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WHOLE-BODY VIBRATION EMISSION AND THE MACHINERY DIRECTIVE

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1. INTRODUCTION

There have been many studies over several decades that have tried to determine the link between exposure to whole-body vibration and injury [1]. These have linked exposure to WBV with various outcomes such as disturbance of the digestive system, disturbance of the function of bodily organs and inguinal hernia, but the strongest evidence exists for an increase in occurrence of back pain [2]. Back pain has also been shown to be caused by many activities undertaken by people regularly exposed to high levels of whole-body vibration, for example, drivers often perform manual handling tasks or sit for long periods in constrained postures.

The European Commission included specific requirements for whole-body vibration when it drafted its Machinery Directive [3]. At about the same time the Commission made proposals for limiting workplace exposures to whole-body vibration [4] but Member State agreement on a Directive is yet to be reached and knowledge of whole-body vibration has changed in the interim.

A number of Standards, mostly to assist with the reporting of vibration emissions, have been developed by CEN to facilitate compliance with the whole-body vibration requirements of the Machinery Directive and these Standards are now approaching maturity.

HSE is evaluating the role of the Machinery Directive and its supporting Standards in preventing ill-health due to whole-body vibration exposure.

2. ILL-HEALTH CAUSED BY WHOLE-BODY VIBRATION

The evidence for whole-body vibration injury has recently been reviewed [2] with the conclusion that occupational exposure to whole-body vibration is associated with increased risk of lower back pain, sciatic pain, and degenerative changes in the spinal system. The epidemiological evidence was not sufficient to outline a clear exposure-response relationship. Annexes to Standards [5,6] derived from earlier scientific evidence provide guidance on the magnitudes of exposure to whole-body vibration that might be expected to affect health.

Palmer et al [7] have reported the most common sources of occupational exposure to whole-body vibration in Great Britain. The study addressed various forms of back pain and included a logistic analysis to determine the prevalence ratios for injuries with variables including exposure to whole-body vibration, working with hands above head height, and daily lifting of heavy weights. The study found whole-body vibration exposure to be no more, and sometimes less, important than other factors considered.

Stayner [8] observed that published work investigating the hypothesis that whole-body vibration is a cause of ill-health shows a stronger inclination to try to support it than test it. Studies of whole-body vibration have tended to focus on WBV as the main source of injury. Where other sources of injury with the same or similar symptoms are reported, it is evident that risks presented by WBV are of a similar or lesser magnitude than those resulting from, say, constrained posture, or manual handling.

The mechanism by which exposure to whole-body vibration causes spinal injury is unclear. Some researchers [9] have studied injury as a function of weighted rms acceleration exposures and observed that injury rates increase with increasing exposure. Other researchers [10,11] have suggested that high acceleration events during industrial exposure to WBV are of sufficient magnitude to present risk of microfractures of the vertebrae (though not instant disability) induced by mechanical fatigue.

3. INDUSTRIAL EXPOSURE

A few examples of whole-body vibration emission magnitudes during industrial exposure are reported by Paddan, et al [12]. The data presented should not be regarded as an accurate reflection of likely emissions in industry as a whole but it does serve to illustrate a number of points. Firstly it shows that the vibration emission magnitude of common vehicles in normal use straddles the Machinery Directive declaration threshold of 0.5 m/s^2 rms - the median emission value of vertical acceleration in many common vehicles is often close to 0.5 m/s^2, i.e. even in the simplest case, the WBV emission of many vehicles is sufficiently high to merit reporting according to the Machinery Directive criterion. Secondly, it shows that components in axes other than the vertical axis usually contribute significantly to the overall vibration. Thirdly, it is seen that the median emission values for the summed vibration (including backrest vibration in this case) usually exceed the declaration threshold. Standards written to support the Machinery Directive should require reporting of 3-axis summed vibration emissions on the seat cushion (or platform for standing operators).

Sandover [10] was concerned about the contribution of high acceleration events to overall risk of vibration injury from industrial exposure to whole-body vibration. He found that accelerations in excess of 20 m/s^2 can occur every few minutes in some jobs. Stayner [8] found that suspension seat end stop impacts contributed less than 3% of the rms exposure of tractor drivers but contributed the majority of acceleration events exceeding 5 m/s^2.

Durations of exposure to whole-body vibration are usually at least several minutes and may extend to several hours. For example, industrial truck usage can vary widely but bus and lorry drivers are likely to be exposed during most of their working hours. Although some information on patterns of exposure to WBV is available more detailed information is required. This may usefully be extended to quantify other risk factors for back injury such as access to and egress from cabs, manual handling, and durations of adopting constrained postures.

To date, information on the whole-body vibration emission performance of machinery appears to lie almost exclusively with the manufacturers themselves. Data in the public domain have identified scope to reduce whole-body vibration emissions in particular vehicles (particularly through replacement of the seat with a model more suited to attenuation of the vibration present at the seat mounts) but have failed to show gross differences in the overall emission levels of machinery in the same class.

European research to assist development of Standards has included study of likely emission values during normal use of industrial trucks [13]. The range in vibration emission varied widely depending on the style and intended use of the truck. WBV emissions approaching 1 m/s^2 were common for counter balance trucks.

Stayner's review of the vibration emission of agricultural tractors [8] showed that emission is highly dependent upon the nature of the task and less so on the model of tractor in use. High speed tasks could produce 2 or 3 times the vibration emission of lower speed tasks. Some models of tractor were seen to perform tasks with lower whole-body vibration emissions than others. The biggest difference was seen when comparing suspended tractors with conventional tractors for transport duties. Vibration emissions of suspended tractors were about 20% lower than those of conventional tractors but the range of vibration emissions was overlapped for about 50% of the examples.

4. THE EU MACHINERY DIRECTIVE

4.1 The Single European Market

The Machinery Directive was written to facilitate the establishment of the single European market by harmonising Member States' health and safety requirements for machinery so eliminating barriers to trade.

The Machinery Directive specifies a hierarchy for selection of methods to eliminate risk of accident or ill-health throughout the foreseeable lifetime of the machine. Designers of new machinery are obliged to:

- eliminate or reduce risks as far as possible (inherently safe machinery design and construction);
- take the necessary protection measures in relation to risks that cannot be eliminated; and
- inform users of the residual risks due to any shortcomings of the protection measures adopted, indicate whether any particular training is required and specify any need to provide personal protection equipment.

4.2 Whole-body Vibration

As with all hazards, the ultimate requirement for whole-body vibration is that the machinery can be used safely. A general requirement for vibration is that '... risks resulting from vibrations ... are reduced to the lowest level ...'. The essential health and safety requirements (EHSRs) for mobile machinery include a requirement to report the whole-body vibration emission level, design seats that reduce vibration transmitted to the driver to the lowest level, and design cabs to ensure that the driver is protected against excessive vibration. The corresponding requirements for hand-arm vibration are not discussed here.

The manufacturer's hazard assessment should determine the likelihood of the machine presenting risk of injury due to whole-body vibration. The intended use of the machine will dictate the likely roughness and profile of surfaces to be traversed and the vehicle speeds that might be expected and thus the mechanical excitation that may require control during design of the vehicle.

Provision of information concerning residual risk is the last resort in tackling a hazard but it is likely that many instances of reasonable use of mobile machinery will give rise to whole-body vibration emissions that exceed the reporting (not risk) threshold of 0.5 m/s^2. When vibration emission exceeds 0.5 m/s^2 the instruction manual for mobile machinery should report the value. Warnings should be provided if occasional occurrences of high accelerations are likely to present risk of injury. Information about its control of vibration should be provided and it may also be appropriate to indicate needs for training, etc. when addressing the wider terms of residual risk.

4.3 Verification of Achievement by Design

The means of verifying conformance with the requirement to reduce risks from vibration to the lowest level has evolved to rely, in the first instance, on an analysis of the reported vibration emission with competitor machinery. The reported vibration emissions for the compared machines should first be verified using of the procedures laid down in EN 12096 [14]. With the current state of immaturity of the Standards it is not unusual to find that the reported vibration emissions are in error.

Machinery that produces the highest vibration emission in a class is always open to challenge and where there are substantial differences between the highest and lowest vibration emissions for a machine class it is to be expected that many of the machines will be challenged by the enforcing authorities of Member States.

5. STANDARDS AND THE MACHINERY DIRECTIVE

5.1 International Perspective

The drafting of European Standards for whole-body vibration emission has been mindful of the content of existing International Standards.

The British Standard for evaluation of exposures to whole-body vibration published in 1987 [5] observed that there was limited evidence for a causal relationship but recommended a criterion value for caution. The revised International Standard for measurement and assessment of whole-body vibration, published in 1997 [6], includes an Annex recommending the upper and lower bounds of a caution zone expressed in two alternative (and inconsistent) measures the upper bound of which is slightly higher than the BS criterion.

This revised International Standard [6] advocates three methods of evaluating the health effects of exposures - root mean square acceleration (rms), maximum transient vibration value (MTVV) and vibration dose value (VDV). The revision introduced several changes including, a new weighting W_k (broadly equivalent to the earlier weighting defined in the British Standard, W_b) for the axis normal to the seat plane, changed the parameters of the weighting W_d used for the axes in the seat plane, and changed the relationship of multiplying factors used when summing accelerations in different axes. These recent changes have introduced difficulties in comparing data reported since issue of the revised Standard with earlier data. Griffin [15] has reported the uncertainties and ambiguities of ISO 2631-1:1997.

A method of evaluating repetitive shocks is currently being drafted by the ISO committee responsible for ISO 2631-1 [6]. Although the purpose of this work item is to prepare a further Annex to the standard, the method is yet to be proven and the work borders on research.

5.2 European Standards

5.2.1 General Emission Standards

The General WBV Standard supporting the Machinery Directive [16] is currently in the later stages of its first full revision. The revision is broadly consistent with the revised International Standard but adopts only the rms evaluation method. It requires acquisition and reporting of acceleration data at the operator position in three mutually perpendicular translational axes, and reporting of magnitudes that are expected during the intended use of the machinery.

The proposed revision gives guidance on how to prepare a machine class specific test code (or can be used directly) and proposes use of either a natural or artificial test track. It helps identify the parameters likely to affect WBV emission levels that will likely need to be recorded. The natural test track method appears to be an effective, simple and reproducible test but limited in its ability to provide fair comparisons between machines. The artificial test track method appears to be a reasonable test of vehicles that work on paved surfaces and has been seen to have some scope for application to off-road machinery. Both of these methods are relatively new and subject to ongoing scrutiny.

The method of declaration and verification of vibration emissions [14] is the same for hand-arm and whole-body vibration. The method is gaining recognition in the field of hand-arm vibration but has been little tested for WBV. This Standard requires reporting of the emission value, ***a***, and the uncertainty in the emission value, ***K***. The uncertainty, ***K***, in the determined emission value, ***a***, is derived from the quantified reproducibility of the Standard test determined by inter-laboratory comparison.

It has already been seen for hand-arm vibration that standard tests may produce a highly repeatable and reproducible result with low uncertainty, ***K***, but may not accurately represent risk nor be useful for comparison of equipment. It remains to be seen how these methods perform for WBV.

5.2.2 Machine Test Codes

The apparent absence of obvious differences in the vibration emissions between machinery of a class in the workplace and possibility of wide variations in emission from task to task suggests that writing test codes to facilitate comparison of machines may often be difficult. Even if the test uncertainty, ***K***, is low, the emission determined by the Standard test may not be a good basis for comparing machine risk unless the risk is dominated by an application that results in similar levels of emission and there are obvious differences between higher and lower risk equipment.

The prime value of the test code may be to indicate the presence or otherwise of risk of whole-body vibration injury.

Reporting vibration emission in accordance with existing Standards is unlikely to be sufficient to cover the requirement to provide information on residual risk. For example, shock may need to be addressed separately from the required vibration data. Guidance for training in best practice for use of machinery may be appropriate.

5.2.3 Seat Test Codes

Seat test codes [17,18,19] have been written to help demonstrate that designs of seat meet the requirement to reduce vibration.

Current standards for seat performance concentrate on the ability of the seat to reduce the rms acceleration. Standards are now in development to take account of high acceleration events that occur with end stop impacts and give appropriate recognition to selection of spring rate and damping in suspension designs.

6. REDUCTION AND CONTROL OF VIBRATION RISK

6.1 Inherently Safe Design

Risks from vibration depend amongst other things on the characteristics of the vibration, and the magnitude, duration, regularity and frequency of exposure. Designers should assess machinery's capacity to generate risk of vibration injury when operating as intended and in other foreseeable conditions of use.

Risks from whole-body vibration are most likely to arise when mobile machinery travels over rough ground. Reduction of risk due to travelling may occasionally be possible by, for example, modifying the layout or mounting of machine components to change vehicle dynamics and prevent amplification or attenuate induced vibration, but protective or informative measures to reduce risk are likely to be required.

There is usually scope for the designer of mobile machinery to prevent internally generated vibration reaching the user's buttocks or feet at levels of emission exceeding the thresholds specified in the Directive.

6.2 Protection Measures

Protection measures, usually taking the form of additional or modified chassis or cab suspensions and selection of an appropriate seat (conventional or suspended), will be required whenever analysis shows that vibration is not reduced to the lowest level.

The relative importance of the mechanisms of injury have important consequences when it comes to suspension designs. Careful judgement is required to balance achievement of low levels of average vibration while avoiding the introduction of shocks created by suspensions running into their end stops during normal machine use.

Research into the selection of seating has shown that incremental reductions in vibration emissions can be achieved in the vast majority of vehicles by selection of an alternative seat. Suspension seats are fitted to a minority of industrial vehicles but it is not clear that their increased use, particularly if ill-considered, will reduce vibration exposures or risk of injury.

6.3 Information Concerning Residual Risk

Machinery purchasers should be made aware of any residual risks that have not been eliminated by design or protection measures so that they can plan for control of the risk during machinery use. Provision of WBV emission data alerts the user to WBV risk. This may need to be supplemented by including, for example, additional information to place the data in context (perhaps recognising the limitations of a Standard), information about shock where this is not otherwise evident, and instruction in safe use of the machine.

HSE guidance [20] on prevention of injury from occupational exposure to whole-body vibration includes example control measures of minimal cost that can readily be introduced as best practice.

7. CONCLUSIONS

The Machinery Directive recognises the association of injury with occupational exposure to WBV and provides an incentive to reduce risk. Standards written in support of the Machinery Directive focus on reporting of vibration emission. The main contributions of the Machinery Directive to prevention of WBV injury include:

- requiring manufacturers to consider WBV emissions;
- requiring minimisation of vibration as part of machinery design;
- encouraging readily achievable incremental reductions in emission by changing the model of seat; and
- highlighting the machinery that causes highest exposure through reporting of emissions.

Uncertainties in the effectiveness of the Machinery Directive in preventing WBV injury include:

- limitations in the ability of standard emission tests to provide fair comparisons of similar machines; and
- failure to reflect concerns that shock may be an important contributor to injury.

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