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# Analysis of Metrological Requirements in Occupational Health and Safety Regulations Related to the Emerging Risk of Exposure to Vibrations

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**Abstract:** In occupational exposure to vibration, the risk assessment process is defined through a regulatory framework that presents some relevant metrological problems. This framework considers methods based on estimation and on measurements. Estimation methods could employ existing information that is provided for each manufacturer to each individual tool or application to carry out such estimation. The use of estimation methods has some problems, such as substantial uncertainty. When using measurement methods, some metrological aspects are not fully defined. Therefore, a new and emerging risk appears due to certain methodologic limitations. Consequently, the variation between the estimated and the actual values could overestimate the level of occupational exposure to vibrations. Thus, with this paper, a critical analysis of this emerging metrological problem is provided. For this, a critical analysis of the metrological requirements regarding European standards is developed. To this end, the estimation method and measure method are investigated, considering, in both cases, the main factors related to uncertainty, reliability, and traceability. With this structure, a set of metrological limitations have been identified, thus pointing towards future lines of research that allow the improvement of the process of assessing the level of occupational exposure to vibrations.

**Keywords:** vibration; metrology; emerging risk; occupational health; regulation

## 1. Introduction

Repeated or continuous exposure to vibrations can cause chronic diseases or lesions (musculoskeletal disorders, specific disorders of the elbow, back pain, etc.) [1–3], not only in in industrial applications, but also in other activities involving machinery or motorized vehicles, such as agricultural activities [4], sea fishing [5], etc. In [6], a literature review was carried out, demonstrating that machines with driving seats seem to be associated with low back lesions, while handheld machines may cause disorders in the upper extremities. It could be concluded that these diseases have their origin in whole-body vibration (WBV) and hand-arm transmitted vibration (HAV).

Workers and operators from different industries are specially affected by this hazardous exposure to vibration, as on many occasions many of their tasks involve the use of machines and equipment involving occupational exposure to vibrations. For this reason, precise Occupational Health and Safety (OH&S) Regulations are required in order to establish the limits for this exposure and to prevent derived damages or diseases.

One of the fundamental aspects when legislating and carrying out correct OH&S regulations is the adequate control and assessment of the methods and physical agents present in work processes. Acceptable exposure values are investigated to ensure the health and safety of workers. Nevertheless, the estimation of the actual exposure values in real applications requires reliable and precise measurements.

From a metrological point of view, it is necessary not only to obtain reliable measurements, but also to ensure the traceability of these measurements. Ensuring traceability permits to determine and document the value and accuracy of a measurement result and to disseminate this knowledge [7]. This way, it is possible to establish a relation, named traceability chain between any instrument employed in a measuring process and the standard associated to the magnitude that is being measured [8].

For OH&S regulations, metrology has a key role when defining risk assessment methods that are employed in the different standards and technical recommendations. Metrological analysis of the measured values in real-life applications are also essential to ensure the real values to which operators are exposed while developing their daily tasks.

This is the case for the vibrations regulations which are to be discussed within this investigation. The occupational exposure to vibrations was identified as a new and emerging risk (NER) considering among other factors the high number of exposed workers in the European Union [9]. Thus, according to the Sixth European Working Conditions Survey [10], 19% of the workers surveyed are exposed to vibrations for more than 25% of their working time; furthermore, an increasing trend is observed in this percentage of workers exposed to vibrations at work.

In the OH&S field, one of the main lines of action is to detect and avoid possible accidents, illnesses, and problems due to the work environment. In this respect, there is a wide range of regulations, which, as in the case of occupational exposure to vibrations, are often based on quantitative values. Those quantitative values are employed to establish admissible limits, preventive actions and they even serve as a reference for legislative actions. However, sometimes these values are not always well treated or easy to determine. This is the case of the vibration exposure values studied in this research.

As stated in [11], when using such quantitative values in a reglementary process, there are a number of questions that are particularly relevant, such as which parameters should be measured, whether it is possible to use the existing metrological infrastructure, or if it would be possible to ensure traceability of the results obtained. The relationship between good regulation (based on correctly established and reliable risk assessment methods) and measurements is therefore evident; some of the main fields where the best possible measurements are especially relevant are shown in Figure 1.

It can then be stated that a metrological characterization of all the parameters involved has a key role in the occupational exposure to vibrations. There are different approaches on how to assess occupational risks in overall processes [12]; however, many studies on how to analyze critical occupational risks include the measuring modules as a complete functional unit to be assessed, where safety allocation methods show that it has an impact on the risk assessment of the overall process [13]. As it is stated in [14], despite the proven need of using metrological techniques (e.g., detailed uncertainty estimation), their application is not properly defined. Unfortunately, current regulations and standards do not always cover all the metrological aspects required for a correct risk assessment, leaving some unresolved issues. As a result, the risk of overestimating or underestimating exposure to vibrations is increasing [15], and it can affect workers wellbeing.

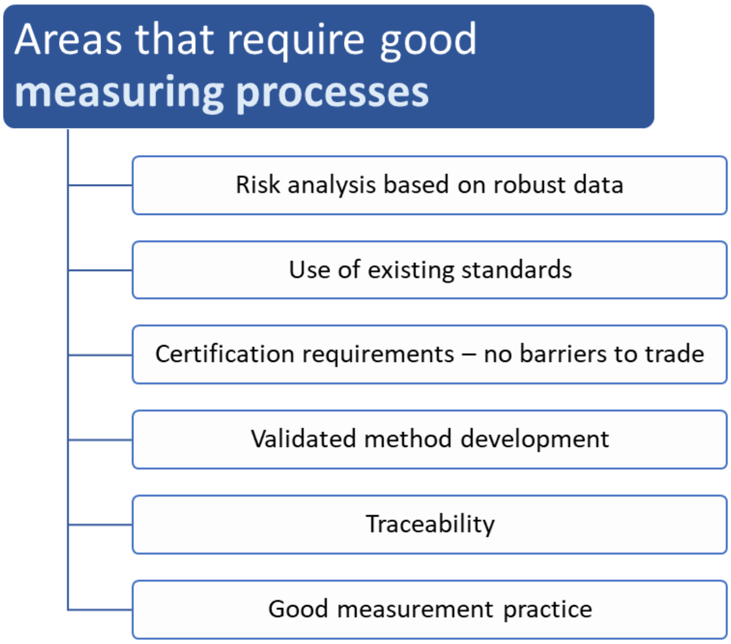


**Figure 1.** Examples of fields where the best possible measurements are especially relevant.

The control strategies necessary to reduce this type of risk require new measuring instruments, tools, and standards to be able to better assess vibration at the workplace [16]. In this way, the authors of [17,18] have studied the risk assessment process for exposure to vibrations, considering such a new and emerging context. From these works, important challenges arise in metrological matters applied to the study of vibrations. Among these challenges, the lack of detailed enough methodologies and procedures stands out proposed by current regulations. This limitation can be considered one of the causes that configure the exposure to vibrations as a NER.

Thus, this work aims to critically review the different alternatives for the assessment of occupational vibrations from a metrological point of view. For this, first a metrological study of the regulatory framework on the occupational exposure to vibrations is approached. Next, a critical analysis of the metrological requirements regarding European standards on how to estimate exposure to vibrations is developed. To this end, the estimation method and measure method are investigated, considering in both cases the main factors related to uncertainty, reliability, and traceability.

## 2. Metrological Study of the Regulatory Framework on the Occupational Exposure to Vibrations

### *2.1. European Directive 2006/42/CE on Machinery*

Exposure to vibrations at workplace normally has to do with the use of different equipment and machinery which are the source for such vibrations. However, there are countless different types of tools, vehicles, and machines use in very different sectors, such as agriculture, transport, or manufacturing among others, and each of these devices has different operating conditions.

European Directive 2006/42/CE [19], for the commercialization and commissioning of machinery, must be considered together with OH&S regulations regarding exposure to vibrations. This directive sets the conditions for which a certain machine can prove to be safe and allows them to be manufactured.

Consequently, this regulation includes requirements that manufacturers and suppliers must include in their machinery before putting them into market. Among these requirements, some essential health and safety requirements are established by the European Directive, including those related to vibrations when applicable:

- When the machine or workstation includes the installation of seats and it is subject to vibrations, it is required to design the seat so that it helps to reduce the exposure to vibrations for the operator (Section 1.1.8 within the CEN/TR). In general, the machine is required to be designed in such a way that the vibrations are reduced to the lowest possible level (Section 1.5.9 within the CEN/TR). However, apart from this indication, after critically analyzing this European Directive, it can be concluded that a specific reference level is not established. Without any other indication, it is not possible to establish a general acceptable level of vibration. Moreover, no indications are given regarding how to measure it; then, each supplier, manufacturer, or final user may calculate or estimate the level of vibrations in a different manner. As a result, high differences might appear, and the different methodologies will make it impossible to obtain a reliable comparison, even between similar machines.
- Some specific values are given in the case of handheld/hand-guided machinery. Section 2.2.1.1 within the CEN/TR establishes a set of reference values for vibrations (2.5 m/s$^2$), which, when exceeded, must be informed in the instructions, together with the uncertainty of the vibration measurement. Nevertheless, no specific information is provided on which procedure must be followed for measuring vibrations or how to estimate the uncertainty of those measurements. The case where harmonized standards are not applied is considered, indicating that, in such circumstances, the vibration must be measured using the most appropriate measurement code.

Although some indications are given regarding the exposure to vibrations, this directive does not specifically explain the procedures and technical considerations when studying the vibration levels. As the Prevention Services Regulations state [20], risk assessment must employ methods that provide confidence in its outcome. As it is commented, the lack of indications on how to measure or estimate the quality of those measurements and the obstacles for comparing the results for similar machines can lead to non-reliable results or estimated values about the level of vibration.

### *2.2. European Directive 2002/44/EC on Exposure of Workers to Vibrations*

European Directive 2002/44/EC [21] on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration) includes further details on how to assess the risk derived from the occupational exposure to vibrations.

The directive defines, characterizes, and establishes the requirements for evaluating the exposure to vibrations, and therefore prevents the possible damages derived from the repeated exposition to this agent. Subject to the part of the body that may be exposed to mechanical vibrations, the Royal Decree distinguishes two types of exposure: Hand-Arm vibration (HAV) and Whole-Body Vibration (WBV). For each of these types the royal decree establishes a series of reference values that must be controlled. Specifically, there are two parameters to be monitored (Table 1) [22]:

- Daily exposure limit value: 5 m/s$^2$ in the case of HAV exposure and 1.15 m/s$^2$ in the case of WVB exposure
- Daily exposure action value: 2.5 m/s$^2$ for HAV exposure and 0.5 m/s$^2$ for WVB exposure

**Table 1.** Reference values European Directive 2002/44/EC (from the work in [22]).

| Exposure Type | Daily Exposure Limit Value (m/s$^2$) | Daily Exposure Action Value (m/s$^2$) |
|---|---|---|
| Hand-Arm vibration (HAV) | 5 | 2.5 |
| Whole-Body Vibration (WBV) | 1.15 | 0.5 |

The daily exposure value can be calculated using the A(8) parameter, related to the effective values of acceleration and the period of exposure.

The calculation of this parameter depends on the case under consideration: HAV vibrations or WBV body vibrations. The HAV are evaluated through the CEN—EN ISO 5349–1:2001 [23] and CEN—EN ISO 5349–2:2001 standards [24], while the WBV type vibrations are evaluated according to the CEN—EN ISO 2631–1:1997 [25].

Although obtaining those acceleration values by directly measuring them is considered, the directive considers that the acceleration values may be obtained by means of estimation methods; this option is sometimes preferred by manufacturers and suppliers rather than measurement-based methods (Figure 2). Thus, the assessment of the level of exposure to mechanical vibration is not always obtained from direct measurements of the vibrations suffered by the worker during the actual use of the machinery, it depends on the tests applied to the machinery when it was originally manufactured. Although this circumstance is in some measure solve by the implementation of the CEN/TR 15350:2013 (for HAV) [26], yet the operating conditions might vary a lot, and so the level of vibrations. This is the base for the study of the NER investigated within this research, that is, the variation between the estimated and the actual values could overestimate the level of exposure to this risk of the occupational exposure to vibrations.

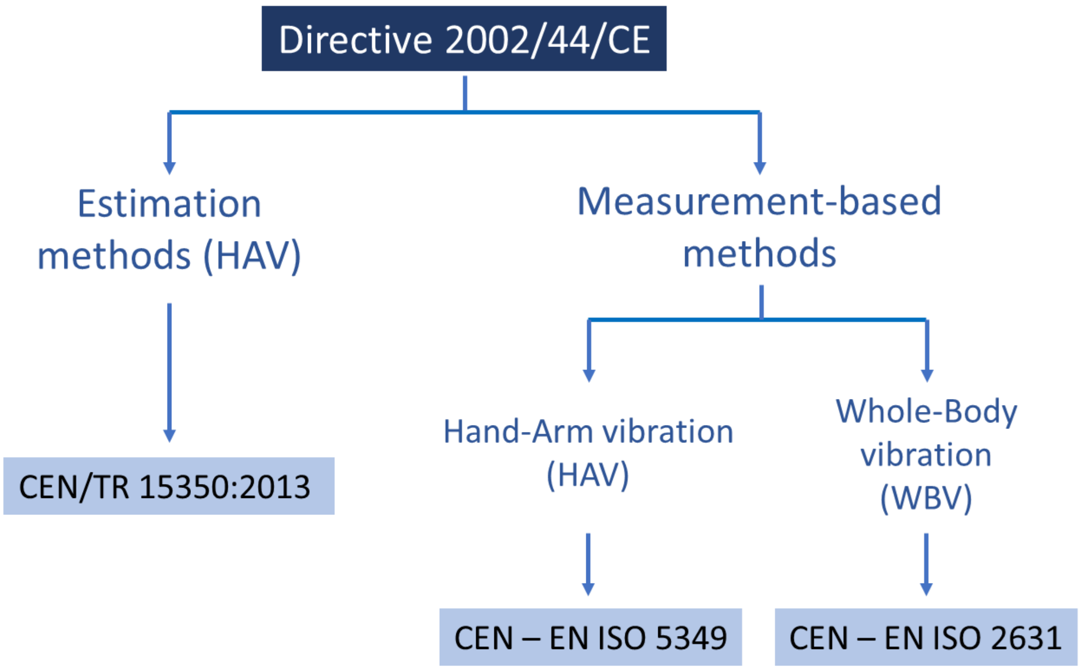


**Figure 2.** Schematic view of the applicable technical regulations for hand-arm transmitted vibration (HAV) and whole-body vibration (WBV).

When estimating the acceleration values, European Directive 2002/44/EC estates that the assessment of the level of exposure may be carried out on the basis of an estimation obtained by means of the information provided by the manufacturers concerning the level of emission from the work equipment used, as well as the observation of specific work practices or on measurement.

However, this information can greatly differ depending on the manufacturer criteria, the essay type used for testing the machine, or the conditions under which those tests were carried out, among other considerations.

Consequently, the level of exposure to mechanical vibration firmly depends on the specific equipment and working methods, as well as the values provided by the manufacturers in each case. Unfortunately, the limitless number of different machines and suppliers with different design and manufacturing processes makes it very difficult to compare the results obtained by the different manufacturer. Therefore, the estimated values can strongly differ from the actual values of the occupational exposure to vibrations, as it is investigated in [27], where it was concluded that, in general, the values provided by the manufacturers were by far overrated in comparison with actual workplace vibration emissions.

European Directive 2002/44/EC also foresees the calculation of the acceleration values by means of direct measurements. Even if direct measurements of the acceleration values would normally have a lower associated uncertainty, the truth is that no general metrological procedure can be applied for carrying those measurements. Technical standards give indications on how to carry out those measurements and estimate their associated uncertainty, although some vital aspects are not considered. As a result, very important aspects regarding the measuring process must be decided by manufacturers or users: selection of the instrument, how to carry out the measurements, how to treat them, etc.

A critical review from a metrological perspective was carried out: both methodologies (estimation methods and measure methods) and their related standards were analyzed.

## 3. Critical Analysis of the Metrological Requirements Regarding European Standards on How to Estimate Exposure to Vibrations

Occupational exposure to vibrations can be both studied through estimation methods or measurement-based methods, both being considered in the European Directive 2002/44/EC. As it has been explained before, there is a lack of specific indications about procedures and technical details on how to carry out the level of vibrations study. Such information can be found within several standards, which are specified in the European Directive 2002/44/EC. However, some requirements or details on how to carry out the different procedures or estimations are unclear or not specified. These standards and their technical requirements are analyzed in this investigation from a metrological point of view.

### *3.1. CEN/TR 15350:2013 on Estimation Method*

As it is stated in the estimation methods are mainly based on the information provided by the manufacturers of the machinery. Several aspects can be commented regarding the metrological requirements that are considered within the CEN/TR 15350:2013.

#### 3.1.1. Uncertainty

Estimation methods have several disadvantages both from a practical and a metrological point of view. The main drawback would be the truly high associated uncertainty for such methodology, especially when compared to uncertainties obtained when direct measurements are carried out. The CEN/TR 15350:2013 provides a number of multiplication factors that are to be applied to the declared value of vibrations provided by the manufacturers, which are to be applied in those cases where necessary, as in those equipment analyzed through uniaxial tests rather than triaxial tests, the latter being more commonly employed since 2005. The authors of [28] studied the instruction manuals of 1822 tools from two of the most representative manufacturers in the market. As of 2005, more than 70% of the manuals analyzed provided triaxial information, thus complying with the stipulations of the ISO 20643:2005 standard [29]. With respect to the requirements of the European Directive 2006/42/CE, for the commercialization and commissioning of machinery, as of 2006, more than 80% of the manuals analyzed included all the required information.

When estimating uncertainty by means of such multiplication factors, uncertainty might dramatically increase. As it is concluded in [27], in general the results obtained in several investigations conclude that the actual values suffered by final operators of the machinery where overestimated when multiplication factors where applied. From a metrological perspective, a vibrations risk assessment based on this method might be affected by high uncertainty values, and, as a result, real level of vibrations might strongly differ from the values employed in the risk assessment, creating a NER as this could overestimate the level of exposure to this risk.

To this respect, a new version of this document, the FprCEN/TR 15350:2020 [30], will supersede CEN/TR 15350:2013. FprCEN/TR 15350:2020 has been submitted to the vote on TR. Among the main changes related to this work, it stands out that Annex C is now based on harmonized standards published after 2007, without the need of multiplying factors; in addition, prior to 2005, the declared emission values for tools based on single-axis should not be used for estimating the daily vibration exposure. The new version of this document is very recent, and as it suggests employing independent harmonized standards, its application and suitability are to be evaluated after it is fully established and applied in actual cases. In any case, this new version does also assume that the daily exposure values have a high level of uncertainty.

#### 3.1.2. Reliability and Traceability

Another relevant inconvenience has to do with the information employed for estimation methods. European Directive 2002/44/EC estates that, when applying estimation methods, the assessment of the level of exposure may be based on information provided by the manufacturers concerning the level of emission from the work equipment used. As a consequence, the input values to be obtain completely depends on the type followed by the manufacturer (typically based on uniaxial or triaxial measurements), and then the values can vary from one supplier to another.

From a metrological point of view, an additional disadvantage related to this variability is the impossibility to compare the values provided by manufacturers or suppliers. Having reliable and comparable results would ensure that the level of exposure is evaluated in a uniform way, despite the brand or equipment type employed. Even when data are directly collected from the manufacturers [31] and the test code employed for the equipment analyses is indicated (requirement necessary to apply the estimation method based in the CEN/TR:2013), there is a lack of information regarding the procedure or the data treatment when estimating their application in real operating conditions; this situation can endanger the risk assessment based on those values.

Article 4 of European Directive 2002/44/EC estates that to assess the level of exposure to mechanical vibration, observation of the specific working methods may be used and appropriate information on the likely magnitude of the equipment vibration may be referred to. According to this recommendation, regulations on the different State Members have developed mechanisms to provide such information. In Spain, where this directive is transposed into Spanish law through Royal Decree 1311/2005 [32], a database is available for sharing information regarding the level of exposure values. In order to provide a reliable source of information for specific working methods and equipment, the Spanish National Institute of Safety and Health at Work (INSST) has developed, together with manufacturers, regulators, and other entities, a database where likely values of vibration for different conditions and equipment are collected [33].

This data base makes it possible to access reliable information to apply the estimation methods and calculations as described in CEN/TR 15350:2013. Nevertheless, although those values can become very useful, neither the associated uncertainty, nor the procedure followed to measure or obtain those values are recorded. From a metrological point of view, it makes it impossible to establish a reliable comparison between different models of similar equipment (and so is advised when entering the data base information). Moreover, not analyzing this information can jeopardize the traceability of those measurements and any risk assessment based on those values.

Similar data bases can be found in equivalent institutions in other countries. In the case of the Italian National Institute for Occupational Accident Insurance (INAIL), similar information is provided for different machines, brands and models [34]. In this case, even those cases where uncertainty is not provided, information about the procedure or standard applied for obtaining the values is provided. Like this, it might be possible to compare different results when the same procedure has been applied. Another advantage of this data base is that, even if a specific associated uncertainty value is not provided, each provided value includes a mean and a deviation, which can give some relevant information from a metrological point of view.

Even if both data bases provided some useful information to carry out the estimation of the vibrations level during real applications, it may happen that the information differs from one source to another.

Table 2 shows the available values obtained by measurement (*ahx*, *ahy*, and *ahz* being the acceleration values in the x, y, and z axes, respectively, and *ahv* the root-sum-of-squares total acceleration value) through the INSST and INAIL, for a specific tool (same manufacturer and model) under similarly operating conditions. The lack of information regarding some relevant aspects as the measurement procedure or the associated uncertainty makes it impossible to ensure the traceability of the obtain results and no reliable comparison can be made between the two results. It becomes clear that there is a high variability from one case to another, and there is a huge variation for the final vibration value to be employed in the risk assessment. The variations can be due to the environmental conditions, the measure method, and many other aspects. In any case, fundamental aspects described in CEN/TR 15350: 2013 should be considered, especially when it indicates that measurements will be required in the workplace when adequate data is not available to represent vibration under specific working conditions or if the results calculation do not help to make decisions about exceeding the reference values.

**Table 2.** Comparison between INSST and INAIL data bases for a specific tool and application (from the works in [33,34]).

| | *ahx* (Mean Value) | *ahy* (Mean Value) | *ahz* (Mean Value) | *ahv* (Mean Value) | Deviation | Value for Assessment | Expanded Uncertainty | Test Code | Test Date |
|---|---|---|---|---|---|---|---|---|---|
| INSST (mean value) | 10.88 | 23.73 | 15.08 | 30.14 | Not specified | 30.14 | Not specified | Not specified | 2005 |
| INAIL (mean value) | 12 | 24.7 | 22.8 | 35.6 | 1.85 | 37.5 | 1.5 | IEC EN 60745-2-6:2003 | 2006 |

Document CEN/TR 15350:2013 was developed to clarify these aspects to some extent, although it has some limitations; although it only considers HAV vibrations, so WBV vibrations are not studied. This document provides information on how to assess exposure to vibrations from machines and power hand tools. However, the methods described here use existing values from different sources. The document itself indicates the possibility of finding a certain variability due to the estimation methods used. Such variability is not only caused by the different essay types; CEN/TR 15350:2013 also considers variations when having real-life use of the different tools, such as the tool employed (variation from one device to another, even from the same type or supplier) drift that appears due to the course of time or the application or task in which the tool is employed (different positions, handlings, etc.).

When analyzing the results from estimation methods, all the possible variations affect the measurement result, sharply increasing its associated uncertainty [17]. Although the CEN/TR 15350:2013 includes indications on how to estimate this uncertainty, the document itself recognizes that uncertainty might be much worse when analyzing the actual use of the tool. In fact, Section 6: "Uncertainty considerations" (within the CEN/TR) estates that uncertainty related to vibrations generated by a certain machine has an associated K factor which is calculated according to document EN 12096:1998, although the vibration associated uncertainty during actual use of the equipment is dramatically higher.

Moreover, some aspects are not completely solved. As it is indicated in [35], even if correction factors are foreseen for the different values obtained by the manufacturers, it is necessary to consider other features, like the conditions under which the different test codes are carried out (or the test codes versions). For example, if the measurements made are carried out according to uniaxial or triaxial tests. Furthermore, it is important to determine the similarity between a certain test code and the final use of the equipment and the actual operating conditions.

Even considering the indications provided by CEN/TR 15350:2013, there is a lack of information on how to treat the uncertainties. Even if correction factors are proposed in this document, considerations regarding the different test types (uniaxial or triaxial) together with the final use of the equipment and its operating conditions should be taken into account. Therefore, some amendments and additional indications could be added to this document.

For example, in [36] a proposal for improving the methodology described in CEN/TR 15350:2013. Part of this proposal includes a classification of the declared values emitted by a device, including four different cases; depending on the case considered, different uncertainty corrections would be applied.

### 3.2. Measurement-Based Methods

The standards about HAV and WBV include indications on how to measure and treat the data; some relevant information is not specified in the descriptions. Some of those aspects, that would require more detail in the treatment of values and their uncertainties, are analyzed from a metrological perspective, taking as an example the CEN—EN ISO 5349–1:2001 and CEN—EN ISO 5349–2:2001 standards.

#### 3.2.1. Uncertainty

It should be noted that in Chapter 7 of the CEN—EN ISO 5349–2:2001 standard, "Uncertainty in the assessment of daily exposure to vibration", some metrological aspects are included and considerations regarding measurement uncertainties are introduced. Despite this, the description employs different terminology than is usual in metrological language (e.g., "factors" instead of "influence quantities") which may generate confusion when estimating such uncertainties. As a result, the described process differs from other standard procedures, and some errors might appear.

Although these "factors" are suggested, no way of estimating them is specified; in fact, the notes in this section indicate that the uncertainties associated with instruments are usually smaller than others considered, but do not establish a means of estimation. On the other hand, it assumes that the calibration of the instrument itself is one of those influences, however, no information about how to treat its associated uncertainty is provided.

- Several investigations have aimed to evaluate the different factors that might appear in real-use condition of the machinery, so that the uncertainty contributions could be determined. In [37], different factors were studied, mainly classified in two types: instrumentation-related factors and non-related. The results showed which factors had a higher influence on the obtained uncertainty, and that some recommendations for reducing it could be exerted and added to the original indications included in the CEN—EN ISO 5349–2:2001 standard (e.g., improvement of adaptors and handles, procedures and periodic calibrations, etc.). For example, in the works [38,39] there is a very high dispersion of values between tools of the same family or group. However, it would be very interesting to update these results considering the evolution of the machines shown by [28].
- When analyzing daily exposure to vibration, apart from the vibration itself, the other variable to be consider is the exposure time, whose measurement will also have a certain uncertainty associated with it. The CEN/TR 15350:2013 specify a method for its estimation, but with reduced accuracy.
- The conditions of the tests for the evaluation of uncertainties are addressed in the Section 6.3 within the CEN—EN ISO 5349–2:2001, entitled "Checking and verification of the measurement chain" and within it, in Section 6.3.1 "Regular checks of functionality". The need for multiple measurements is specified, which translated into a metrological procedure would be a way of obtaining the contribution of repeatability to the overall uncertainty. However, in the proposed examples it is suggested to change the measurement conditions (using different machine configurations). When this happens, and according to the Guide to the expression of Uncertainty in Measurement (GUM) [40], repeatability cannot be estimated; reproducibility would be obtained instead.

Other developments and technologies affected by the treatment of the vibrations measurements are those who aim to improve operator's comfort, by measuring and minimizing the effect of vibrations through specific systems, as in [41]. Such an article presents a new development for seat suspension, where vibrations are measured on site in real time operation, and active dampers aim to reduce it. Again, the measuring system will be affected by the influences mentioned above, and the lack of information might affect the efficiency of the damping system. Other investigations suggest employing available measurements together with measurements or information from the secondary vehicle suspension (spring and damper) [42].

Some studies aim to compare the different standards and guidelines in order to set the basis for a common procedure, although, again, they face the problem of comparing data or procedures which may have different operating conditions, data treatment, etc. [43].

It can be stated that the measurement-based methods proposed in CEN—EN ISO 5349–1:2001, CEN—EN ISO 5349–2:2001 and CEN—EN ISO 2631–1:1997 standards are more detailed and provide indications about the measurement process and how to treat uncertainties estimation. In spite of this, it does not deepen on important details related to the measurement procedure and how to consider some relevant uncertainty contributions. This way, it is up to each user to decide how to consider those influences, and therefore, not all the users will carry out their tests by following the same procedure.

### 3.2.2. Reliability and Traceability

The necessary calibration of the equipment is considered in Section 4.2.1 within standard CEN—EN ISO 5349–1:2001. However, in a contradictory manner, it states "This equipment, for its correct operation, must be checked before use". This does not clarify whether a complete metrological calibration would be necessary or whether a simple check of the equipment adequate performance is enough or if only checking some minor parameters would be needed.

The use of a "vibration calibrator" is indicated in Section 6.3 within the standard CEN—EN ISO 5349–2:2001 entitled "Checking and verification of the measurement chain" and within it, in the Section 6.3.1 "Regular checks of functionality". However, when analyzed, the description of the process suggests that it would not be a complete calibration but an adjustment of the equipment before its use. No information on how to carry out this process is provided, so that each evaluator must decide about the process.

Some investigations, such as the one described in [44], aim to find an effective method for a reliable monitorization of the exposure to vibration. On-the-wrist and on-the-elbow applications are proposed to measure the vibrations during real operation. Results showed that the vibration measurements obtained from the wrist data were a reliable approach for evaluating the exposure. Other approaches [45] directly suggest the use of new and widespread technologies, like smartwatches, although their compliance with the CEN—EN ISO 5349–2:2001 standard is still being investigated.

Comparisons between different situations will not be reliable under these conditions. Finally, the lack of a common procedure might lead to a certain variability of the measurements. For all these reasons, a revision of the current regulation could be faced from a metrological point of view, improving the results, and minimizing the emerging risk of an inaccurate assessment of the occupational exposure to vibrations.

## 4. Conclusions

This investigation has managed to analyze the metrological requirements in occupational exposure to vibrations assessment for both estimation- and measurement-based methods.

For this, the regulatory framework has been analyzed. European Directive 2002/44 / CE sets the base for such a framework. The CEN—EN ISO 5349–1: 2001, CEN—EN ISO 5349–2: 2001, and CEN—EN ISO 2631–1: 1997 standards arose as references to assess the occupational exposure to vibrations based on measurement-based methods and CEN/TR 15350: 2013 as a reference for the estimation methods.

Even if the current regulatory framework considers some metrological aspects regarding the assessment of the level of vibrations, yet many relevant aspects are not considered or established. The estimation-based methods present more important problems than measurement-based methods. The main problems are related to the uncertainty, reliability, and traceability of the results. In this way, the variation between the estimated and the actual values could overestimate the level of exposure to this risk of occupational exposure to vibrations.

Regarding the regulatory framework, big differences might appear from one case to another depending on the influences, procedure and features considered in the assessment of the exposure to vibrations. These risk factors can affect the risk assessment results, as operators might be suffering higher or lower levels of vibrations than those estimated.

The standards referring to measurement-based methods provide more detailed information than estimation methods on how to proceed when carrying tests, as well as indications on how to determine their uncertainty. Unfortunately, some relevant aspects are unclear or not fully define, and, consequently, manufacturers or users must consider them on their own criteria. This situation does also affect the comparability of the results obtained.

When CEN/TR 15350:2013 is applied, in the case were estimation methods, the uncertainty values they are much higher than measurement-based methods. This might lead to an inexact evaluation of the level of vibrations, which will turn into a bad risk assessment. With the new version FprCEN/TR 15350:2020, the daily exposure values have a high level of uncertainty too as well as other unsolved metrological problems in the estimation process. In any case, with the final version of said document (it is currently submitted to the Vote on TR) it will be important to carry out a comparative analysis between versions through future research works.

As the European Directive and associated standards indicates, when applying estimation methods input data provided by handbooks, data bases or manufacturers test results might be used. Given the elevated number of different equipment and test codes (and test codes versions) for evaluating them, the available values may vary a lot from one case to another. Furthermore, the values of associated uncertainty are not always included, which makes it difficult to correctly estimate the level of vibrations.

These characteristics of the estimation methods make this alternative less useful from a practical and a metrological point of view. No reliable comparison among similar machines and their level of vibrations can be made. Moreover, traceability of the available values cannot be ensured, due to the lack of information on how the procedure employed for obtaining these results or their associated uncertainty.

Current regulation regarding exposure to vibrations and its assessment has set the basis for evaluating the different scenarios and machinery that might affect operators. However, it would be interesting to carry out an update of the commented standards, including further details and descriptions about the required procedures, influences to be considered and how to estimate the associated uncertainties to the values provided by manufacturers and the measurements involved.

On the other hand, this research has limitations. Among these limitations, the study of a real case is remarkable. Thus, it would be interesting to evaluate the inefficiencies of the different methods proposed in current standards by comparing them in a real case study; however, that would need of the cooperation of different entities, like the manufacturers of the different equipment as well as the participation of certified laboratories. This study could be developed in the future, in order to compare both methods and to investigate the additional procedures and details to be included in the standards.

Thanks to a better analysis, not only a better risk assessment will be performed, but it will also be possible to ensure the traceability of the values and measurements included in the assessment process. Acquiring traceability for the results obtained is crucial for fair trading as well as for reliable risk assessment.

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