Occupational exposure to vibrations: some considerations with reference to the recently issued regulations

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## Coal Mining: Technologies, Processing Equipment and Quality Control

# Occupational exposure to vibrations: some considerations with reference to the recently issued regulations

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ABSTRACT: The 2002/44/CE Directive on occupational exposure to vibrations, and its Italian enforcement D.Lgs. 187/05 rise to great evidence the problem of an effective evaluation and management of the vibration related risk.
In the 2002/44/CE a pronounced trend can be observed leading towards the "evaluation" approach, *when necessary* supported by measurements, but generally drawn from "guideline" documents and published data banks.
In the authors' opinion nevertheless, an exposure assessment based uniquely on data drawn from data bases can't totally fulfill the basic requirements of the 89/391 European Directive, where a special risk analysis is required, which must take into the due account each local working situation. It can in fact be stated that seldom an exposure estimation drawn from a general data base can significantly represent the real situation and be used in the decision making phase of an effective risk management: at least in some industrial activities a minimal requirement should be that the estimate is based only on local data, where available and statistically significant.
This statement is supported by a series of examples, drawn from direct measurement campaigns as carried out at a number of different extractive sites of different typology in terms of overall layout and mining techniques, and machinery: it clearly appears that the actual vibration level depends on different aspects (worked material, machinery maintenance conditions, ...) that can dramatically differ form the test condition of reference for the general databank data at present available, and can't be easily forecasted due to the continuous evolution of operations and work layout. Since, moreover, the workers' exposure depends on work organization, exposure duration, ...), and the associated consequences in terms of health impairment are affected by local conditions (e.g. temperature, etc.), the final result as drawn from the direct measurements differs -sometimes even dramatically- from the mean one suggested in the data bases.
A first result of general value achieved at the end of the field research is that in the extractive industries the data bases providing only mean exposure levels cant be of help, but here necessarily only the data bases giving an exposure span reference can be used. Finally, the paper provides some suggestion to help the analyst in the selection of the most representative data from literature to be applied in each real situation.

## 1 INTRODUCTION

The 2002/44/CE Directive approach to the evaluation and management to vibration related risk is substantially similar to the general methodological approach arising from 89/391/CEE standard in matter of risk evaluation.
But, for the evaluation of vibration related risk, the 2002/44/CE Directive highlights the importance of the evaluation based on an estimate of the risk rather than the evaluation based on experimental exposure measurements. The same approach is proposed by the Italian enforcement of the 2002/44/CE Directive

(D.Lgs n. 187 19/08/05), here the concept is even more strengthened, and the measurement based evaluations are due only in support to evaluation procedure in the lack of information supplied by data banks managed by ISPESL, Regions, C.N.R. or equipment manufacturers and suppliers.
Of course, the evaluation approach not supported by measurements offers undeniable advantages of economization, rapidity and simplicity, and above all the very important opportunity to preventively plan new “free vibration” working facilities, but on the other hand it shows some critical aspects, particularly regarding the reliability and the precision of the methodology, moreover actual vibration generation (as for other pollutants) strongly depends on a series of factors as machinery maintenance conditions. Such uncertainties must carefully be considered, specially in fields where the vibration exposure of workers can result particularly important, such as extractive, building and civil works industries.

## 2 VIBRATION DATA BANKS

### *2.1 Existing data*

In the Italian law system, the evaluation of vibration exposure at workplaces was not explicitly named before the D.Lgs. 187/05, and consequently it has been neglected for a long time from a great percentage of enterprises. However, according to the professional experience of the authors, the interest for this risk factor has been mainly cultivated in the extractive, building industry and in the public transport, fields where protection requirements were mainly perceived. This forced interest, in the time has however produced a private and business know-how background, that joins to the similar experience acquired in university and research centers. Unfortunately this info seem actually not recovered, and unless a favorable involvement from Regions, ISPESL and other “authorized” subjects, it is destined to get lost.
In the list of the credited sources from the Italian legislative provision is also remarkable the absence of the European data bank, developed within the European plan “Vibration Injury Network” between 1997 and 2001 (even if in ISPESL data bank there is a link to it).

### *2.2 Data from manufacturers and suppliers*

The certification of vibration levels of machinery and equipment is a mandatory point for the CE marking, as stated by 98/37/CE standard (machinery directive) and its Italian enforcement (D.P.R. 24 luglio 1996 n. 459). The aforesaid standard requires that the manufacturer insert in the use instruction document, the root mean square value of frequency weighted acceleration only if this value exceed the threshold limits (2.5 $m/s^2$ for hand harm vibrations and 0.5 $m/s^2$ for whole body vibrations).
The standard’s target is to make available a series of coherent and comparable data in order to help work organization in the respect of health and safety criteria.
For a number of machine and portable equipment typologies, test conditions are settled in a series of technical standards (e.g. UNI EN 28662 1993) which define use conditions of equipment, materials, mounting benches (for hand arm vibrations), or driver’s seats (for whole body vibrations) etc. in order to standardize the test conditions and to allow comparisons among machinery of different origin, but on the other hand this standardized test condition can significantly differ from real use conditions (that generally depend on worked materials, maintenance condition of equipment and machinery, working environment and operator actions, ...), so leading to the difficulty of use of these data.
Moreover the documentation often is not complete and only provides some numerical value, without any info about test conditions, numerical span of obtained data or measurement uncertainties.

### *2.3 Italian data banks*

Some years ago the Piemonte Region published some Guidelines on risk from hand arm vibrations and cumulative trauma disorders (Regione Piemonte 1997) which contained a lot of data for portable equipment and the interactions between vibration exposure and related factors (as repeated movements or stresses), but unfortunately the Guidelines refer to and old edition of technical standards; so at present, in Italy, only ISPESL Bureau (with the cooperation of Azienda USL 7 di Siena) issued a free available updated data bank (for both hand arm and whole body vibrations).
The data stored in ISPESL data bank, realized taking into account previous experiences (European vibrations data bank and Regione Piemonte Guidelines above all), are drawn from experimentally

measured values and technical data from machinery and equipment manufacturers, divided into homogeneous classes of machinery and equipment typologies and with different levels of detail, unfortunately at the moment their number is not yet totally adequate and some machine typology or equipment use condition is not yet represented.
A detailed use instructions guide is provided, with useful considerations and notices about correct use of data not directly measured and taking into account problems related to measurement uncertainties. The data bank editor “suggests” to avoid using available data if their use can lead to an underestimate of risk and rather to make direct experimental measurements, this happens in situations where there is a lack of machinery maintenance, where there are special operative conditions, or use conditions differ from the described ones in the data bank or from those fixed by machine manufacturer and where environmental conditions can critically affect resulting vibrations (e.g. roads, worked materials, …); for some machine typologies some corrective factors are provided, to be applied to manufacturers’ data.

## 3 VIBRATION MEASUREMENTS: METHODS AND PROBLEMS

Vibration measurement procedure are described in a number of technical standards: ISO 2631-1 (1997) for whole body vibrations and ISO 5349-1&2 (2001) for hand arm vibrations and in the new Italian Law (D.Lgs. 187/05). The fundamental parameters to be considered are the value of frequency weighted acceleration (in $m/s^2$) in the contact point between exposed subject and vibration source (e.g. handle of portable equipment or driver’s seat for vehicles) and the measured values have to be referred to a standardized biodynamic coordinate system (UNI ISO 8727 1999).
The accelerometers have to be surely fixed on vibrating surfaces, via magnetic fixing, glues, bolts, etc.; special adapters are provided for special measuring condition, as measurements on driver’s seats (Fig. 1) or equipment’s handles (Fig. 2).

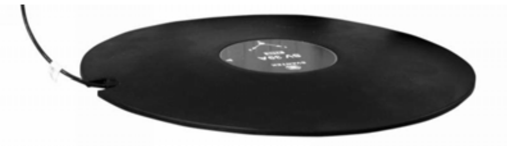

Figure 1. Triaxial accelerometer for seats, according to EN 30326-1 (1994) and ISO 10326-1 (1992) (from technical documentation of manufacturer).

Figure 2. Commercial adapters for different handles (from technical documentation of manufacturers).

Obviously, all fixing systems must have an adequate frequency response, in order not to affect measurements, and measuring instrumentation’s mass should be small if compared with measured machine (or equipment) mass, to avoid dynamic coupling conditions between vibration source and human body. Furthermore a problem arise when hand arm vibrations are measured, since the presence of the measuring probe can modify the normal and correct way of use of the tested equipment; the minimization of this uncertainty factor substantially depending on the experience and “sensibility” of the technician and on the availability of suitable adapters.
A particular case of hand arm vibration exposure arise from use of drive controls, in particular steering wheels; this way of exposure is characterized by different level of interest in various Italian Regions, but literature data and experimental measurements don’t show critical exposure conditions (with values widely less than threshold limit values, 2.5 $m/s^2$) with the exception of bad maintenance conditions, bumpy roads or very old vehicles (in particular for those having large and light steering wheels).

Table 1. Experimental results on steering wheels, ref ISO 5349-1 (2001). Vibration levels can be very much higher if vehicles are overloaded.

| Vehicle | Use conditions | General work environment | Surface | Measured $A_{wh}$ m/s$^2$ |
|---|---|---|---|---|
| Off highway truck (different manufacturer and size) | blasted rock transportation - good maintenance conditions | opencast limestone mine (for cement plant) | mine uneven and rocky dirt road (in grade) in the proximity of the loading areas | **3.44** |
| | blasted rock transportation - good maintenance conditions | opencast limestone mine (for cement plant) | mine uneven and rocky dirt road (in grade) in the proximity of the loading areas | **2.78** |
| | pre blasted and ripped rock transportation - good maintenance | opencast limestone mine (for cement plant) | dirt road (moderate grade) partly muddy | **2.55** |
| | aggregates quarry transportation - poor maintenance conditions | aggregate quarry | dirt road | **4.30** |
| Rubber tyred loader (different manufacturer and size) | yard loading and transportation operations from a stockpile to the chutes | opencast limestone mine (for cement plant) | asphalt surface | **1.01** |
| | feeding of a mobile primary crusher | opencast limestone mine (for cement plant) | dirt muddy road | **0.99** |
| | plant feeding and yard operations | aggregates quarry | dirt road | **1.94** |
| | plant feeding and yard operations | aggregates quarry | dirt road | **1.87** |
| | plant feeding and yard operations | aggregates quarry | dirt road | **0.98** |

It is proper to notice that vibration measurements on drive controls shows great technical problems, because of the need to fix the instrumentation on moving bearings, because of the fact that the presence of instrumentation can impede normal operator’s actions (this also leading to safety problems) and the fact that normal use of drive controls is intrinsically very variable.
In the lack of a wireless technology for the accelerometer connection to the analyzer (or the recorder), it is possible to suspend connection cables or to fix whole instrumentation on the drive controls; the first solution can lead to an overestimate of the measured accelerations, due to cable shaking, while for the second method (preferable) it is necessary to take into account the possible damping effect related to hte mass increase. (Fig. 3)
The dynamic variations  and the effects of shocks produced by the hands on the steering wheel during the drive have to be carefully taken into account, because they also can cause an overestimate of acceleration levels (in particular for medium-high frequencies).

Figure 3. Adapter and measuring instrumentation fixed on a truck steering wheel.

The performed measurement campaigns, analyzed for homogeneous machinery typologies, show a significant variability of results; this is substantially due to maintenance conditions and a number of

“external parameters” as mechanical and geometric features of worked material, operator position during the activity, operator experience or general conditions (e.g. fatigue), engine regulations, etc for hand arm vibrations and seat settings, tyres conditions, road conditions, load features, drive habits and velocity for of vehicles for whole body vibrations.
From the instrumentation point of view, possible error causes can be the inadequate setting or fixing of accelerometers and analyzers, measuring duration not representative of performed activity and DC-shift related to resonance effects typical of coupling between accelerometers and vibrating equipment with impulse phenomena.

Table 2. Some examples of the influence of the DC-shift.

| Tool | Use conditions | General work environment | Used on / for | Measured $A_{wh}$ m/s$^2$ |
|---|---|---|---|---|
| hand held hammerbreaker n.1 | demolition (with mechanical dampener) | opencast limestone mine (for cement plant) | poorly coherent material in a feeder | **31.33** |
| | demolition (with mechanical dampener) | opencast limestone mine (for cement plant) | poorly coherent material in a feeder | **28.51** |
| | demolition (no dampener) | opencast limestone mine (for cement plant) | material in a feeder | **124** |
| hand held hammerbreaker n.2 | demolition (with mechanical dampener) | underground mine | 35 mm dia drillholes in rock | **22.5 (**meas. according to ISO 5349:**1986)** |
| | demolition (no dampener) | underground mine | 35 mm dia drillholes in rock | Accelerometer breakage |
| hand held hammerbreaker n.3 | demolition (with mechanical dampener) | opencast limestone mine (for cement plant) | limestone blocks | **20.47** |
| | demolition (with mechanical dampener) | opencast limestone mine (for cement plant) | limestone blocks | **21.10** |
| | demolition (no dampener) | opencast limestone mine (for cement plant) | limestone blocks | **116** |

In addition, some typologies of vibration exposure are not considered in updated European and National legislation, e.g. there is a lack of info and evaluation methods for single or multiple shock vibration exposure, even if this kind of exposure is not so rare, specially in mining activities (e.g. stone hand cutters in some dimension stone shops).

## 4 COMPARISON BETWEEN THE MEASURED VALUES AND THE LITERATURE DATA

The measured values obtained in the experimental campaigns are substantially comparable with literature data (e.g. from ISPESL data bank) but they show a very wide variability since the single measured values deeply depend on the aforesaid external parameters, and only after have taken into account these factors it is possible to recognize a “typical” range of vibration values for a given machinery typology.
In the ISPESL data bank a complete list of info is attached to each measurement campaigns, with the identification of date, place of the measurement campaign and some info on the technical body performing the campaign; also the used reference standard is listed together with a series of details about external conditions (e.g. ground or road conditions), features of used machine (e.g. seat settings), of performed activities and operator actions (e.g. drive habits) (Fig. 4).

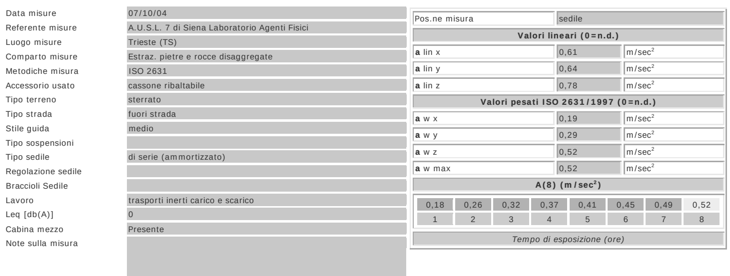


Figure 4. Example of the stored info related to each measurement in the ISPESL data bank. (ISPESL website).

The comparison between experimental values and the data bank data is possible only if all the aforesaid info are similar and consistent; in other words the data from data bank can be used for risk evaluation purpose only if the real situation is the same as the stored one; at present only a limited number of machinery and equipment, and activities are included in the data bank, so limiting the possible use of this tool until it will contain a very large number of machinery and operations.

## 5 CONCLUSIONS

The variability of measured values for a single machine typology, even in comparable operative conditions, points out the very high criticality of a correct use of data obtained in different conditions, and even more for a correct use of data drawn from standardized test measurement (e.g. for the machine characterization and not aimed to the operator exposure evaluation). In particular some external factors can affect actual vibration levels, generally depending on maintenance condition of equipment and machinery, worked materials, working environment and operator actions.

Problems related to possible errors caused by inadequate setting or fixing of accelerometers and analyzers, measuring duration not representative of performed activity, etc. point out the necessity of a careful definition of measurement methodologies which have to take into account all the involved factors and also the statistical significance of data (high number of samples, adequate measurement duration, ...).

In order to increase the number of available data in the data banks a cooperation is desirable among all involved subjects (research centers, technicians, manufacturers, ... ).

A mixed methodology seems to be more adequate in order to assure health and safety of workers as stated for the minimization of risk related to professional noise exposure (D.Lgs. 277/91) and maintained in the recently issued revisions of general safety legislation (D.Lgs. 626/94) where a screening based on literature data is proposed, with some following detailed studies, focused on border-line or critical situations.

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