in complying with their duties to select suitable equipment and otherwise prevent vibration injury. Thus it is hoped, over a period of time, market pressures will encourage machinery manufacturers to reduce the vibration emissions of their vehicles. However, in order for the emission values declared by different manufacturers to be easily comparable, the standardisation of test conditions is essential.

For mobile machinery two procedures for developing a standard test have been proposed. These procedures are set out in Annexes E and F of European Standard prEN 1032. The first procedure uses a precisely defined artificial test track. The method is developed in a type-C European Standard, prEN 13059. The second procedure uses a natural test track. No type-C Standard has been developed for this procedure, and those who wish to use it are required to develop their own type-C standard. In both cases the intention was to develop a reproducible standard test which produces a realistic emission level for the type of vehicle under test.

This paper presents typical magnitudes of whole-body vibration emission from various types of industrial truck. The test methods presented in Annexes E and F of prEN 1032 are then described and discussed in the light the Health and Safety Laboratory's experience of applying both test methods to the same all-terrain telescopic lift truck (teleporter).

1.2 Whole-body Vibration Emissions From Mobile Machinery

Whole-body vibration emissions have been measured on various types of industrial vehicle under EU project MAT1-CT-940077 'Development of mobile machinery vibration emission tests'. Figure 1 is reproduced from the final report on the project. The measurements on which Figure 1 is based were made under normal working conditions for the vehicles in question.

Standard prEN 13059 divides industrial trucks into a number of categories, the sixth being all-terrain vehicles. All the measurements reported in this paper were made on a vehicle from this category. The range of values presented in Figure 1 for all terrain vehicles extends from 0.06 m/s^2 to 1.77 m/s^2, for frequency weighted acceleration in the z-axis (vertical) direction. Thus if the two test methods presented in prEN 1032 are to be acceptable they should produce emission levels in, or close to, this range.

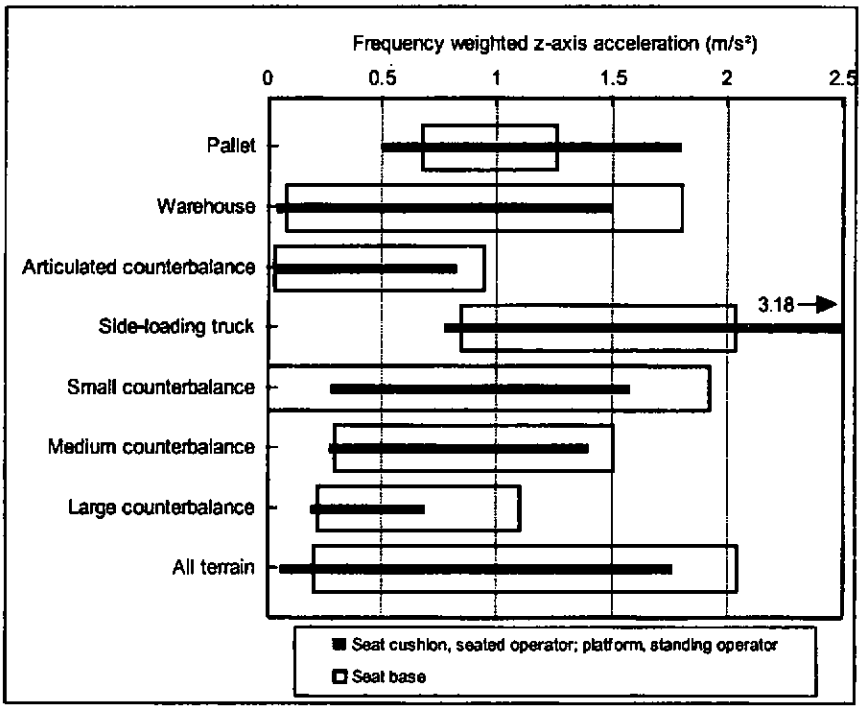

Figure 1. Summary of workplace z-axis whole-body vibration measured under real conditions

2. EMISSION TESTING USING THE ARTIFICIAL TEST TRACK

2.1 Test Procedure

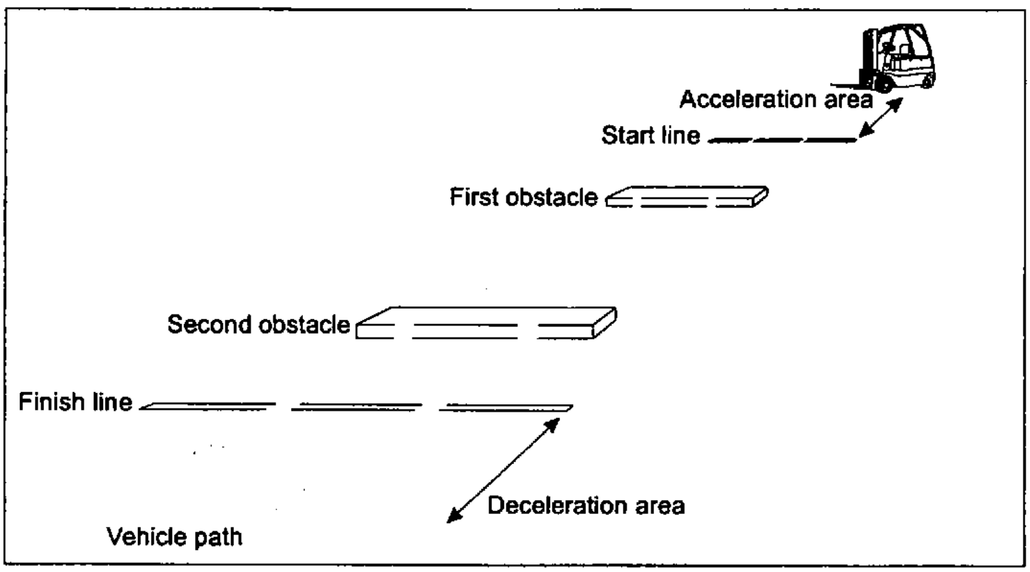

Figure 2. Basic features of the artificial test track

The test procedure for this method is outlined in Annex E of European Standard prEN 1032 and developed into a type-C standard in European Standard prEN 13059. The procedure involves measuring the vibration transmitted to the operator when the test vehicle is travelling over an artificial test track at a constant speed. The vibration emission is measured in the vertical direction, on the floor for standing operators and on the seat for seated operators. For seated operators the vibration emission may be measured close to the mounting point below the seat (referred to as the seat base), and Seat Effective Amplitude Transmissibility (S.E.A.T.) data used (if available) to calculate the vibration emission on the seat. The operator continues to drive the vehicle over the test track until the coefficient of variation of N consecutive runs is less than 0.15, N being at least five. The mean of the N emissions is then calculated.

For all-terrain vehicles the artificial test track is a flat, straight, smooth length of track 25m long (see Figure 2). Two obstacles are placed across the track at 5m and 15m respectively from the start line. The obstacles are 30 mm in height and rectangular in form, with a width of 150 mm. The smoothness of the track must be such that the acceleration at the seat base when the vehicle travels over the track without the obstacles in place, is less than 50% of that when the vehicle travels over the track with the obstacles present. Sufficient space is allowed at either end of the track for the vehicle to maintain a constant speed of 10 km/h along the entire length of the track.

The vehicle is tested with a specified load, which for all terrain vehicles is 50-60% of the rated load capacity of the truck.

2.2 Application of the method to the teleporter

The test procedure requires the use of one driver with a weight of 75 (-10,+0) kg, provided that the seat in the vehicle has passed the relevant seat laboratory test code (prEN 13490). However as the seat laboratory test code had not been published at the time the measurements were made no such seats were available. If the seat manufacturer cannot prove that the seat has passed the relevant seat test code the test procedure requires the use of two drivers, whose weight equals 55 (-5,+0) kg and 98 (-8,+0) kg respectively. In the study reported here practical constraints meant that one driver was used for the August, April and May tests, and two drivers for the October, November and December tests. It was not possible to select the drivers by weight. The weight of each driver at the time of each test is given in Table 1.

Table 1. Weight of each driver (kg)

Month of test	August	Oct.	Nov.	Dec.	April	May
Driver 1	73	89	89	73	96	96
Driver 2	-	86	96	96	-	-

2.3 Findings

Vibration emission measurements made on the teleporter on the artificial track over a period of time are summarised in Table 2. A new seat was fitted to the vehicle between December and April, therefore the seat emissions for the April and May tests are shown in a separate column.

For seat A (for which the majority of measurements were made), the mean of the seat vibration emission values was 1.44 m/s², with a standard deviation of 0.18 m/s². Assuming that this standard deviation is equivalent to the standard deviation of reproducibility (i.e. there would be no variation in measured emission level due to the use of different laboratories), then according to BS EN 12096, Annex B.2, the uncertainty, K, in the emission level would be 0.29 m/s². Thus K for the teleporter is at least 0.29 m/s², i.e. at least 20% of the mean emission value (1.44 m/s²).

Table 2. RMS vibration emission measurements on the artificial track.
(z axis acceleration measurements in m/s², ISO 2631:1997)

Date of test	Driver	Mean $a_{w,z\ seat}$			No. of runs
		Seat A	Seat B	C_v	
17-Aug-98	A	1.11		0.07	6
27-Oct-98	B	1.68		0.03	10
27-Oct-98	C	1.45		0.04	10
16-Nov-98	B	1.54		0.03	10
16-Nov-98	D	1.44		0.07	10
14-Dec-98	A	1.36		0.07	10
14-Dec-98	D	1.50		0.04	10
21-Apr-99	D		0.98	0.03	10
24-May-99	D		1.06	0.02	10
Mean		1.44	1.02		
Standard deviation		0.18	0.06		
Coefficient of variation		0.12	0.06		

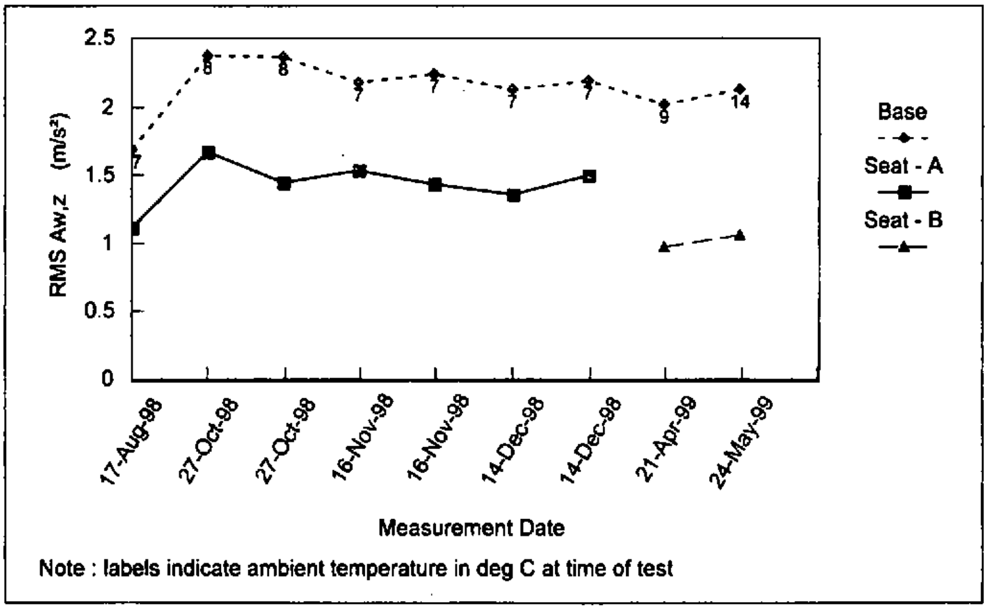

Figure 3. Vibration emission measurements on the artificial track.(z axis, ISO 2631:1997)

The mean vibration emission measurements for each test are plotted in Figure 3. The ambient temperature at the time of each test is given underneath the seat base emission. No significant dependence of emissions levels on ambient temperature was identified.

There was no indication that driver weight affected the measured emission levels, or that failure to meet the driver weight specification in prEN 13059 was important.

Standard prEN 13059 states that a test series of N consecutive runs is valid if the coefficient of variation, C_v, of the series is less than 0.15. All of the test series satisfied this criteria. Moreover the C_V of every set of five consecutive measurements was also less than 0.15.

The smoothness criteria for the test track was not met for the measurements made in November and May. However, these measurements are entirely consistent with those from the other tests. This suggests that the smoothness criteria laid down for the artificial track may be overly conservative for this vehicle.

The mean emission level from the August test is lower than the levels from subsequent tests. The driver used for the August measurements was also one of the drivers used in December, indicating that the lower emission level was not due to the operator. Previous work (EU Project MAT1-CT 940077 final report) has found that the emission from an all terrain vehicle may show distinct peaks as the speed of the vehicle over the artificial track is increased. The method used to control the speed of the vehicle over the artificial track was altered for the second and subsequent tests. Consequently, the average speeds in the August test were between 9 km/h and 10 km/h, while in the later tests they were mostly between 10 km/h and 11 km/h. To examine whether this difference in speed affected the measured emission level, the level measured for each run by driver A was plotted against the run speed (see Figure 4). The measurements shown in Figure 4 are those made in August and December. There is a slight increase in the emission level with speed, but no indication of significant peaks and troughs between 9 km/h and 11 km/h, the allowable speed range. It should be noted that Standard prEN 13059 recommends that the average speed be varied within the allowable tolerance.

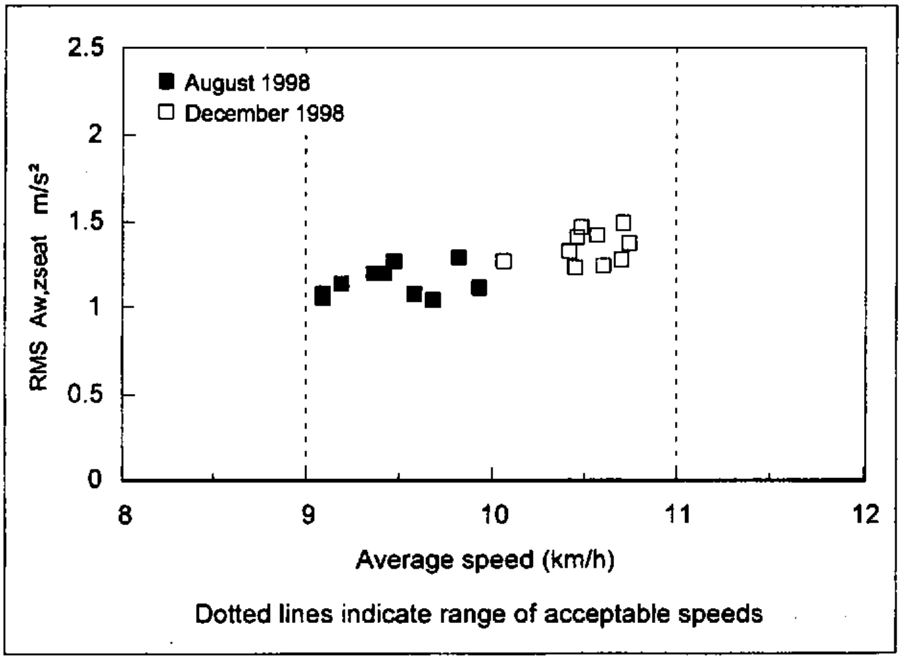

Figure 4. Variation of emission measurements on the artificial track with run speed, driver A. (z axis, ISO 2631:1997)

3. TESTING USING A NATURAL TEST TRACK

3.1 Test Procedure

Implementation of this procedure requires the selection of a control point on the test vehicle which is representative of the vibration excitation due to travelling. Positions close to the contact between the machine and the ground are recommended as normally suitable by Standard prEN 1032. Information on the vibration at the control point is then gathered while the vehicle is driven over surfaces typical of those used by that category of vehicle, at speeds normally used by the vehicle. The vibration is measured in three orthogonal directions.

From this information a target value at the control point considered to be representative of the highest vibration values in typical use of the machine category is selected. Standard EN 1032 suggests using the 75th percentile of the acceleration values collected in the field measurements. The acceleration value used is the equivalent acceleration for the x-, y- and z- directions according to equation (1) below, or if one direction is dominant the weighted root mean square (r.m.s.) acceleration value in that direction. The equivalent acceleration, a_v, is found from

$$a_v = [(1.4a_{wx})^2 + (1.4a_{wy})^2 + a_{wz}^2]^{1/2} \quad (1)$$

where a_{wx}, a_{wy}, a_{wz} are the root mean square (r.m.s.) values of the weighted acceleration in the x direction, y direction and z direction, respectively.

Having defined a target value a natural test track is then chosen for the test. The track should have enough roughness for sufficient whole-body vibration to be generated at a safe speed. The vehicle is driven over the track at a constant speed while the vibration is measured in three orthogonal directions simultaneously at the control point and at the emission point. For a seated operator the emission point would normally be on the seat cushion. At least 180 seconds of data must be gathered. If the track is too short for this to be possible at the chosen speed, then several runs over the track must be made.

This process is repeated until data for at least four different speeds has been collected. The speeds must be selected so that vibration values at the control point are achieved which are both higher and lower than the target value.

The equivalent acceleration at the emission point is then plotted against that at the control point and a linear regression line drawn through the data. The information from each individual run is used separately in the calculation of the regression line. The emission value for the vehicle is the vibration value at the emission point corresponding to the target value at the control point.

3.2 Findings

Using the same all-terrain telescopic vehicle as before, the procedure was followed using five different natural tracks; two grass tracks, two rough tracks and one tarmac track. Of the two rough tracks the first was a mud track with deep potholes while the second was a very poor quality potholed tarmac track. The tests were carried out on two separate days, one week apart. Due to operational constraints the tests were carried out with only one operator, but the same driver was used for all the tests. The weight of the operator was 98 kg.

The control point selected for the tests was on the left hand side of the vehicle's front axle. The vibration at the control point was monitored while the vehicle was driven over tarmac and grass surfaces at typical working speeds. The target value (1.2 m/s²) was then chosen using the method outlined in Section 3.1.

The linear interpolation lines for the data recorded on each of the test tracks are plotted in Figure 5. The target value for the control point is marked by the additional grid line on the x-axis. The emission value for each track was determined from linear interpolation of the data. The coefficient of correlation for all the linear regression lines were high indicating that a linear relationship between the seat emission and the control point emission does exist for the teleporter at the vibration levels of interest. The natural track procedure is based on the assumption that this relationship is linear.

The slope of the linear regression line for the first grass track is quite different from that of the regression lines for the remaining tracks. In fact the data for this track did not comply with the requirement that at least one of the values measured at the control point must be greater than the target value for the test to be valid. However the test speeds used for this track were very similar to those used for the other tracks. No explanation been found for this result. This data was not used in the calculation of uncertainty.

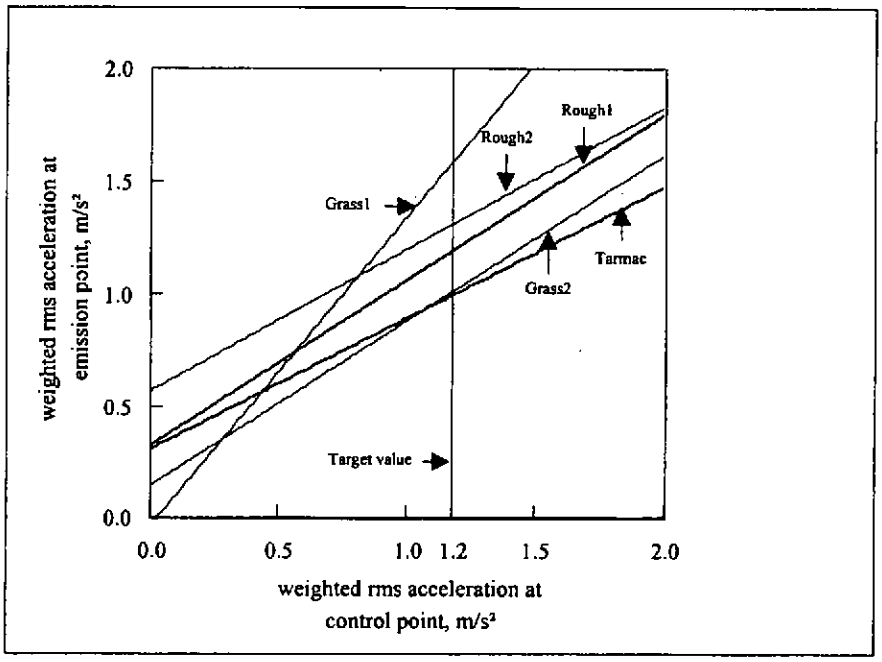

Figure 5. Reproducibility test - Linear regression line for the data from each test track

Table 3. Emission values measured in reproducibility test

Date of test	Test track	Emission value (m/s², ISO 2631:1997)	Correlation coefficient for linear regression line
26/10/99	Rough track 1	1.19	0.89
26/10/99	Grass track 1	1.58	0.93
26/10/99	Rough track 2	1.31	0.94
2/11/99	Tarmac track	0.99	0.94
2/11/99	Grass track 2	1.01	0.84

It was also noted that the characteristic of the vibration measured on the various test tracks differed. Although no direction was consistently dominant on the tarmac and rough surfaces, the vibration level was generally highest in the z direction for these surfaces. On the grass tracks, the vibration levels were broadly similar in all three directions.

The standard deviation of reproducibility for the test will be at least as great as the standard deviation for the emission value measured on different test tracks. For the two rough tracks, grass track 2 and the tarmac track, according to BS EN 12096, Annex B.2, the uncertainty, K, in the emission level will be at least 0.25 m/s^2, i.e. at least 22% of the mean emission value (1.13 m/s^2). This is a minimum value of reproducibility as testing different machines, at different laboratories could only increase the spread of emission levels.

4. SUMMARY

The mean emission level measured on the artificial test track was 1.44 m/s^2 with an uncertainty, K, at least 0.29 m/s^2, i.e. at least 20% of the mean emission value. This value was for acceleration in the z-axis (vertical direction).

Similarly for the measurements made on the natural test track, the mean level was 1.13 m/s^2 with an uncertainty of at least 0.25 m/s^2, i.e. at least 22% of the mean emission value. This value was for the equivalent acceleration.

Both of these emission values were realistic for all-terrain vehicles.

The uncertainty for the two tests (at least 20% and at least 22% of mean value respectively) brings into question their usefulness in reducing levels of whole-body vibration emission from such machines. Measurements made on five all-terrain vehicles as part of a vibration ranking exercise (EU Project MAT1-CT 940077 final report) gave emission levels ranging from 1.03 m/s^2 to 1.41 m/s^2. Given this relatively narrow range of emission levels, and uncertainties of at least 20/22%, it is not clear that either test will be capable of distinguishing the lower emission machines from those with higher emission levels.

5. REFERENCES

BS EN 12096 : 1997
Mechanical vibration - Declaration and verification of vibration emission values

EU Project MAT1-CT 940077
Development of mobile machinery vibration emission tests using artificial test tracks. Final report

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Safety of industrial trucks - Test methods for measuring vibration

European Standard prEN 13490
Mechanical vibration - Industrial trucks - Laboratory evaluation of operator seat vibration.

ISO 2631-1:1997
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