Proceedings of the Institute of Acoustics

MEASUREMENT UNCERTAINTY IN THE EVALUATION OF HAND-ARM VIBRATION EXPOSURE IN THE WORKPLACE - AN INTRODUCTION TO ISO 5349-2

P M Pitts Health and Safety Laboratory, Buxton, Derbyshire SK17 9JN

1. INTRODUCTION

A new standard will shortly be issued as a draft International Standard (DIS), which provides practical guidance on the evaluation of vibration exposure in the workplace. This standard, ISO/DIS 5349-2, concentrates on the practical problems of the measurement of vibration, exposure time and the evaluation of daily exposure in the workplace.

The development of ISO/DIS 5349-2 has had to consider carefully how measurement uncertainty affects the way measurements are carried out, or should be carried out in practice. Uncertainty due to instrumentation and calibration are generally considered to be small compared to the uncertainty of measurement location, mounting systems, accelerometer mass and the use of mechanical filters. The importance of other forms of uncertainty, for example the differences between workers using the same tools, will depend on the purpose of the exposure evaluation.

2. PROPOSALS FOR ISO 5349 PARTS 1 AND 2

International Standard ISO 5349:1986 "Mechanical vibration - Guidelines for the measurement and assessment of human exposure to hand-transmitted vibration" provides the basic Standard for the evaluation of exposure to hand-arm vibration. This Standard has been used as the basis of many other European and International Standards for measurement and testing relating to hand-arm vibration.

ISO 5349:1986 is currently being revised by ISO Technical Committee TC 108. The revision provides an opportunity to update and rationalise the Standard. The significant changes introduced by the revision are:

- A requirement to evaluate the frequency weighted vibration total value (a root-sum-of-squares combination of the three axes of measurement, recognising that the vibration from many tools is not dominated by a single axis);
- Use of an 8 hour normalisation factor for daily exposure (rather than the 4 hour factor previously used), to bring vibration exposure assessment into line with daily exposures assessment methods for noise and chemical substances;
- Use of the frequency weighting defined in ISO 8041:1990.

In parallel with the work on the revision of ISO 5349 a European Standards working group began the preparation of a document to provide guidance on the practical measurement of hand-arm vibration in the workplace. This document has become a proposal for a part 2 to ISO/DIS 5349-2 "Mechanical Vibration - Measurement and assessment of human exposure to hand-transmitted vibration - Part 2. Practical guidance for measurement in the workplace".

The aim of ISO/DIS 5349-2 is to provide practical guidance on workplace exposure measurement,

covering the issues summarised in Table 1.

The introduction of ISO/DIS 5349-2 has allowed ISO/DIS 5349-1 (the revision of ISO 5349: 1986) to become a more compact specification of measurement parameters, by transferring discussion of issues such as dc-shift, mechanical filters and mounting methods to part 2.

Table 1 Issues addressed by proposed ISO/DIS 5349-2

Instrumentation	• Accelerometer characteristics • Mounting methods • Fixing locations • Routing of cables from accelerometers • Identification of signal distortions • Sources of uncertainty • Calibration and verification
Identification of work tasks	• Identification of external parameters affecting vibration magnitude (e.g. work surfaces, materials) • Identification of modes of operation of tools or machines • Selection of operations to be measured • Selection of measurement periods, based on tool or machine cycles or work patterns
Assessment of exposure times	• What is meant by exposure time • Methods for assessing exposure times
Calculation of daily vibration exposures	• Practical examples of different types of calculation, based on different work patterns and tool / machine types

3. MEASUREMENT UNCERTAINTIES

3.1 General

Much of the debate that has taken place in the working group responsible for ISO/DIS 5349-2 has been related to the questions:

- how are uncertainties introduced into the measurement of vibration exposure and
- how can they be controlled?

Uncertainties can be considered to arise from:

- Identification of what tools or machines are to be measured,
- Identification of the processes or tasks to be measured,
- Selection of the periods over which measurements are made
- Identification of appropriate measurement locations,
- Fixing of accelerometers to measurement surfaces,
- Instrumentation used for the measurement of vibration levels,
- Measurement of exposure times, and
- Evaluation of daily exposure.

The aim of ISO/DIS 5349-2 is to control uncertainties by guiding users through the decisions which have to be made when carrying out exposure evaluation.

3.2 Purpose of the exposure evaluation

The first question to be asked when planning vibration exposure evaluations is: what are the objectives of the evaluation? Having a clear idea of the what information is required at the outset will ensure that the appropriate measurements are made, and the unnecessary uncertainty is not introduced into the information obtained.

Evaluations of vibration exposure will normally be intended to provide information on the exposure of either an individual worker or a particular task. For an evaluation of a specified individual, the variation in vibration levels and work-rates from one person to the next will not be important: if the exposure evaluation is for a task, some assessment of the variation between operators may be required.

In most cases, a secondary objective will be to provided information which will assist in lowering excessive daily vibration exposures. This may mean obtaining vibration magnitude information on equivalent tools from different manufacturers. Such comparisons usually need repeated measurement of the same task using the same operator to minimise the effect of measurement uncertainties.

3.3 Identification of tools or machines to be measured

Before any measurements of vibration can be made it is important to make a careful assessment of the tasks being carried out; to identify each phase of a task and identify any changes in tool operation for which separate measurements should be made. Tools may be used on different materials at different stages in a task, or different attachments may be used with the same tool. Some tool attachments, particularly abrasive discs, wheels or sheets, can change their vibration properties through their working life. It is important to identify all factors which may affect the vibration levels on a tool or machine, and plan the measurements to take account of these changes.

The accuracy of any evaluation will depend on how well the measurements of vibration levels, and corresponding exposure times reflect the actual use of vibrating tools and machines.

3.4 Identification of the processes or tasks to be measured,

The vibration levels a person is exposed to will be dependent on how the tool is used. The grip and feed forces applied to the tool or work piece can have a significant affect on vibration level. It is therefore important to assess how the tool operator is working, to look at their posture, the variation in applied forces and determine what phases of the work processes need to be measured.

3.5 Selection of measurement periods

The period over which vibration measurements can be made will be dependent on the type of operation being carried out, whether there are natural work cycles, breaks in operation of the tool and periods when the hand is removed from the vibrating surface.

The work process must be observed carefully, to ensure that measurement periods can be chosen which avoid measurement artefact from events such as temporary removal of a hand from the tool handle or dropping of the tool onto work surfaces. The practicality of measurement should be assessed at this stage, consider the mobility of the worker, safe cable routing and how the measurement will affect the work process. In some situations it may be appropriate to set up

simulated work operations, rather than attempt measurements under real working conditions.

3.6 Identification of measurement locations

Having identified which processes to measure, accelerometers must be fitted to the tool at positions which represent the vibration entering the hand. ISO/DIS 5349-1 specifies that:

"*measurements should be made on the vibration surface as close as possible to the centre of the gripping zone of the machine, tool or workpiece*".

In practice, however, the size and shape of accelerometers and their mounting systems makes it difficult, if not impossible, to measure at the optimum location, at the centre of the gripping zone.

For practical measurements, accelerometers often have to be attached at one end of the gripping zone. Unfortunately, for some tool types, particularly those with side handles, the variation in vibration level across the gripping zone can be very large: differences of up to 300% have been reported along the length of side handles of hand-held grinders. It is therefore important to select carefully the best measurement location. ISO/DIS 5349-2 gives general advice on where to fix transducers and shows example of measurement location for a range of tool types (see Figure 1).

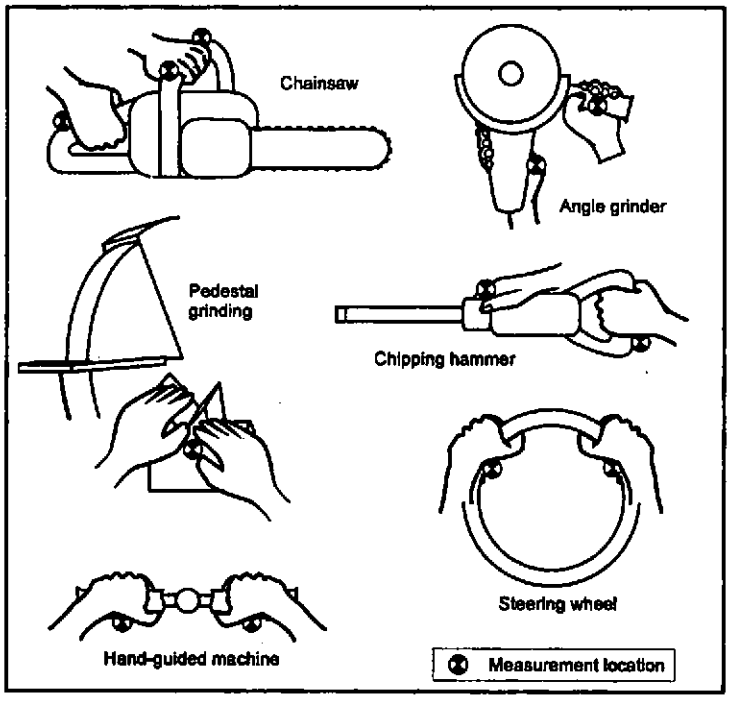

Figure 1 Examples of measurement locations (from ISO/DIS 5349 part 2)

3.7 Fixing of accelerometers to measurement surfaces

An accelerometer, or accelerometers, must be rigidly attached to the surface of a vibrating tool. A poor mounting system can have resonance characteristics which will introduce large errors in to the measurement system; heavy mounting systems can themselves affect the vibration characteristics

of the tool, particularly lightweight tools or tool handles and mounting systems which support the transducers at a distance from the surface of the tool can amplify rotational vibration modes.

ISO/DIS 5349-2 provides some information on popular mounting system, identifying the advantages and disadvantages of each (see Figure 2). No mounting method is ideal. They all add mass to the tool handle and all affect, to some degree, the way the tool is operated.

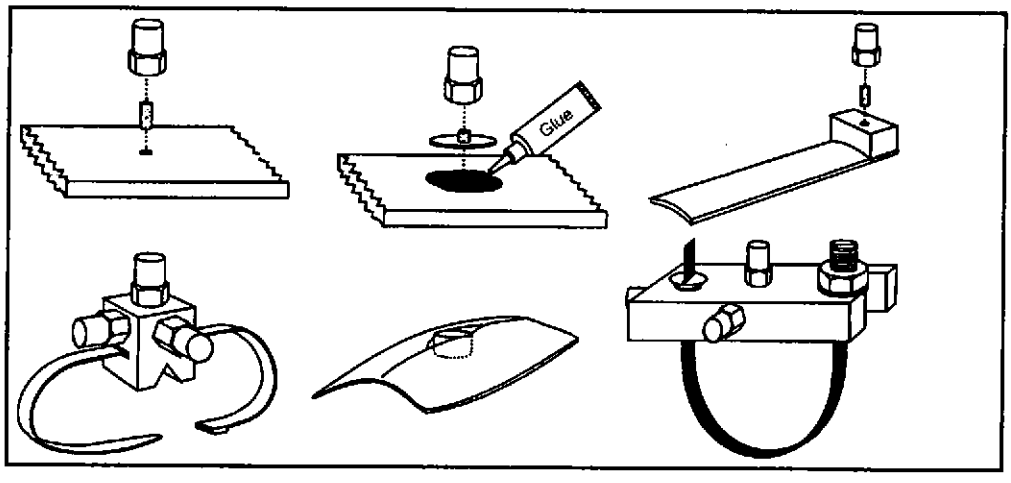

Figure 2 Examples of accelerometer mounting systems (from ISO/DIS 5349-2)

3.8 Instrumentation used for the measurement of vibration levels

The requirements for vibration instrumentation are specified in ISO 8041:1990. ISO/DIS 5349-2 recognises the importance using of instrumentation which conforms to ISO 8041:1990, and makes recommendations for regular checks of functionality and routine verification of the measurement instrumentation.

The proposed standard also provides information on how to control sources of uncertainty due to the instrumentation systems. Interference and distortion effects such as electromagnetic pickup, triboelectric effect and dc-shift are all discussed along with cable connection problems, the commonest source of error in hand-arm vibration measurement. The use of mechanical filters is also covered, as a method of controlling dc-shift; with general information provided on their required characteristics and selection.

3.9 Measurement of exposure times

The assessment of daily exposure time must be related to the durations over which the measurements of vibration are carried out. For example, in some cases measurements may be made over a period for which the hand is in contact with a vibrating surface, in which case daily exposure time is the total time in contact with that vibrating surface; other measurements may be over a typical period of use (perhaps including short periods during which the tool is not operating) in this case the exposure time is more closely related to the time taken for the task than the actual contact time.

Clearly, careful consideration must be given to what is meant by exposure time for a given measurement procedure. ISO/DIS 5349-2 uses worked examples to explain the alternative approaches which may be used.

3.10 Evaluation of daily exposure

The daily vibration exposure $A(8)$ is given by:

$$A(8) = \sqrt{\sum_{i=1}^{n} a_{hvi}^2 T_i},$$

where a_{hvi} is the vibration magnitude during the exposure period T_i. The uncertainty associated with daily vibration exposure is therefore dependent on the uncertainty of the measures of vibration magnitude and exposure time.

ISO/DIS 5349-2 observes that "the uncertainties associated with the evaluation of $A(8)$ are often very high (e.g. 20 - 40%)".

4. CONCLUSIONS

The uncertainties associated with hand-arm vibration evaluations can be large. ISO/DIS 5349-2 states that:

"*When measuring vibration transmitted to workers the uncertainty will be affected by factors related to individual measurements, such as:*

- *instrumentation accuracy,*
- *calibration;*
- *electrical interference and*
- *mounting of accelerometers,*
- *mass of accelerometers;*
- *location of accelerometers;*
- *changes from the normal operation of the power tool and changes to hand posture and applied forces brought about by the measurement process (i.e. mounting of accelerometers and associated cables);*
- *changes in the operator's method of working, as a response to being the subject of the measurement.*

In addition accuracy of the overall assessment of vibration exposure will be affected by changes which occur in the course of any working day, such as:

- *changes in the condition of power tool and equipment (e.g. changing the wheel of a grinder may change the vibration transmitted to the operator dramatically);*
- *changes in posture and applied forces (ISO WD 15230);*
- *changes in the characteristics of the materials being processed."*

The measurements of vibration level are affected by many factors related to the tool or machine, the person, the vibration measurement process and the assessment of exposure time. The main influences on uncertainty being related to the tool operation and the selection and planning of the measurements. For most practical measurements of exposure the uncertainty associated with instrumentation and calibration, electrical interference and mounting and mass of accelerometers should be small compared to the uncertainties which arise from selection of measurement location and variability in the work operation.

It clearly unrealistic to attach a high degree of accuracy to any evaluation of daily vibration exposure. ISO/DIS 5349-2 attempts to highlight the factors which have to be considered when performing an evaluation of vibration exposure, and in doing so, to control the uncertainties of the evaluation.

5. POSSIBLE FUTURE DEVELOPMENTS OF ISO 5349-2

Currently ISO/DIS 5349-2 deals principally with the evaluation of a daily vibration exposure. However, ISO/DIS 5349-1 recognises that there are many potential contributing factors to the risk of injury from hand-arm vibration. Factors such as thermal environment, noise exposure, grip force and feed forces can all be evaluated, while others such as hand-arm and body postures could be reported. Future developments of ISO/DIS 5349-2 could usefully introduce practical guidance on the evaluation and reporting of these factors.

6. REFERENCES

International Organisation for Standardisation (1986) Mechanical Vibration - Guidelines for the measurement and assessment of human exposure to hand-transmitted vibration. International Standard, ISO 5349.

International Organisation for Standardisation (1999) Draft International Standard on Mechanical Vibration - Measurement and assessment of human exposure to hand-transmitted vibration - Part 1. General guidelines. ISO/DIS 5349-1.

International Organisation for Standardisation (1999) Draft International Standard on Mechanical Vibration - Measurement and assessment of human exposure to hand-transmitted vibration - Part 2. Practical guidance for measurement in the workplace. ISO/DIS 5349-2.

International Organisation for Standardisation (1990) Human response to vibration - Measuring instrumentation. International Standard, ISO 8041.