Patterns of Whole-Body Vibrations in Open Pit Mining

C. Bernardo, M. L. Matos[1], J. S. Baptista
Research Laboratory on Prevention of Occupational and Environmental Risks (PROA / LABIOMEP), Faculty of Engineering, University of Porto, Porto, Portugal
[1]*LNEG, Laboratório Nacional de Energia e Geologia, S. Mamede de Infesta, Portugal*

ABSTRACT: The main objective is to detect Whole-Body Vibration (WBV) patterns in different mining equipments along their working cycles. Three activities / equipment were studied (rock drill, shovel and dumper) in a north Portugal quarry. The WBV measurement and analysis was conducted in accordance with ISO 2631-1 (1997). It was studied three WBV transmission ways: 1) seat surface, 2) seat backrest and 3) cabin floor (feet). Rock drill shown a WBV pattern, where there was an extensive drilling phase, with residual accelerations values, and a short phase when the vehicle have to move to do another hole. In shovel, was not detected any associated pattern. In dumper, can be distinguished all tasks: loading, loaded and unloaded travel, dumping. Big differences were found when WBV is transmitted through the seat backrest, with the longitudinal x-axis dominating. Rock drill and dumper shown WBV patterns, as opposed to shovel.

Mining operations in quarry involve many activities that generate vibrations. These vibrations can be transmitted to workers through their hands, feet or seats. Rocks drills, shovels and dumpers are strongly present in open pit mining. In these ones, the vibration is transmitted mainly to the worker body – Whole-Body Vibration (WBV) (Hill, Langis *et al.* 2001; Donoghue 2004; Gallagher & Mayton 2007; Kunimatsu & Pathak 2012).

Typically, a mining environment involves operations well defined and with short duration which are associated with different vibration amplitudes. Thus, measurements should be made for each operation and the result obtained from the combination of these (ISO 1997).

Some work has been developed in task characterization in the mining equipments such as rock drills and shovels. Nevertheless, dumpers are often studied. On one hand, they have the highest WBV exposition; on the other hand they have well-defined and very different tasks into its working cycle.

Dentoni & Massacci (2013) studied the WBV exposure in shovel, in two different tasks separately: haulage and material shifting. They found that the haulage task leads to greater exposure than the material shifting. In both tasks, the main axis is the longitudinal, x-axis.

In the dumper analysis, the tasks are loading, loaded travel, dumping and unloaded travel. The majority of time was spent during loaded travel and the least amount of time was spent during the dumping phase. The remaining time was almost equally divided between unload travel and the loading phase (Smets, Eger *et al.* 2010). The highest Root Mean Square (RMS) vibration magnitudes were founded in loaded and unloaded travel (Kumar 2004; Smets, Eger *et al.* 2010). The predominant frequencies of vibration generally lay in the band of 2-4 Hz (Kumar 2004).

The main objective is to detect WBV patterns in different mining equipments (rock drill, shovel, and dumper) along their work duty cycles. This allows the definition of a work duty cycle, identifying and comparing working tasks among themselves and between different equipments.

2.1 *Facilities, operators and machinery*

The experimental work was carried out between April and June 2013 in a quarry in the north of Portugal, dedicated to the production of crushed rock aggregates.

According to the objectives set, were selected for the study three jobs, ie three different equipments: rock drill (n = 1), shovel (n = 1) and dumper (n = 1). The characteristics of the equipment are presented in Table 1.

Workers were in a sitting position, controlling the vehicle with joysticks (rock drill and shovel) and a hand wheel (dumper). In the quarry, vehicles moved on a gravel road. Each job is associated with a worker. All of them have a daily vibration exposure, with a work schedule of 8 hours per day, divided by one hour lunch break. The workers were instructed to do their typical work routines.

Table 1. Features of the equipment under study.

Equipment	Rock drill	Shovel	Dumper
Brand	Atlas Copco	CAT	Terex
Model	Rock D7	374 D	TR 45
Year of manufacture	2007	2011	2005

2.2 *Measurement of Whole-Body Vibration*

WBV exposure measurements were conducted in accordance with the protocol defined by International Standards Organization (ISO) standard 2631-1 (1997). An SV 106 tri-axial accelerometer manufactured by SVANTEK, Poland was used. It measured vibration in three translational axes (longitudinal = x-axis; lateral = y-axis; vertical = z-axis). In order to measure vibration at the operator/seat and operator/floor interface, the accelerometer was mounted in a rubber seat pad and fixed in three different ways: (1) supporting seat surface; (2) seat backrest and (3) cabin floor. This is shown in Figures 1, 2 and 3, respectively. It was possible to study three-way transmission of WBV in the sitting position: input through the buttock, back and feet of the operator. The rubber pad was well fixed with tape trying to stay as close as possible to the surface.

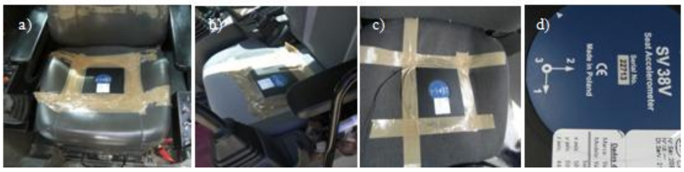

Figure 1. Placement of the whole-body accelerometer in the supporting seat surface a) rock drill, b) shovel and c) dumper.

Figure 2. Placement of the whole-body accelerometer in the seat backrest of the a) rock drill, b) shovel and c) dumper.

Figure 3. Placement of the whole-body accelerometer in the cabin floor of the a) rock drill, b) shovel and c) dumper,

d) Orientation of the coordinated axis (fig.1, 2 and 3).

2.3 *Data collection procedure*

For each workplace, typical work duty cycles were monitored. In rock drill, it included (1) Drilling; (2) Vehicle movement and positioning. In shovel, (1) Loading trucks or dumpers; (2) Material shifting and placing. In dumper, (1) Loading the bucket with rock; (2) Driving with loaded bucket to a dumping zone; (3) Dumping the loaded bucket; (4) Driving with an empty bucket back to the development heading to load another bucket.

The time spent performing each task in the cycle was dependant on the skill of the operator, layout of the quarry and environmental factors (e.g. road conditions). Therefore, the total data collection time per workplace varied between 1 and 3h.

The tasks were timed and the vibration measurements were accompanied by an observation and occurrences registration, sometimes with the aid of video recordings.

2.4 *Analysis of Whole-Body Vibration exposure*

WBV analysis was conducted in accordance with ISO 2631-1 (1997) and carried out with SVAN PC ++, 1.5.10 version, developed by SVANTEK Poland.

The analysis included a graphical monitoring, establishing a pattern of instantaneous acceleration versus time. The work duty cycle and each task were identified.

3 RESULTS

3.1 *Work phases*

The percentage of total daily work time spent in each work phase was calculated for all vehicles (Table 2).

In rock drill, the drilling phase is the dominant (93%). In shovel, almost half of the time (49%) was spent during the material shifting and placing phase. The loading phase also has a considerable percentage of the time (42%). In dumper, the majority of the time (34%) was spent during loading and the least amount of time (5%) was spent during the dumping phase, which is very short (less than a minute). The loaded travel takes a little bit more time than the unloaded one. There are some waiting moments (7%) mainly because dumper has to wait until the shovel can load it.

The time spent in each phase of the work duty cycle of the dumper is in accordance with Smets, Eger *et al.* (2010) have found.

Table 2. Work phases in rock drill, shovel and dumper duty work cycles.

	Average time of the task [min]	% in total daily work time
Rock drill		
(1) Drilling	12,1	93
(2) Vehicle movement and positioning	1,1	7
Shovel		
(1) Loading	6,0	42

(2) Material shifting and placing	7,3	49
Waiting moments	2,6	9
Dumper		
(1) Loading	4,6	34
(2) Loaded travel	3,6	29
(3) Dumping	0,6	5
(4) Unloaded travel	3,2	25
Waiting moments	2,3	7

3.2 *Whole-Body Vibrations patterns (instantaneous acceleration versus time)*

3.2.1 *Rock drill*

In Figures 4, 5 and 6 is shown an example of a rock drill WBV pattern (instantaneous acceleration, m·s^{-2}, versus time), transmission through the seat surface, seat backrest and cabin floor, respectively. The tasks are indicated.

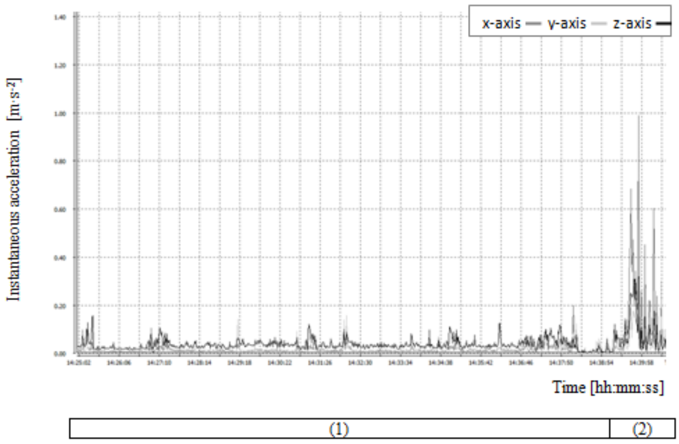

Figure 4. Example of a rock drill WBV pattern with transmission through the seat surface.

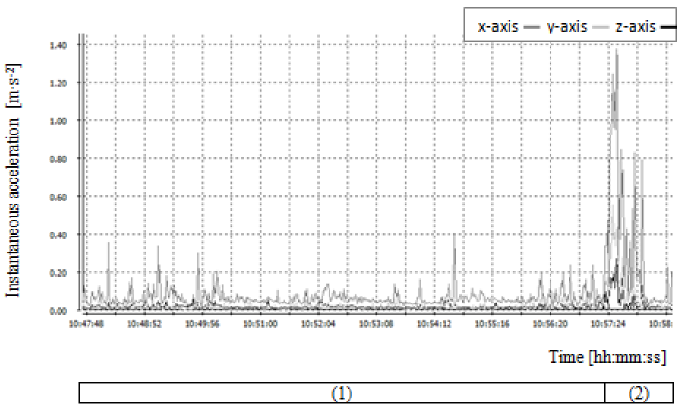

Figure 5. Example of a rock drill WBV pattern with transmission through the seat backrest.

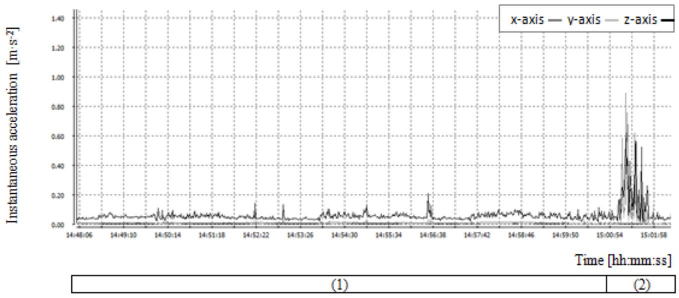

Figure 6. Example of a rock drill WBV pattern with transmission through the cabin floor.

3.2.2 *Shovel*

In figures 7, 8 and 9 is shown an example of a shovel WBV monitoring (instantaneous acceleration, m·s^{-2}, versus time), transmission through the seat surface, seat backrest and cabin floor, respectively. The tasks are indicated.

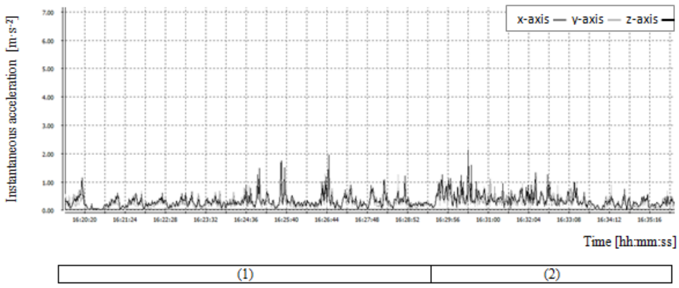

Figure 7. Example of a shovel WBV monitoring with transmission through the seat surface.

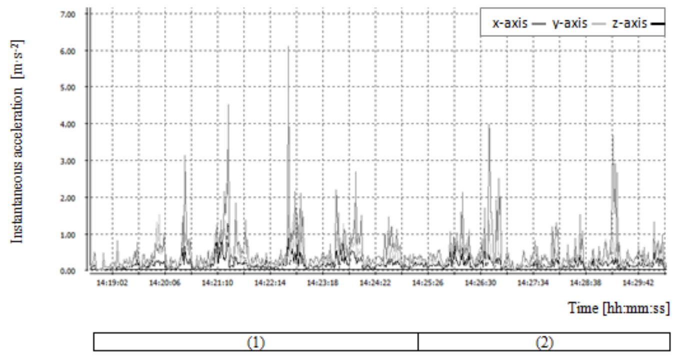

Figure 8 Example of a shovel WBV monitoring with transmission through the seat backrest.

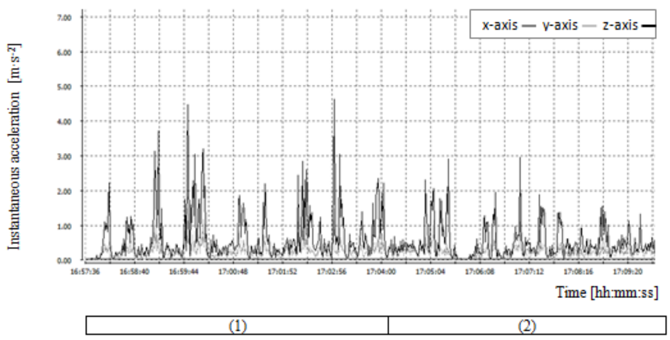

Figure 9. Example of a shovel WBV monitoring with transmission through the cabin floor.

3.2.3 *Dumper*

In figures 10, 11 and 12 is shown an example of a dumper WBV patterns (instantaneous acceleration, $m \cdot s^{-2}$, versus time), transmission through the seat surface, seat backrest and cabin floor, respectively. The tasks are indicated.

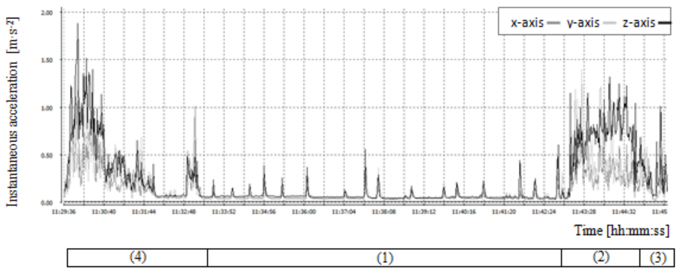

Figure 10. Example of a dumper WBV pattern with transmission through the seat surface.

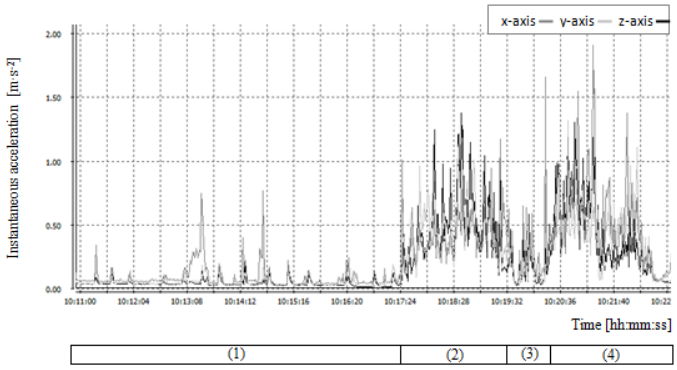

Figure 11. Example of a dumper WBV pattern with transmission through the seat backrest.

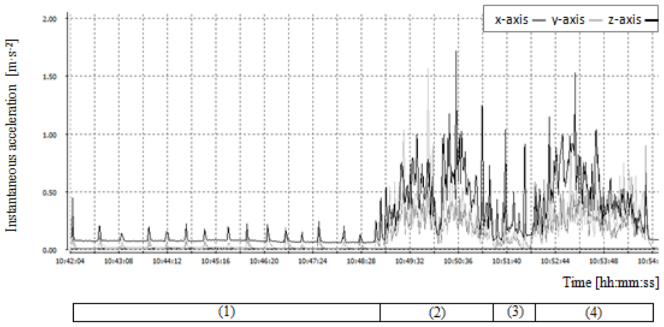

Figure 12. Example of a dumper WBV pattern with transmission through the cabin floor.

4 DISCUSSION

The analysis of Figure 1, 2 and 3 allows the identification of a WBV pattern of the rock drill work duty cycle, which is reproducible along the work day. In this pattern can be distinguished two clear tasks: (1) drilling and (2) vehicle movement and positioning.

The task (1) is the longest and it is characterized by low values of acceleration, below 0.20 $m \cdot s^{-2}$. It is not possible to distinguish the entrance of the different drilling sticks in the execution of the same hole, nor are identifiable behaviours associated with other specific situations as contact stick with a harder rock portion, jamming sticks or other technical problems. The task (2) is very short in the work duty cycle of the rock drill. Nevertheless it implies higher vibration levels, with a characteristic peak.

The shape of graphics (Figure 4, 5 and 6) is similar, but the dominant axis is not. When the WBV transmission is made through the seat surface and cabin floor (feet), the dominant axis in task (1) is the vertical zz and in the task (2) the longitudinal xx. When the seat backrest is analysed, the vibration acceleration is higher (mostly in task 2), and the dominant axis is the longitudinal xx in all the monitoring.

The operator spends more time during drilling phase, which is the one with lowest vibration values. In turn, the most critical phase in terms of exposure to WBV is that one where he spends less time.

Figure 7, 8 and 9 correspond to the work duty cycle of the shovel, including the tasks (1) loading and (2) material shifting and placing. However, these tasks are not distinguishable individually and there is not a visible pattern of vibration. The shape of the graphics is very irregular and rugged. The work made by the shovel is highly dependent on how the disassembled material is selected and the dismount that is necessary, so the work can be extremely variable. The main axis is the vertical zz when the vibration is transmitted through the seat surface and cabin floor (feet) and the longitudinal when the vibration is transmitted through the seat backrest.

In Figures 10, 11 and 12 it is possible to identify a WBV pattern, typical from dumper work duty cycle. It includes (1) loading the bucket with rock; (2) driving with loaded bucket to a dumping zone; (3) dumping the loaded bucket; (4) driving with an empty bucket back to the development heading to load another bucket.

Across all WBV transmission way, loaded and unloaded travel had the highest vibration magnitudes, as checked by Salmoni, Cann *et al.* (2010) and Kumar (2004). It would appear that the heavy load dumper carries has damping effect on the magnitude of vibration.

In loading operation (1) the dumper is parked, while it was loaded by shovel. Thus, this operation is characterized by residual vibration levels interrupted by peaks corresponding to the buckets loaded by shovel. This was also confirmed by the observations *'in loco'* and by the registration of the number of buckets loaded. The rock knocking on the box dumper causes the impact. The magnitude of vibration felt depends on factors like the type of material loaded, the amount of rock already loaded, the practice of workers, among others.

At (3) dumping there is a sudden drop in the level of vibration by vehicle stop and a new vibration peak, by the material discharge, and by downloading the box of the dumper and consequent impact on the operator's cabine.

The dominant axis when the vibration is transmitted through the seat surface and cabin floor (feet) is the vertical zz in all monitoring and the longitudinal xx when the vibration is transmitted through the seat backrest.

The operator spends the majority of time during the loading phase, which has the least vibration values associated. Nevertheless, considerable time was spent during loaded and unloaded travels, and here the vibration levels are the highest.

5 CONCLUSIONS

There is a WBV pattern in rock drill and dumper work duty cycles. In rock drill there is a long phase of drilling with residual vibration and a short phase, while the vehicle is moving, with a peak of vibration in longitudinal x-axis. In dumper all the phases are clearly distinguishable. Loaded and unloaded travels had the higher acceleration values, and loading the least ones. The operator spent more time in loading phase, and the least in dumping. In shovel, there is no WBV pattern identified.

6 ACKNOWLEDGMENT

The authors would like to thank Master in Occupational Safety and Hygiene Engineering (MESHO), of the Faculty of Engineering of the University of Porto (FEUP), all the support in the development and international dissemination of this work.

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