ICSV13 - Vienna
The Thirteenth International Congress on Sound and Vibration
Vienna, Austria, July 2-6, 2006

LONG TERM MEASUREMENTS AND ANALYSIS OF DAY-TO-DAY VARIABILITY ON WHOLE BODY VIBRATION EXPOSURE LEVELS IN WORK ENVIRONMENTS

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Abstract

Long term vibration measurements were made to several mobile work machines at Finnish work sites. The measurements were made continuously for several weeks using developed measuring device. The motivation for this study was to find out how much day-to-day variability there is on whole body vibration exposure levels within the same machine or work phase during a longer period. This paper shows the preliminary results of selected mobile work machines. Current standards and guidelines of whole body vibration have varying instructions for measurement periods. Depending of the standard the minimum period can be from about one to four minutes to every work phase used for analysis. The results can then be used to represent an eight-hour work day and give an estimate of the health effects of "typical" day. The assumption is that the vibration values from short term measurements will represent the average exposure to human during normal work. There have not been enough studies that have concluded if the short term measurements of the daily exposure levels are enough to conclude the health effects of specific work environment. Several variables exist that can change the daily values, such as weather, length of work period, changing work phases and road conditions among other things. The variables can change the exposure values significantly and the short term measurements may give a wrong impression of the real vibration health risks in the work site. There is a need to conclude if long term measurements are necessary to have more specific information on vibration health risks.

INTRODUCTION

The basis for this study was the conclusion from literature search that there is not enough information on day-to-day variability of whole body vibration in human operated mobile work machines. In another words, there are no continuous long term measurements of whole body vibration done for work machines previously [6].

The goals of the research project were to develop methods and equipment to enable continuous long term measurements of mobile work machines and analyse the day-to-day variability of vibration levels. Several work machines from small to full size were measured continuously from two weeks to several months. The author has not been able to find any similar kinds of measurements or results from the literature. This paper shows the preliminary results of selected work machines.

The hypothesis is that short term measurements do not give overall picture of the daily exposure of a machine or a work phase. This hypothesis has not been evaluated enough as there have not been any practical instruments to allow long term measurements. Vibration measurements of couple of minutes have been normal in whole body vibration publications and longer measurements have been suggested to be needed [6]. The data for analysis might have been gathered in a period of several days or months, but the measurement periods have been much shorter than a full day. The author feels that long term data needs to be gathered to conclude its usefulness on determining “typical” day values for work machines. This kind of data might give more representative vibration values that can be used to evaluate the machine in its typical work environments.

Instruments for measuring whole body vibration today are designed and aimed mostly for research purposes. The instruments found in the market work well for whole body vibration research. The problem is that these types of instruments are not feasible for small or medium sized employers as the costs are relatively high and usage requires knowledge of measurement techniques and whole body vibration. The motivation for developing own equipment was because commercial equipment does not allow practical automatic long term measurements. One of the problems with continuous measurements is the fact that there can be no supervision of the process and it cannot rely on the machine operator. This has been learned in practice as the operators found difficult to simultaneously work and control the measurements. Also it is not feasible for a researcher to supervise the measurements continuously for several weeks or months.

ISO 2631-1 (1997) gives guidance on how to measure and calculate whole body vibration levels. It gives the frequency weighting curves and analytical equations for calculating RMS- or VDV-values [4]. The standard does not give exact time for minimum or maximum measurement period, but it states that "*the duration of measurement shall be sufficient to ensure reasonable statistical precision and to ensure that the vibration is typical of the exposures which are being assessed.*" This statement gives very loose guideline for conducting the measurements. In a note the standard states however that from the signal processing point of view the minimum measurement period should be 227 seconds for registering signals down to 0,5 Hertz. Different standards of whole body vibration give different values ranging from 60 to 227 seconds [6]. Thus it is up to the measurer to choose the right procedure and guidelines.

One of the reasons that EN 14253 standard was produced was the need to give more practical guidance on whole body vibration assessment, measurements and analysis at the work place [2]. About the day-to-day variability and long term vibration exposure the standard states that “*There is no method for evaluating the* *combined vibration exposure for more than one day. Therefore, to know what is a typical day when vibration varies from one day to another, it is recommended to evaluate the variability of the daily vibration exposure A(8) over days.*" This statement clearly states that there might be a need for long term measurements. Regarding the continuous measurements the standard states that "*ideally, measurement of the daily exposure will be continuous throughout the working day and some modern instruments facilitate this. However, this is often impracticable and it is then necessary to establish a method of sampling appropriate periods of vibration exposure.*" The developed measuring device was produced to enable continuous long term measurements to overcome this problem.

The physical agents directive (PAD) has limit values based on the dominant direction for an eight-hour work day [1]. The assessment or measurements of vibration exposure should be made at suitable intervals and kept up-to-date.

In field measurements there are several factors that contribute to the combined variability of the values. The technical specifications alone allow errors from ±10% [8] to even up to ±27% [6]. Although the commercial measurement equipment should give systematic results, in the study [7] the difference between measurement systems were concluded to be even 25% of each other. In addition to errors from technical factors, an operator's handling of the machine, speed, weather, road conditions, measurement periods and so on affect the final result. These factors require enough measurement data for conclusion of the vibration levels. And this requirement might be several days or even weeks.

The measurements and analysis conducted in this paper are part of KEISU-project, which was funded by the Finnish Work Environment Fund, VTT and participating Finnish companies.

METHODS

This study used RMS-method for analysis as it is the primary method in Europe and only method in Finnish legislation to estimate whole body vibration exposure. The calculations were based on the standards [2, 4]. The standards are not designed for analysis of long term measurements, but the same procedure can be implemented as the daily *A(8)* values are used.

The equipment was programmed to calculate running RMS-values (RRMS) with one second integration time based on the standard [4]. Each second the RRMS-values and date and time were recorded for offline analysis. The values were only recorded when the vibration was present to save the memory. From this data daily RMS-values, exposure times, break times and work phases can be analysed afterwards. The equations for calculating RRMS and RMS can be found from [4].

To measure whole body vibration continuously, it will require memory and either automatic or easy data gathering for permanent data storage (i.e. database). Also the equipment itself should be easy to use, low power, small, affordable and robust. These requirements were the basis for developing the new measurement equipment. Figure 1 shows the developed device installed on a seat. It consists of an

FPGA-platform, with memory and signal processing units, and of a tri-axial digital MEMS accelerometer. The seat pad was designed to be smaller than the standard pad as it was found to be unacceptable for sitting on it for several weeks. The designed seat pad was compared with the standard pad, so that the measurement error was not significantly affected. The developed seat pad is the same size as the diameter of the rigid part of the standard seat pad [3].

Figure 1. Developed measurement system.

The frequency weighting was realized using a digital IIR-filter design. The filter was designed using the requirements of ISO/FDIS 8041 (2004) standard. The filter and the sensor were tested in a calibrator at VTT to comply with the type 2 specifications of the standard [5]. However it should be noted that this equipment is a prototype, thus the required process for calibrating commercial equipment was not done.

Coefficient of variation (CV) was used to analyse the variability of daily values. CV is defined as "*a dimensionless number that allows comparison of the variation of populations that have significantly different mean values*" [9]. It can be used to analyse normal distribution of positive values. The equation is defined as:

$$c_v = \frac{\sigma}{\mu} \tag{1}$$

, Where σ = standard deviation
μ = mean

RESULTS AND ANALYSIS

This paper includes data from two work machines; 1) a multipurpose wheel loader and 2) a road grader. Both of the machines were measured under winter conditions. For this reason the work phases included such activities as snow ploughing, road gritting, loading and transporting gravel or snow. The measurement devices were installed to the machines and left to continuously record the vibration. During that period the operator worked normally without any interference of the device.

Table 1 shows the measurement and work periods. The road grader was driven in eight-hour shifts continuously around the clock. The wheel loader operator had regular work schedule from 06:00 to 14:00, but it was used also when there was a snow storm, thus the work schedule changed almost every day (table 3). In some days the machines were not in use, thus there was no vibration recorded. The average daily work period in the table 1 represents the period when the machine was first and last used in a day. The work period of the operator might have been longer in that day, but it did not include any more usage of the machine (i.e. no vibration exposure).

Table 1 shows that in average the wheel loader was in operation almost eight hours per day, which is close to the work period of PAD. The period of vibration present during that time was in average 4,8 hours, constituting 60% of the operation time. The rest of the time was spent either idling or in a break. For the road grader the vibration exposure time of the work period was almost 100%, because the operators did not take any bigger breaks until at the end of their shift.

Table 1. Measurement periods and work times of the machines.

Work machine	**Measurement period**	**Total work hours***	**Average daily work period****	**Average daily exposure period*****
Multipurpose wheel loader	25 days	152 hours	7,6 hours	4,8 hours
Road grader	15 days	258 hours****	18,4 hours****	17,9 hours****

* Value indicates combined work hours when the machine was first and last used in a day (including break times)
** Value indicates the average period when the machine was first and last used in a day (including break times)
*** Value indicates the average period the operator was exposed to vibration in a day
**** The machine was driven in three 8-hours shifts around the clock

Table 2 shows the variability of daily RMS-values and exposure periods. The values have been calculated from the days that the machines were used. The data from the road grader has been divided into three parts representing three work shifts.

The wheel loader exhibited large variability in both daily RMS-values and exposure periods. This was because the machine was used for different purposes in almost every day, thus the work period and the work phase (i.e. speed and road surface) constantly changed. The average eight-hour vibration level during the measurement period (25 days) was 0,54 m/s^2 and the CV was 30%. The minimum and maximum daily RMS-values changed from 0,12 m/s^2 to 0,98 m/s^2. This meant that in average the vibration exposure was exceeding the action limit of the PAD (0,5 m/s^2), but there was large variability between consecutive days. In some days it was even close to the exposure limit value (1,15 m/s^2). The exposure period exhibited even larger variations than RMS-values with average being 4,8 hours and CV over 50%. The daily exposure period ranged from 50 minutes to 10 hours.

The road grader was driven almost constantly around the clock. Because the machine was used in three defined shifts the work period (i.e. maximum exposure period) of a single operator did not change daily, as it did with the wheel loader operator, but the exposure period changed (CV was 36%). The average daily RMS-values did also change, but it was not as significant as with the wheel loader (CV was 15-17%), because the road grader was used for more specific work phases (e.g. snow ploughing). The eight-hour vibration level rarely exceeded the action limit, highest being 0,55 m/s^2 and lowest 0,29 m/s^2, and all three work shifts exhibited the same kinds of vibration levels.

Table 2. Variability of RMS-values and work periods.

Work machine	**Average daily RMS***	**CV of daily RMS**	**Average daily exposure period**	**CV of daily exposure period**
Multipurpose wheel loader	0,54 m/s^2	30 %	4,8 hours	50 %
Road grader				
1st shift	0,41 m/s^2	16 %	6,0 hours**	36 %
2nd shift	0,42 m/s^2	17 %	6,0 hours**	36 %
3rd shift	0,44 m/s^2	15 %	6,0 hours**	36 %

* Value represents the value in dominant direction proportioned to eight-hour work period
** Value divided equally to all work shifts

Table 3 shows a sample of data gathered from the wheel loader. From the table 3 one can see how drastically the work hours changed in each day. Also the vibration levels changed depending of the work phase and environment. The effect of these two variables created significant differences of the eight-hour vibration levels between work days. This was due to the winter conditions, where snow storms dictate the work schedules. In these days the vibration levels get higher, because they have to be proportioned to represent an eight-hour value.

The interesting information in the table 3 is the variability of the daily work period. In this case a single operator was using the machine in each day. From the 15 days eight days exceeded the action limit and seven days were under it (including days when the machine was not used). In some days even five hours of work was enough to exceed the action level. The table 3 also shows the work days when the machine was not used.

Table 3. A sample of the measured vibration data.

Date	**Work started***	**Work ended***	**Work period**	**Dominant RMS****	**Dominant 8-hour RMS*****
27.2.06	6:35:56	13:04:50	6,5hours	0,42 m/s^2	0,38 m/s^2
28.2.06	3:41:35	13:20:43	9,7 hours	0,49 m/s^2	0,54 m/s^2
1.3.06	2:21:49	13:23:47	11,0 hours	0,49 m/s^2	0,58 m/s^2
2.3.06	6:30:35	12:19:14	5,8 hours	0,82 m/s^2	0,70 m/s^2
3.3.06	6:38:31	11:55:30	5,3 hours	0,63 m/s^2	0,51 m/s^2
4.3.06	-	-	-	-	-
5.3.06	6:57:40	13:45:43	6,8 hours	0,62 m/s^2	0,57 m/s^2
6.3.06	6:41:39	13:06:48	6,4 hours	0,44 m/s^2	0,39 m/s^2

7.3.06	0:33:36	13:33:32	13,0 hours	0,52 m/s^2	0,67 m/s^2
8.3.06	6:36:50	13:17:04	6,7 hours	0,38 m/s^2	0,35 m/s^2
9.3.06	2:23:06	13:05:50	10,7 hours	0,60 m/s^2	0,69 m/s^2
10.3.06	6:34:52	12:36:50	6,0 hours	0,47 m/s^2	0,41 m/s^2
11.3.06	-	-	-	-	-
12.3.06	-	-	-	-	-
13.3.06	6:37:43	14:00:57	7,4 hours	0,70 m/s^2	0,68 m/s^2

* Time indicates the first or last existence of vibration in a day
** Cumulative value of the whole work day in dominant direction
*** Daily value proportioned to eight-hour work day in dominant direction

CONCLUSIONS

The legislation, concerning vibration exposure, requires assessing the levels in suitable intervals. In theory the vibration levels should not to be exceeded in any work day, which is practically impossible to assure for an employer without continuously monitoring vibration exposure. There are standards and equipment for whole body vibration, but they are designed for short term measurements. Using short term measurements it is practically impossible to conclude in a specific work place what percentage of the work days the vibration levels will exceed the Directive's limits.

This paper gave preliminary results of long term whole body vibration measurements. The goal was to find out how much day-to-day variability there exists in typical mobile work machines, what usage the long term measurements have and is it even necessary to measure for long term.

The results showed that work machines or phases can have drastic differences in daily exposure periods and vibration levels, especially if the work environment requires flexible work hours. The time spent using the machine can fluctuate from few hours to even twelve or thirteen in winter conditions. Exceeding the eight-hour exposure period quickly increases the comparable levels, but it was noted that in some days even five hours of work exceeded the action limit.

It is important to understand the work profile of the machine and an operator. It was noted that especially daily exposure period showed large variability in both machines. As the time period of exposure is as important as the vibration levels (or even more important), the study showed that the information about the daily work periods need to be carefully evaluated. The road grader was used in three defined work shifts, thus an operator was never exposed to vibration more than eight hours per day. In addition to that the work phases all exhibited the same kinds of vibration levels. In the case of the wheel loader operator the daily vibration exposure changed from couple of hours to even thirteen hours per day and the vibration exposure levels also changed significantly in each day. The results indicate that the road grader is easier to evaluate using short term measurements, but the wheel loader exhibits so large variations that the measurement period should be much longer than few days or might even require continuous monitoring.

To develop technology for long term measurements is not a straight forward procedure. There are many problems that do not occur when performing shorter measurements, such as usability, robustness of hardware, amount of data, etc. The long term measurements required automatic devices, which were challenging to develop.

As the results in this paper are preliminary and the measurements will continue at least at the end of 2006 it is still hard to make any final conclusions of the need and usage of long term measurements. However this paper already showed that the values can change from day to day and with short term measurements this change might not be noticed. It might be because of shorter or longer work periods or different work environments or phases.

New measurement equipment is most likely coming to the market soon, which is more employer friendly. With more data gathered the usability of long term measurements will be clearer.

REFERENCES

[1] Directive 2002/04/EC, "On the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration) (sixteenth individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC)", 7 (2002)

[2] EN 14253, "Mechanical vibration - Measurement and evaluation of occupational exposure to whole-body vibration with reference to health - Practical guidance", (2003).

[3] ISO 10326, "Mechanical vibration - Laboratory method for evaluating vehicle seat vibration – Part 1: Basic requirements", (1992).

[4] ISO 2631, "Mechanical vibration and shock: evaluation of human exposure to whole-body vibration - part 1: general requirements", Geneva: International Organization for Standardization, (1997).

[5] ISO/FDIS 8041, "Human response to vibration: measuring instrumentation", Geneva: International Organization for Standardization (2004).

[6] Mansfield N.J., "Effect of increasing measurement duration on 'accuracy' of whole-body vibration field measurements", 38th United Kingdom Conference on Human Response to Vibration, Gosport, England (2003).

[7] Tyler R., Darlington P., "Measurement uncertainty in human exposure to vibration", report (2004).

[8] Pitts P., "Uncertainty in evaluating exposure to hand-transmitted vibration", Acoustic Bulletin, Vol. 28, No. 5. (2003).

[9] Wikipedia, http://en.wikipedia.org/wiki/Coefficient_of_variation, (2005).