NORTH ATLANTIC TREATY ORGANIZATION

SCIENCE AND TECHNOLOGY ORGANIZATION

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STO TECHNICAL REPORT **TR-SVK-CAN-AVT-16-1**

Evaluation of In-Vehicle Vibrations and Their Effect on Vehicle Structures and Personnel Health and Performance

(Évaluation des vibrations internes aux véhicules et de leur effet sur les structures des véhicules et sur la santé et les performances du personnel)

NATO STO/AVT Support Project No. SVK-AVT-16/01. Final Report.

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The NATO Science and Technology Organization

Science & Technology (S&T) in the NATO context is defined as the selective and rigorous generation and application of state-of-the-art, validated knowledge for defence and security purposes. S&T activities embrace scientific research, technology development, transition, application and field-testing, experimentation and a range of related scientific activities that include systems engineering, operational research and analysis, synthesis, integration and validation of knowledge derived through the scientific method.

In NATO, S&T is addressed using different business models, namely a collaborative business model where NATO provides a forum where NATO Nations and partner Nations elect to use their national resources to define, conduct and promote cooperative research and information exchange, and secondly an in-house delivery business model where S&T activities are conducted in a NATO dedicated executive body, having its own personnel, capabilities and infrastructure.

The mission of the NATO Science & Technology Organization (STO) is to help position the Nations' and NATO's S&T investments as a strategic enabler of the knowledge and technology advantage for the defence and security posture of NATO Nations and partner Nations, by conducting and promoting S&T activities that augment and leverage the capabilities and programmes of the Alliance, of the NATO Nations and the partner Nations, in support of NATO's objectives, and contributing to NATO's ability to enable and influence security and defence related capability development and threat mitigation in NATO Nations and partner Nations, in accordance with NATO policies.

The total spectrum of this collaborative effort is addressed by six Technical Panels who manage a wide range of scientific research activities, a Group specialising in modelling and simulation, plus a Committee dedicated to supporting the information management needs of the organization.

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These Panels and Group are the power-house of the collaborative model and are made up of national representatives as well as recognised world-class scientists, engineers and information specialists. In addition to providing critical technical oversight, they also provide a communication link to military users and other NATO bodies.

The scientific and technological work is carried out by Technical Teams, created under one or more of these eight bodies, for specific research activities which have a defined duration. These research activities can take a variety of forms, including Task Groups, Workshops, Symposia, Specialists' Meetings, Lecture Series and Technical Courses.

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List of Acronyms

AGTE	Aircraft Gas Turbine Engine
AOS	Military Academy of Slovak Republic
APC	Armored Personnel Carriers
AVT	Applied Vehicle Technology – NATO STO Panel
B & K	Brüel & Kjær
CCLD	Constant Current Line Drive
FFT	Fast Fourier Transform
HMD	Head-Mounted Display
HSE	Health and Safety Executive
HUD	Heads-Up-Displays
IFV	Infantry Fighting Vehicles
LF TUKE	Aeronautical Faculty of Technical University in Košice
NI	National Instruments
NRC	National Research Council
NVG	Night Vision Goggles
RMS	Root Mean Square value
VDV	Vibration Dose Value
WBV	Whole Body Vibration

List of Nomenclature

$k.a_w$ Vibration Acceleration Weighted and Multiplied by *k* Factor

Glossary

Brüel & Kjær	Acoustic and Vibration Measurement Technology Producer
Constant Current Line Drive	Type of Signal Measurement Connection
Daily Vibration Exposure, A(8)	The 8-hour energy equivalent vibration total value for a worker in metres per second squared (m/s^2), including all whole-body vibration exposures during the day.
Exposure Action Value	A value for either a worker's daily vibration exposure, A(8) of $0{,}5 m/s^2$, or a worker's daily VDV of $9{,}1 m/s^{1,75}$, above which the risks from vibration exposure must be controlled.
Exposure Limit Value	A value for either a worker's daily vibration exposure, A(8) of $1{,}15 m/s^2$, or a worker's daily VDV of $21 m/s^{1,75}$, above which workers should not be exposed.
Exposure Time	The duration per day that a worker is exposure to a vibration source.
Frequency Weighting	A filter applied to vibration measurements to mimic the frequency dependence of the risk of damage to the body. Two weightings are used for whole-body vibration: • Wd for vibration in both the fore-aft (x) and side-to-side (y) axes, and • Wk for the vertical (z) axis.
Health and Safety Executive	An institution in Great Britain
Health Surveillance	A programme of health checks on workers to identify early effects of injury resulting from work activities.
National Instruments	A test and measurement equipment producer.
National Research Council	An agency of the Government of Canada which conducts scientific research and development.
Vibration Dose Value	A cumulative dose, based on the fourth root of the fourth power of the acceleration signal. VDV has units of $m/s^{1,75}$.
Vibration Emission	The vibration value provided by machine manufacturers to indicate the vibration likely to occur on their machines. The vibration emission value should be obtained using standardised test code and has to be included in the machine's instructions.
Whole-Body Vibration	The mechanical vibration that, when transmitted to the whole body, entails risks to the health and safety of workers, in particular lower back morbidity and trauma of the spine.

Forward

Duration of the Project: **3 years**

Supported Nation: Slovak Republic

Supporting Nation: **Canada**

Participating Establishments Slovak Republic: Armed Forces Academy

Participating Establishment Canada: National Research Council Canada, Aerospace Portfolio.

The vibratory forces generated during the operation of land vehicles such as Armored Personnel Carriers (APC), Infantry Fighting Vehicles (IFV) and aircraft including both fixed wing and helicopters, expose both the vehicle to structural vibration and the military personnel inside to a Whole-Body Vibration (WBV) environment. Vibration transmitted to vehicles and their occupants originates from a host of causes, including, road roughness, aerodynamic forces and engine- and powertrain-induced vibration.

Vibrations transmitted to the structures can degrade vehicle performance and may be responsible for damage accumulation that typically leads to mechanical fatigue and subsequent failure of metallic or composite vehicle components.

The mechanical vibration transmitted through the structure to the human body increases fatigue, degrades comfort, interferes with mission performance and affects operational safety, in the short term. Long-term exposure to WBV is known to contribute to occupational health issues including neck pain and back pain, among other aircrew health concerns, that may lead to short-term unavailability of personnel due to sickness or long-term disability issues that lead to high cost for the healthcare system. The integration of equipment on the pilot's helmet such as Night Vision Goggles (NVGs) and Heads-Up-Displays (HUDs) further increases the mass of the helmet, which interacts with the vibration to increase the dynamic forces experienced by the pilot.

For military land vehicles, terrain roughness is the major source of vibration. Vibration must stay within some boundaries for a vehicle operator to maintain effective vehicle control. Improvements to occupant seats such as integrating an active system consisting of actuators controlled by a real-time control law has been investigated by scientists to provide enhanced WBV mitigation to the crew. Other methods using passive approaches have also been proposed.

The ISO 2631 standard is the most widely used metric to assess the effect of whole-body vibration exposure as it pertains to vehicles. In general, this standard recommends that the human operator and vehicle interface vibration has to be measured at locations and directions as specified in the standard. This standard also specifies a number of frequency weighting functions to be applied between 0.01 Hz and 80 Hz to acceleration measurement to account for the human body sensitivity at specific frequencies. The standard also provides a guidance to evaluate and assess effects of WBV in terms of discomfort, perception and health effects.

This Support Project is linked to the previous Support Project SVK-AVT-12-01, "Application of Advanced Analysis Methods to the Health Monitoring of Gas Turbine Engines Operating in the Slovak Air Forces", under which signal analysis techniques were developed. The current project proposes to apply those techniques to in-service applications to improve vehicle and operator performance.

Methods Used: Based on Standard ISO 2631-1 and Health and Safety Executive, Regulations 2005, The Control of Vibration at Work, were analysed and procedures for WBV monitoring in military vehicles were tailored. The plan of work was as follows:

1) Collecting theory about whole-body vibration.
2) Making measurements in a vehicle cabin.
3) Making experimental measurements on a driver's seat.
4) Evaluation of results.
5) Personnel monitoring procedure proposal.

Results: Proposal of monitoring tools and personnel health surveillance system for transport vehicles used by the Slovak Armed Forces.

Summary: International cooperation led to the development of a personnel whole-body vibration monitoring procedure based on standards and in-operation measurements. An evaluation method is aimed at military personnel. The results were achieved thanks to the knowledge and experience of the supporting nation and excellent cooperation between both nations – Canada and Slovakia.

AVT-16-1 List of Participants

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Evaluation of In-Vehicle Vibrations and Their Effect on Vehicle Structures and Personnel Health and Performance

(STO-TR-SVK-CAN-AVT-16-1)

Executive Summary

Fatigue and decreased performance among personnel can be observed during armed forces training and missions under specific conditions. The effect of vibration on the human body is among those factors that can have a negative influence on personnel. It can result in fatigue in actual time and in permanent health problems after end of duty.

Certain factors and problems are common to some kinds of civil vehicle operators. A system of prevention can be implemented using standards. The main task of the current project was to evaluate vibrations from two points of view – the magnitude of the vibration and its duration.

During the course of the current project, a basic methodology and the resulting measurements were used to calculate human exposure to vibration.

Objective: The objective of the study was to develop measurement methods and evaluation criteria for assessing the risk of vibration exposure to both vehicle structures and military personnel for vehicles operated in the Armed Forces of the Slovak Republic.

Scope: The main problems to be addressed in this project to achieve the objective were:

- Identify requirements for sensors and data acquisition systems used to measure vehicle vibration and Whole Body Vibration (WBV) of vehicle occupants;
- Identify installation requirements and sensor locations to maintain data integrity for in-vehicle measurement while satisfying safety requirements for vehicle operation;
- Establish the required data analysis techniques and suitable software platforms to process the data;
- Identify approaches to select the most suitable evaluation metric based on the application; and
- Develop methods to assess the measured vibration data in order to assess the risk of vehicle degradation that may lead to reduced operational readiness/availability for the vehicle; and WBV that may lead to short-term or long-term impact on military personnel of the Armed Forces of the Slovak Republic.

Results: This NATO STO/AVT support project aimed to develop monitoring tools and a medical surveillance system for personnel on transport vehicles used by the Slovak Armed Forces.

A team of specialists from the supporting nation cooperated with specialists from the supported nation in different fields, in finding the right recording methods, developing suitable signal processing methods and data evaluation methods aimed at whole body vibration behaviour assessment.

In the project, measurements were performed to assess vehicle responses to external forces and to evaluate how these may affect the life of the vehicle, and degrade the comfort and performance of the vehicle operator and passengers.

The result of this cooperation has been the establishment of a systematic methodology for surveillance. Methods are based on experimental measurements, analyses, and the requirements of international standards. The theory used is specified in Chapters 3 – 5. Examples of the processing of real signals are contained in Chapters 8 – 9, followed by the interpretation of results.

Évaluation des vibrations internes aux véhicules et de leur effet sur les structures des véhicules et sur la santé et les performances du personnel

(STO-TR-SVK-CAN-AVT-16-1)

Synthèse

Dans certaines conditions bien spécifiques, on observe une fatigue et une baisse des performances du personnel pendant l'entraînement et les missions des forces armées. Les mouvements vibratoires agissant sur le corps humain font partie des facteurs ayant une influence négative. Ils peuvent entraîner une fatigue en temps réel et des problèmes de santé permanents après la fin du service.

Les facteurs et les problèmes sont similaires à ceux de certains types d'opérateurs de véhicules civils. Un système de prévention peut être établi à l'aide de normes. La tâche principale du projet en cours était d'évaluer les vibrations de deux points de vue : l'amplitude et la durée des vibrations.

Pendant le projet, des bases méthodologiques et des résultats de mesure ont été collectés et utilisés pour calculer l'exposition humaine aux vibrations.

Objectif(s) : Développer des méthodes de mesure et des critères évaluant le risque d'exposition des structures de véhicule et du personnel militaire aux vibrations, pour les véhicules exploités dans les forces armées de la République slovaque.

Portée du document : Les principaux problèmes à traiter dans ce projet pour atteindre l'objectif étaient les suivants :

- Identifier les exigences applicables aux systèmes de capteurs et d'acquisition de données qui servent à mesurer les vibrations du véhicule et la vibration globale du corps des occupants du véhicule ;
- Identifier les exigences applicables à l'installation et déterminer l'emplacement des capteurs pour maintenir l'intégrité des données en cas de mesures embarquées, tout en garantissant la sécurité de fonctionnement du véhicule ;
- Établir les techniques d'analyse des données requises et les plateformes logicielles adaptées pour traiter les données ;
- Identifier les démarches permettant de sélectionner l'indicateur d'évaluation le plus adapté en fonction de l'application ;
- Développer des méthodes pour évaluer les données de vibration mesurées – afin d'évaluer le risque de dégradation du véhicule pouvant entraîner la réduction de l'état de préparation opérationnelle ou de la disponibilité du véhicule – et la vibration globale du corps susceptible d'avoir des conséquences à court ou à long terme sur le personnel militaire des forces armées de la République slovaque.

Résultats : Le projet de soutien de l'AVT/STO de l'OTAN visait à développer des outils de suivi et un système de surveillance médicale des hommes en rapport avec les véhicules de transport utilisés par les forces armées slovaques.

L'équipe de spécialistes du pays de tutelle a coopéré avec les spécialistes du pays aidé dans différents domaines, pour déterminer les bonnes méthodes d'enregistrement, développer des méthodes adéquates de traitement du signal et des méthodes d'évaluation des données axées sur l'évaluation du comportement de vibration globale du corps.

Le résultat de la coopération est la méthodologie d'établissement d'un système de surveillance. Les méthodes reposent sur plusieurs analyses de mesures expérimentales et sur les exigences de normes internationales. La théorie employée est précisée aux chapitres 3 à 5. Les chapitres 8 et 9 contiennent des exemples de signaux réels, suivis de l'interprétation des résultats.

EVALUATION OF IN-VEHICLE VIBRATIONS AND THEIR EFFECT ON VEHICLE STRUCTURES AND PERSONNEL HEALTH AND PERFORMANCE

1.0 INTRODUCTION

Transportation vehicles are powered by piston engines, gas turbines or other kind of engines. Their power units produce some kind of noise and/or small periodic shaking called mechanical vibration. The vehicles can move in a rough manner, or, in military vehicles, there can be weapons used, which are accompanied by high impacts, residual damped noise, shaking, etc. All of these phenomena belong to some kind of vibration.

Vibration evaluation is widely used in machinery as a diagnostic method [1]. In rotating machines it is used as an indication of structural dynamic loading. In the case of a simple machine, when a high level of vibration is observed, the machine is dismounted and repaired or disposed of. In the case of a complicated machine, a source of higher vibration is investigated using a suitable vibroacoustic method; efforts are then made to eliminate the vibration.

The vibroacoustic method is also used for personnel load evaluation. The human body exposed to high vibration reacts by exhaustion, attention and decreased performance [2]. Vibration of long duration can cause severe permanent health punishment.

Drivers of work vehicles and mobile machines including tractors, forklift trucks, quarrying and earth moving machinery, can be exposed to Whole Body Vibration (WBV) (Figure 1). Likewise, WBV can affect occupants of military vehicles that are transported by vehicles, or operators of equipment built into the vehicle. Frequent exposure can cause back pain and can contribute to:

- Degenerative disorders of the spine;
- Nervous, circulatory and digestive system problems;
- Hearing loss; and
- Disorders of the female reproductive organs and problems with pregnancy [4].

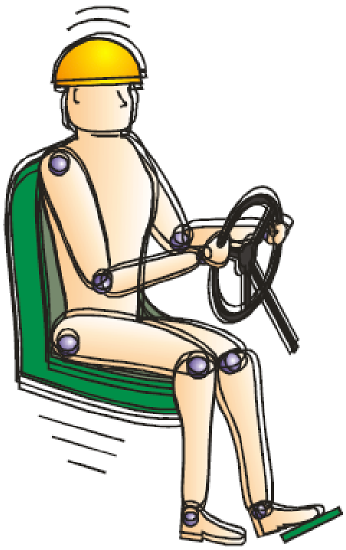

Figure 1: Driver's Body Exposed to Vibration [3].

To protect drivers and occupants from health problems caused by WBV, the Control of Vibration at Work Regulations 2005 were put into force [5]. These regulations contain action and limit values for WBV:

- Exposure action value of 0.5 m/s^2 A(8), at which level organisations (employers) should introduce technical and organisational measures to reduce exposure; and
- Exposure limit value of 1.15 m/s^2 A(8), which should not be exceeded.

These "Regulations" are based on a European Union Directive requiring similar basic laws throughout the Union on protecting workers from risks to their health and safety from vibration. The European Physical Agents (Vibration) Directive (2002/44/EC) deals with risks from vibration at work and is one of several Directives dealing with Physical Agents such as Noise and Vibration. The "Regulations" do not apply to members of the public exposed to vibration from non-work activities.

The "Regulations" require more specific duties compared to earlier general health and safety regulations, such as the Management of Health and Safety at Work Regulations 1999, which still apply. If employers comply with the Vibration Regulations and follow guidance, it may be possible to eliminate any new incidence of disability from hand-arm vibration by 2015, and to stop employees developing advanced stages of these diseases. There are simple, non-technical and common sense measures which can be introduced to reduce exposure to vibration. They are:

- Advice for employers (http://www.hse.gov.uk/vibration/hav/advicetoemployers/index.htm);
- Advice for workers, (http://www.hse.gov.uk/vibration/hav/yourhands.htm); and
- Further information (http://www.hse.gov.uk/vibration/hav/information.htm).

Action must be taken to prevent risk of exposure to WBV. Other methods or machines that eliminate exposure can be substituted, especially where employees are subject to large shocks and jolts. If this is not possible, the operator (employer) must reduce exposure to as low a level as is reasonably practicable.

The factors described above motivate designers, users and national (regional) health authorities to utilize suitable methods to evaluate in-vehicle vibration. The method can be part of vehicle development tests or the vehicle operational system. The operator's or occupant's health is also monitored if needed.

A well-designed vehicle needs to undergo a detailed check of vibration during its certification process. This check requires in-operation tests. Vibration testing involves the identification of vibration sources so that transfer paths and properties can be modelled and tested. Simple machines, for example electric motors, are tested only during development and after production. Complicated systems like airplanes, helicopters, vessels and submarines use online vibration measurement systems. These inform the vehicle's central diagnostic systems about recorded vibration signals, and in some cases, they are also authorized to turn off a (power) unit that is a source of unacceptable/dangerous vibrations.

From the previous section it may be gathered that modern vehicles should not produce potentially dangerous vibrations. This means vibrations that are a danger for machine itself, causing a quick wearing process and posing a danger for the staff and occupants of vehicle. However, some vibration sources are significant, when machine is in a steady state, not only during operation at high power. An example could be the main helicopter rotor, which continues to generate some vibration rotating while waiting on the ground. Further vibration occurs during actions such as rescues, probably in windy conditions in mountains. Similar conditions can occur during helicopter support actions for ground forces, while in training, or in fighting conditions. Under such conditions, vibrations can undermine the health and consume the energy of personnel on duty.

1.1 When Whole-Body Vibration Occurs

WBV occurs when a person's body is supported on a vibrating surface. This is most likely when sitting on the seat of a moving vehicle or other form of transport, or when operating vibrating machines. WBV can be caused by:

- Movement of the wheels or tracks of a vehicle or mobile machine crossing an uneven surface;
- The rotation of the rotor blades of a helicopter, which may transmit WBV through the airframe into the seats;
- Fast boats travelling across rough seas, lakes, rivers;
- Railway vehicles (less obvious);
- Flying in uneven/gusty air; and
- Operating large static compacting, launching, hammering or punching machines, such as hammer mills and mobile crushers.

1.2 Land Vehicles

There are two approaches to vehicle vibration evaluation. The first one deals with the health of machine that produces vibration. Mass rotation, moving parts, contacts and changes of inertia, burning processes, gas flow and associated phenomena generate vibrations that impact on dynamic loading of bearings and supporting members of structure. Structural parts that transfer loads participate in vibration damping or amplification, depending on their frequency characteristics.

The second approach to vehicle vibration is based on knowledge that vibrations negatively influence human body and mind, which directly influences the safety of transport. For this reason, vibration transfer from the body of the vehicle to the body of the personnel is evaluated. The purpose of the current research/interest is to state limits for vibration level and limits for time exposition in humans. Amplitude and time are considered to have a functional correlation.

Land vehicles can have several sources of shock and vibration. These include power units and their equipment, on-board weapons (when used) and the kind of terrain or trace travelled. Also, other working systems can be taken into consideration, when various agriculture and building machines are added to research, for example agricultural tractors, road rollers, etc.

1.3 Aerial Vehicles

Airplanes and helicopters are usually not exposed to high amplitude shaking. Such conditions occur only in air blasts, or upon heavy landing, or eventually during some kind of weapons fire. More dangerous for flight safety are small amplitude, high frequency vibrations that act on the on-board equipment and cause its failure. The vibration of the power unit (indicating its health) is evaluated separately from vibration of the aircraft body, or some part, indicating possibility of fatigue. This approach takes into account the different goals and different methods used for vibration signal processing and interpretation.

The vibrations in modern aircraft engines are monitored by an on-board diagnostic system. Multiple vibration sensors are placed at key points in the structure and broadband vibration signals are recorded and evaluated. Indications coming from various vibration diagnostic tools (methods) can be used to obtain reliable results. A multiparameter method decreases the uncertainties of diagnosis.

Both airplanes and helicopters can be equipped with additional systems, including a heavy pilot's helmet. A heavy helmet causes additional dynamic load to the cervical spine and supporting muscles (Figure 2). Older helmet models are lighter. Newer ones use optical sensors embedded in the aircraft, to calculate the pilot's exact head position and angle. With head-tracking technology and integrated night vision camera, the helmet aims to help the pilot access more information than ever. It builds on the already well-established Striker Head-Mounted Display (HMD), which has been used in combat on Typhoon and Gripen C/D aircraft for decades [6].

Figure 2: Striker II Helmet (Picture: BAE Systems).

1.4 Other Vehicles

Introduced vibration measurements are also utilized in space vehicles and vessels [7], [8]. All vehicles currently in production need reliable diagnostic equipment because on-condition maintenance is the most applied method. Additionally, the comfort of travelers and/or personnel, reliability and the life of the sensitive equipment partially depends on the vibration of the vehicle. Human health and safety began to gain importance in recent decades after human failures were observed following long-term exposition to higher vibration.

Exhaustion in actual time and permanent harm to the vehicle operator after the end of his duty are unwanted. Therefore, vibrations are measured and evaluated when vehicles are operated during missions, or during training. In the armed forces, the training usually takes longer than the real time spent using weapons. Training time is required to ensure permanent readiness and higher workmanship among personnel. Training provides the occasion to test armored or transportation vehicles in "rough conditions". Results and experiences can be followed-up and personnel performance can be controlled.

Practically, vibration measurement equipment can be used for both central purposes – machine health monitoring and human health guarding – when a suitable setup is used.

2.0 VIBRATION MEASUREMENT USED FOR DIAGNOSTIC PURPOSES

The information that follows is introduced for the purpose of better understanding the differences between machine diagnostics and human health guarding. In order to monitor machine vibration, the sensors have to be placed around the machine body at suitable measurement points. These are as close as possible to the particular sources of vibrations so that the undamped, raw vibration signal can be recorded and evaluated.

With increasing distance from the vibration source, the signal is damped or amplified. This distorts its original amplitude and shape. Such a signal is not as valuable for diagnostic purposes as the original.

Several different sources of vibrations with various frequencies act on the machine parts. They have to be recorded across a wide frequency range to capture all related phenomena. When the gears and rolling bearings are built into the machine, the frequency range reaches tens of thousands of Hertz. The recording range is for example 10 – 20000 Hz. In simpler machines, the range up to hundreds or thousands of Hertz is enough [9], [10].

A good indicator of the health of the vehicle's structure can be the overall level of vibrations at some sensitive point on the vehicle's body. For example, it can be the same measurement point, as the one used on the floor of vehicle, when the transfer to the seat is investigated (this is described later). If a different sensor location is used, it must be kept in mind that sensors have to be mounted on suitable rigid parts of structure.

An evaluation method should be taken from previous projects focused on AGTE vibrations.

3.0 HUMAN EXPOSURE TO VIBRATION

The comfort experienced by a human in a given environment can be classified as a subjective assessment, because it is possible to find considerable variation in the responses of different people to the same situation [11].

A human is sensitive to low frequency vibration and shock. The human body is able to tolerate higher vibrations that are significantly damped. Soft parts of human body are susceptible to shaking at a low frequency. This fact has been observed in past and was reason for the development of international standards. The first edition of ISO 2631: "Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration", was issued in 1985. The standard has two Parts and several Annexes [2]. It was revised several times on the basis of experience.

The frequency range considered differs according to the purpose of the evaluation. The range is from 0.5 Hz to 80 Hz for health, comfort and perception evaluation and from 0.1 Hz to 0.5 Hz for motion sickness. Informative annexes indicate current opinion and provide guidance on the possible effects of vibration. The standard also defines the principles of transducer mounting for determining human exposure. Vibration motion is transmitted to the human body through the supporting surfaces. A standing person receives vibrations through his feet; a sitting person is in contact with a vibrating vehicle via the vehicle seat (through the buttocks, back and feet); and a recumbent person is in contact through supporting equipment.

Basically, the person standing, sitting or lying in a horizontal position touches some known areas. Through these areas the power of motion can be transferred to the human body. However, the person can make use of additional support in the vehicle, for example holding the door handle during the journey in order to eliminate or add energy to the vibration transferred to his body.

4.0 RISK ASSESSMENT

The theory introduced above, ISO 2631 and the acceptance of the "Regulation" requirements form the basis for risk investigation. The risk assessment is based on several factors that should be identified and qualified. They involve:

- Identification of health or safety risk factors for which WBV is either the cause or a contributory factor;
- Estimate personnel exposure and compare it with the exposure limit values;
- Identify the available risk controls;
- Identify the steps that should be in a plan to control and monitor WBV risks; and
- Record the assessment, the steps that have been taken and their effectiveness.

Along with WBV, other ergonomic factors may contribute to back pain, these include:

- Poor posture while driving or operating plant;
- Sitting for long periods without being able to change position;
- Poorly placed operational controls, which require the driver/operator to stretch or twist;
- Poor visibility during the operation, which requires twisting and stretching to get an adequate view;
- Manual lifting and carrying of heavy or awkward loads; and
- Repeatedly climbing into or jumping out of a cab with high or difficult access.

All these factors can separately cause back pain. However, the risk will be increased where a person is exposed to one or more of these factors while being exposed to whole-body vibration. For example:

- Being exposed to WBV for long periods without being able to change position;
- Being exposed to WBV while sitting in a stretched or twisted posture (e.g., looking over his shoulder to monitor the operation of attached equipment); and
- Being exposed to WBV and then doing work involving manually lifting and carrying heavy loads.

Environmental factors, such as temperature may further increase the risk of back pain or injury.

All these causes must be considered together in plans to minimise risk of back injury. Regulations and guidance on manual handling of materials should be considered where this is a factor in the work of personnel.

A starting point in the risk assessment is to consider the work being carried out, the processes involved and the machinery and equipment used.

All types of vehicle, when in motion, are likely to cause the driver to experience WBV. The risks to health increase where people are regularly exposed to high levels of WBV over a long period. WBV exposure may also arise from non-driving activities, e.g., where personnel stand and work on vibrating platforms.

5.0 DETERMINING EXPOSURE DURATION

Before the daily vibration exposure (A(8) or VDV) can be estimated, the evaluator needs to know the total daily duration of exposure to the vibration from the vehicles or machines used. The evaluating specialist should be careful to use data that is compatible with measured vibration magnitude data, for example, if the vibration magnitude data is based on measurements when the machine is working, then count only the time that the person is exposed to the vibration. Machine or vehicle operators questioned on their typical daily duration of vibration exposure usually state a value containing periods without vibration exposure, e.g., truck loading and waiting times.

Usually, the vibration that occurs when the vehicle is travelling will dominate vibration exposures. However, some exposures are dominated by operations being performed while the vehicle is static, such as rocket launcher.

Work patterns need careful consideration. For example, some workers may only operate machines for certain periods in a day. Typical usage patterns should be established, as these will be an important factor in calculating a person's likely vibration exposure.

5.1 Daily Exposure to Vibration [5]

The daily exposure to vibration A(8) of a person is ascertained using the formula:

$$A(8) = k.a_w\sqrt{\frac{T}{T_0}} \tag{1}$$

where:

- a_w Is the vibration magnitude (root-mean-square frequency-weighted acceleration magnitude) in one of the three orthogonal directions, *x*, *y* and *z*, at the supporting surface.
- T Is the duration of exposure to the vibration magnitude a_w.
- T_0 Is the reference duration of 8 hours (28,800 seconds).
- k Is a multiplying factor.

To avoid confusion between vibration magnitude and daily exposure to vibration, it is conventional to express daily exposure to vibration in m/s^2 A(8). Daily exposure to vibration A(8) is evaluated separately for the *x*, *y* and *z* directions of vibration. For horizontal vibration (*x* and *y* directions), k = 1.4 and a_w is obtained using the *Wd* frequency weighting. For vertical vibration (*z* direction), k = 1.0 and a_w is obtained using the *Wk* frequency weighting. Definitions for the frequency weightings are given in International Standard ISO 2631-1:1997.

If the work is such that the total daily exposure consists of two or more operations with different vibration magnitudes, the daily exposure A(8) for the combination of operations is ascertained using the formula:

$$A(8) = \sqrt{\frac{1}{T_0}\sum_{i=1}^{n} a_{wi}^2 T_i} \tag{2}$$

where:

- n is the number of individual operations within the working day;
- a_{wi} is the vibration magnitude for operation *i*;
- T_i is the duration of operation *i*.

6.0 DETERMINING VIBRATION MAGNITUDE

Whole-body vibration magnitude is the frequency-weighted acceleration value in the highest of three orthogonal axes (x, y, z) for a seated or standing person, see Figure 3.

The vibration information used for vibration assessment usually needs to match closely the likely vibration performance of the machine being used (both the machine's specifications and the way the machine is operated).

There are various sources of information on vibration magnitudes, which are often sufficient to allow the specialist to decide whether either the exposure action value or the exposure limit values are likely to be exceeded. Some data can also be found in various technical or scientific publications and on the Internet.

Ideally, a specialist should use vibration information for the machine (make and model) that is planned for use. However, if this is not available, one may need to use information relating to similar equipment as a starting point, replacing the data with more accurate values when this becomes available.

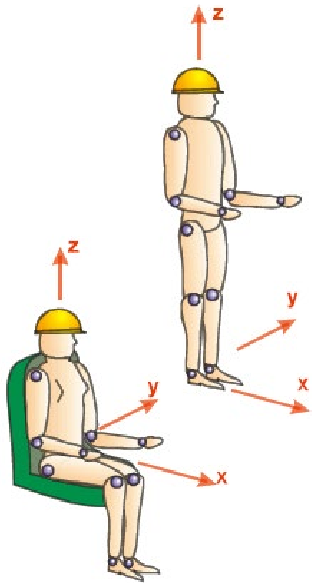

Figure 3: WBV Orthogonal Axes.

When choosing published vibration information, the factors to be taken into account include:

- The type of equipment (e.g., terrain car for transport of personnel);
- The class of equipment (e.g., power or size, weight);
- The power source (e.g., electric or combustion engine);
- Any anti-vibration features (e.g., suspension systems, suspended cab, seats);
- The task the vehicle was used for (mode of using), when collecting the vibration information (e.g., transport, readiness);
- The speed it was operated at[1]; and
- The type of surface it runs on (e.g., road, terrain).

[1] The term speed can be understood in two ways. The first meaning is the speed of a travelling vehicle and the second is the speed of a rotating machine. The machine can be a power unit of the vehicle, or some built-in system (e.g., air-conditioning).

When using published vibration data, it is good practice to try to compare data from two or more sources. It is not necessary to measure vibration when reliable sources of information are available. Otherwise, some basic experimental measurements should be made. If the vehicle can be used in different conditions, they have to be included in the investigation.

7.0 MEASUREMENT OF VIBRATION MAGNITUDE

The Manufacturer's data and information from other sources may give a useful indication of the vibration exposure of machine operators and occupants. However, WBV exposure is very dependent on the quality of road surfaces, vehicle speeds and other factors, such as how the vehicle is operated. Therefore, it may be necessary to confirm the initial exposure assessment by making measurements of vibration magnitudes.

It is important that whoever makes the vibration measurements has sufficient competence and experience.

Human exposure to WBV should be evaluated using the method defined in International Standard ISO 2631-1:1997. Detailed practical guidance on using the method for measurement of vibration at the workplace is given in EN 14253: 2003.

The Root-Mean-Square (RMS) vibration magnitude is expressed in terms of the frequency-weighted acceleration at the seat of a seated person or the feet of a standing person. It is expressed in units of metres per second squared (m/s^2). The RMS vibration magnitude represents the average acceleration over a measurement period. It is the highest of three orthogonal axes values ($1.4a_{wx}$, $1.4a_{wy}$ or a_{wz}) that is used for the exposure assessment.

The Vibration Dose Value (or VDV) provides an alternative measure of vibration exposure. The VDV was developed as a measure that gives a better indication of the risks from vibrations that include shocks. The units for VDV are meters per second to the power 1.75 ($m/s^{1.75}$), and unlike the RMS vibration magnitude, the measured VDV is a cumulative value, i.e., it increases with measurement time. It is therefore important for any measurement of VDV to know the period over which the value was measured. It is the highest of three orthogonal axis values ($1.4VDV_{wx}$, $1.4VDV_{wy}$ or VDV_{wz}) that is used for the exposure assessment.

7.1 Making Vibration Measurements

Measurements should be made to produce vibration values that are representative of the vibration throughout the working period of personnel. It is therefore important that the operating conditions and measurement periods are selected to achieve this aim.

The primary quantity of a vibration magnitude shall be acceleration. In the case of very low frequencies and low vibration magnitudes, velocity measurements can be made. Next, saved signals are translated into acceleration.

Vibration transducers located at the measurement point shall be positioned orthogonally.

The location of the transducer shall be at the interface between the human body and the source of vibration. For example, the seat of driver has two correct locations. The first location is at the point that is beneath the ischial tuberosities; the second location is at the point of maximal pressure when the back is supported. In praxis this second point is not utilized for several reasons, some of which can be found in Refs. [2], [12].

The duration of measurement shall be sufficient to ensure that the vibration is typical of the exposures that are being assessed. When various periods of different characteristics can occur in an operational environment, separate analysis of the various periods shall be made.

Both, the magnitude and duration of any vibration exposure being assessed must be reported.

Most vibration transducers produce an output that is related to acceleration (their output depends on the force acting on a fixed mass within the transducer and, for a fixed mass, force and acceleration are directly related), so acceleration has traditionally been used to describe vibration.

The vibration transducer measures acceleration in one direction only, so to get a more complete picture of the vibration on a surface, three transducers are needed (Figure 3).

7.2 Frequency Weighting

Frequency represents the number of times per second the vibrating body moves back and forth. It is expressed as a value in cycles per second, more usually known as Hertz (Hz).

For WBV, the frequencies thought to be important range from 0.5 Hz to 80 Hz. However, because the risk of human body damages it is not equal at all frequencies. A frequency-weighting is used to represent the likelihood of damage from the different frequencies. As a result, the weighted acceleration decreases when the frequency increases.

For WBV, two different frequency weightings are used. One weighting (the Wd weighting) applies to the two lateral axes *x* and *y*, and another (the Wk weighting) applies to the vertical, *z*-axis vibration.

When considering the risks to health from whole-body vibration, an additional multiplying factor must be applied to the frequency weighted vibration values. For the two lateral axes (*x* and *y*) the acceleration values are multiplied by 1.4. For the vertical, *z*-axis vibration the factor is 1.0.

7.3 Parameters Used for Exposure Assessment

The vibration directive allows for two vibration assessment methods:

- The daily exposure, A(8) – the continuous equivalent acceleration, normalised to an 8 hour day, the A(8) value is based on root-mean-square averaging of the acceleration signal and has units of m/s^2; and
- The Vibration Dose Value (VDV) is a cumulative dose, based on the 4th root-mean-quad of the acceleration signal with units of $m/s^{1,75}$.

Both parameters A(8) and VDV are defined in ISO 2631-1:1997.

8.0 EXPERIMENTAL MEASUREMENTS

8.1 Single Channel Measurements

Measurements connected with this research started using a personal car as an experimental platform (Figure 4 and Figure 5). The first measurement was made at a point located on the floor of the car cabin. The front seats of the car are connected to the floor by rails, allowing the seat to slide forward and backward. The rails are mounted by vertical screws. One of screws was replaced by longer one, allowing an additional pad to be mounted. The pad had a vertically oriented hole with an inner thread for sensor mounting.

A miniature Brüel & Kjær accelerometer of BK4394 type was used for single channel recordings. National Instruments Signal Express software and data acquisition hardware were the basis of a measurement system. The signal from the sensor was connected to the input of the NI 9234 module hosted in the frontend NI DAQ-9181. This hardware was controlled by NI Signal Express software. The recorded signal was exported in text format in files opened consequently by Mathworks MATLAB software.

The results of the measurements were processed using functions built into the MATLAB Signal processing toolbox. Peaks in a signal were evaluated using time domain representation and the frequency content of signal was analysed using FFT calculation. Both domains revealed the random nature of vibration.

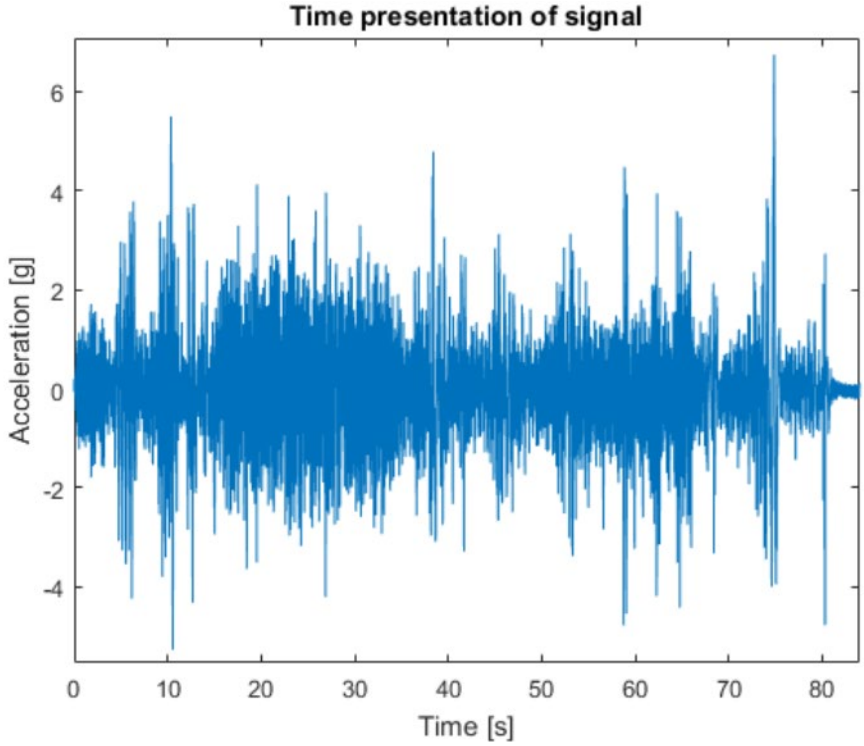

Figure 4: Vibration Signal in Time Domain.

Several higher peaks in the signal (up to 6 g) come from road potholes.

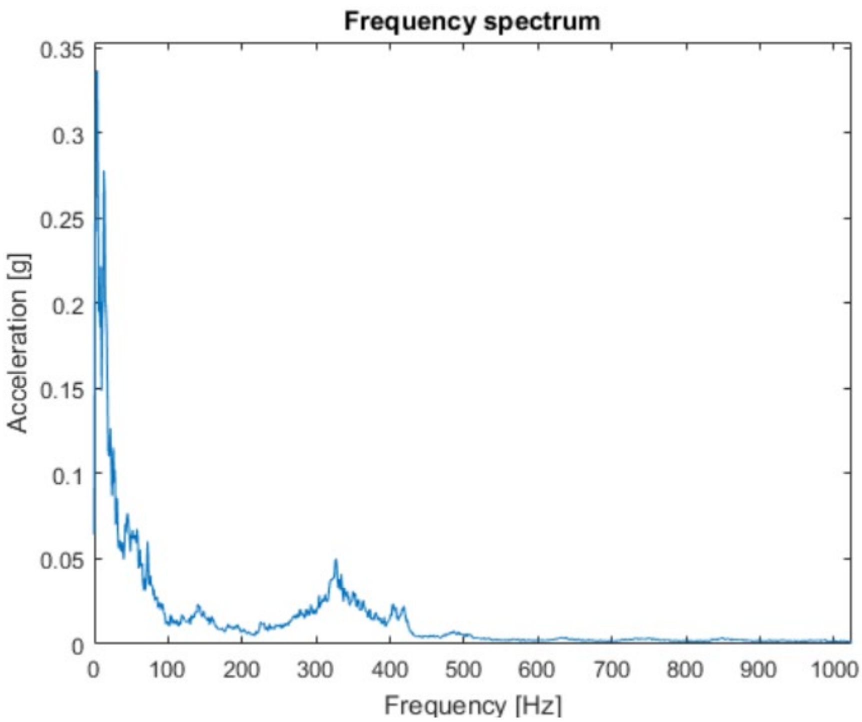

Figure 5: Vibration Signal in Frequency Domain.

The spectrum of vibration signal was calculated as an average of partial spectra. In the spectrum can be seen poor frequency content. It can be noticed that high peaks visible in the time presentation have a random occurrence, so their contribution to the averaged presentation of signal is low. In other words, amplitudes of single components in the spectrum are significantly lower in comparison.

A frequency region of interest is visible in the zoomed spectrum shown in Figure 6. Here we see the main amount of vibration power. Less power is spread in higher frequencies.

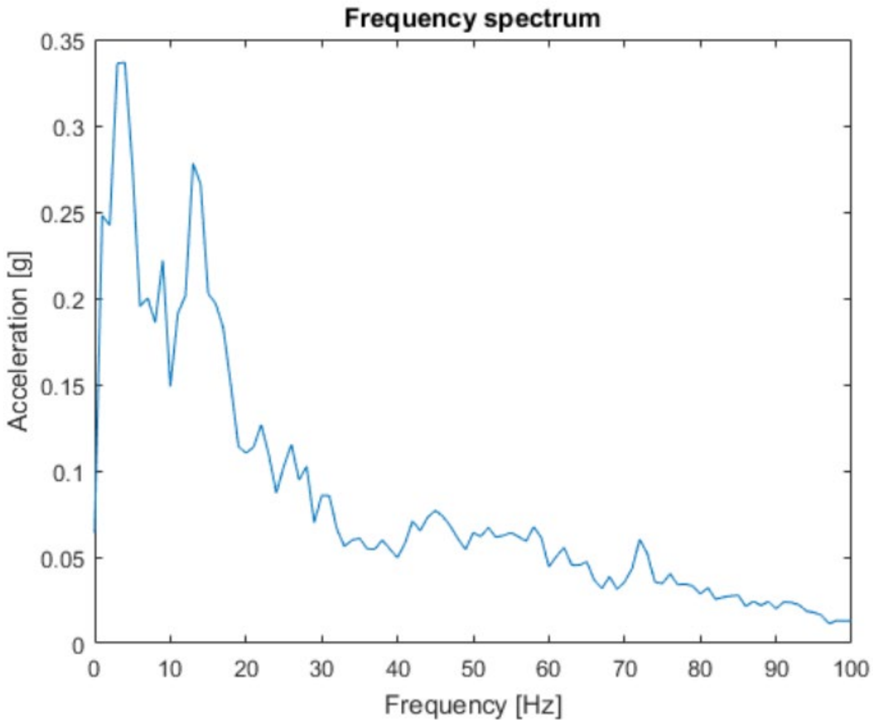

Figure 6: Zoomed Spectrum of Signal.

If the new spectrum is calculated each time, when the new set of samples is available, a set of partial spectra can be obtained. The calculation process uses overlapping of time recorded section by 50%. The set of spectra can be collected together into three dimensional (3D) graphs. Judgment of low frequency content of signal can be seen in the 3D presentation (Figure 7). However, this 3D presentation also helps to reveal 'interesting' parts of the recorded signal. The specialist can then zoom in on such parts and make a deeper analysis.

Vertical vibrations recorded during experiments by a sensor mounted on the floor of vehicle revealed their strong dependence on the trace used. This factor has a random character. It means that the local conditions at the mission, where vehicle is used will significantly influence the health of personnel.

8.2 Multichannel Measurements

Experimental measurements continued using a 3-channel accelerometer set on the driver's seat. The fourth channel of the measurement system was utilized for a vertically oriented sensor located on the floor. Units used in Figure 8 and Figure 9 are metres per second squared.

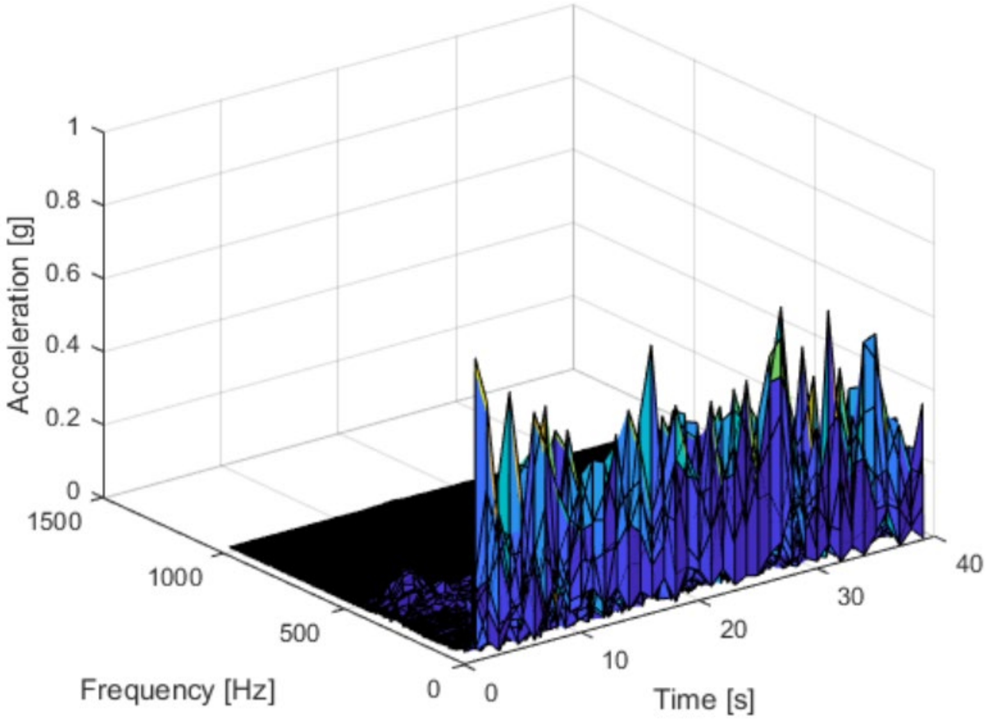

Figure 7: 3D Presentation of Signal.

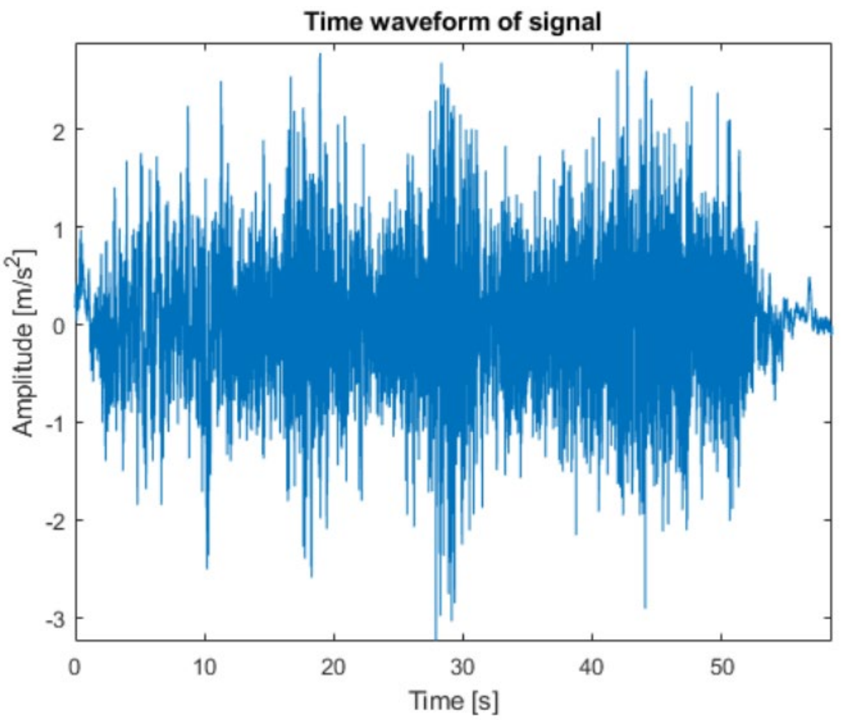

Figure 8: Vibration Signal in Fore-Aft (x) Axis.

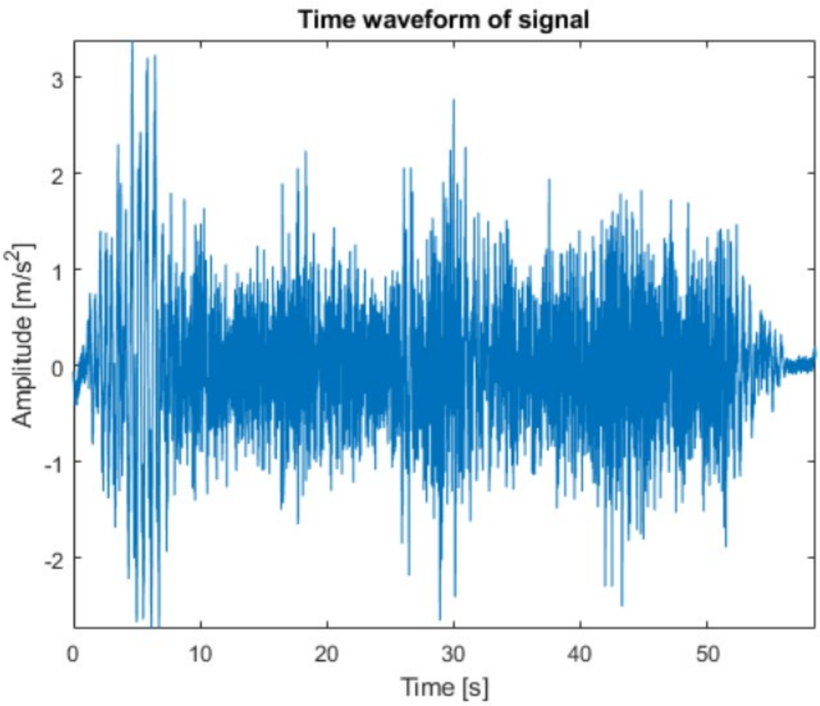

Figure 9: Vibration Signal in Side-To-Side (y) Axis.

It can be observed on the set of figures that floor vertical vibrations are a bit higher than "on-seat" vibrations in all three directions (Figure 10 and Figure 11). Also, it may be supposed that its asymmetry is the result of passing potholes, together with vehicle suspension characteristics.

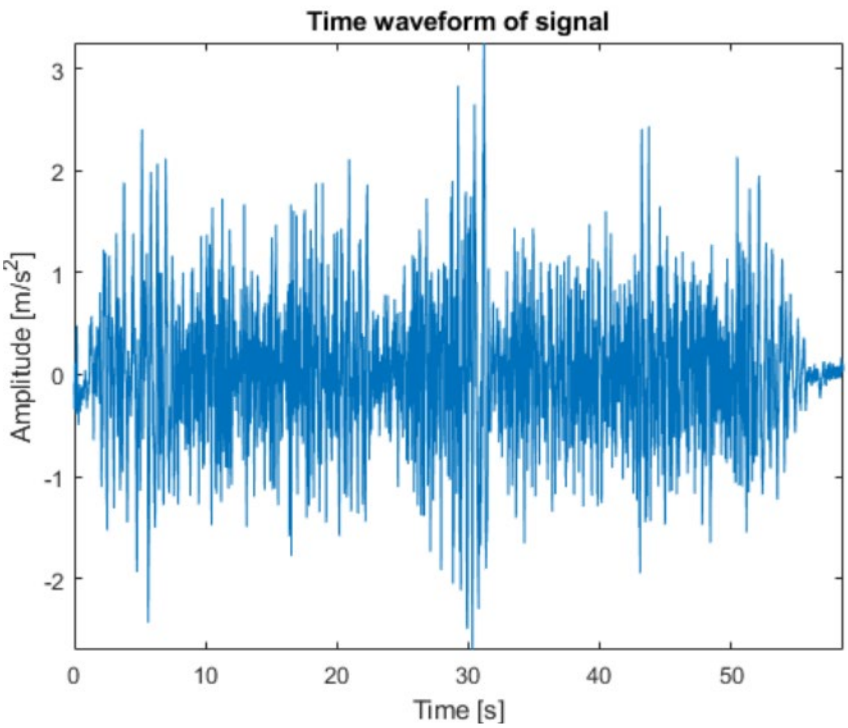

Figure 10: Vibration Signal in Vertical (z) Axis (Seat).

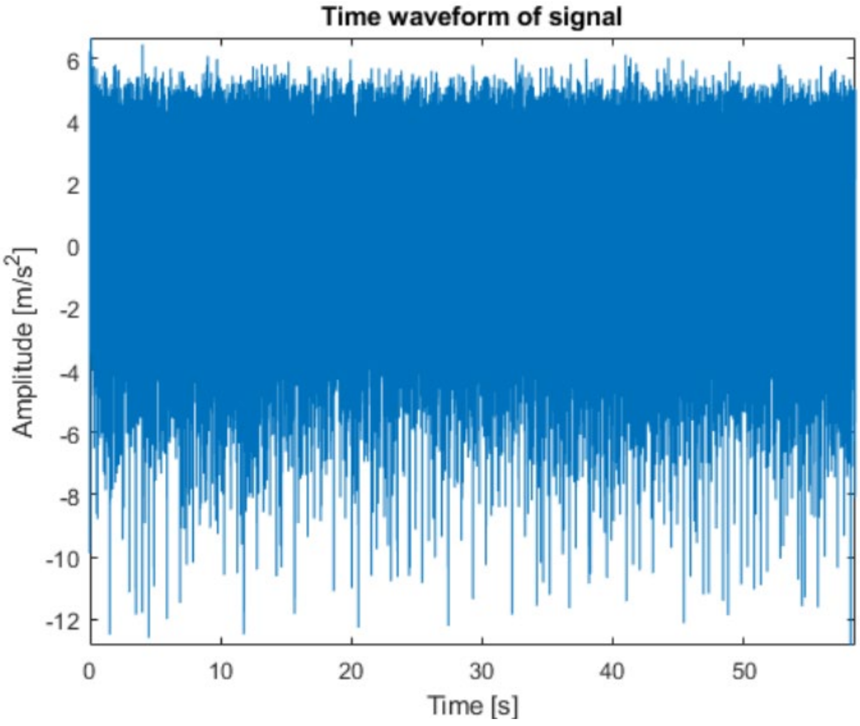

Figure 11: Vibration Signal in Vertical (z) Axis (Floor).

RMS values are calculated from recorded signals. Three signals coming from seat sensors have to be weighted by filtering in evaluated frequency range (Figure 12, Figure 13, Figure 14).

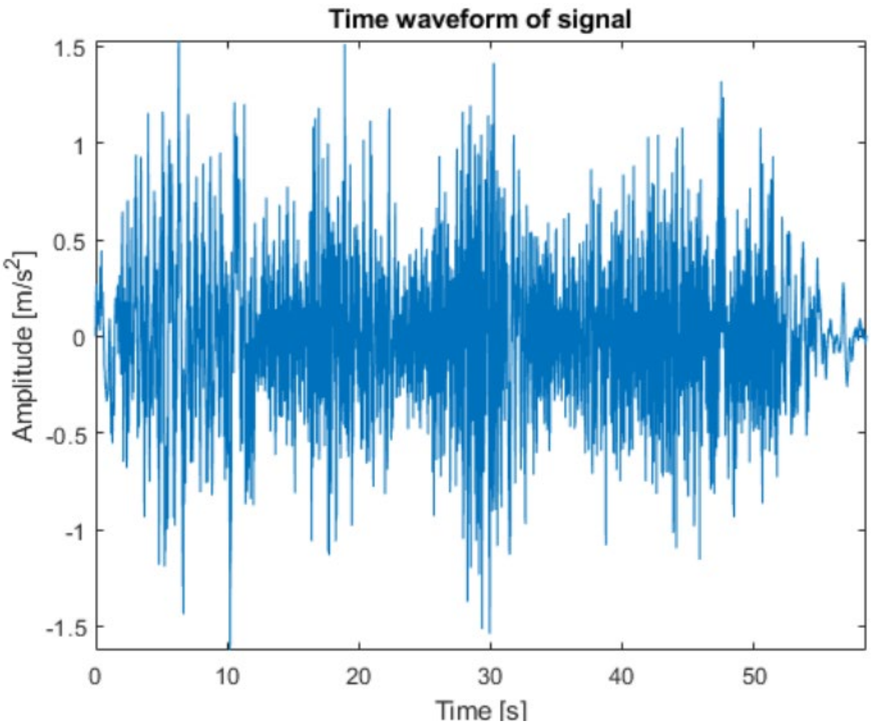

Figure 12: Signal in Fore-Aft (x) Axis Wd Weighted.

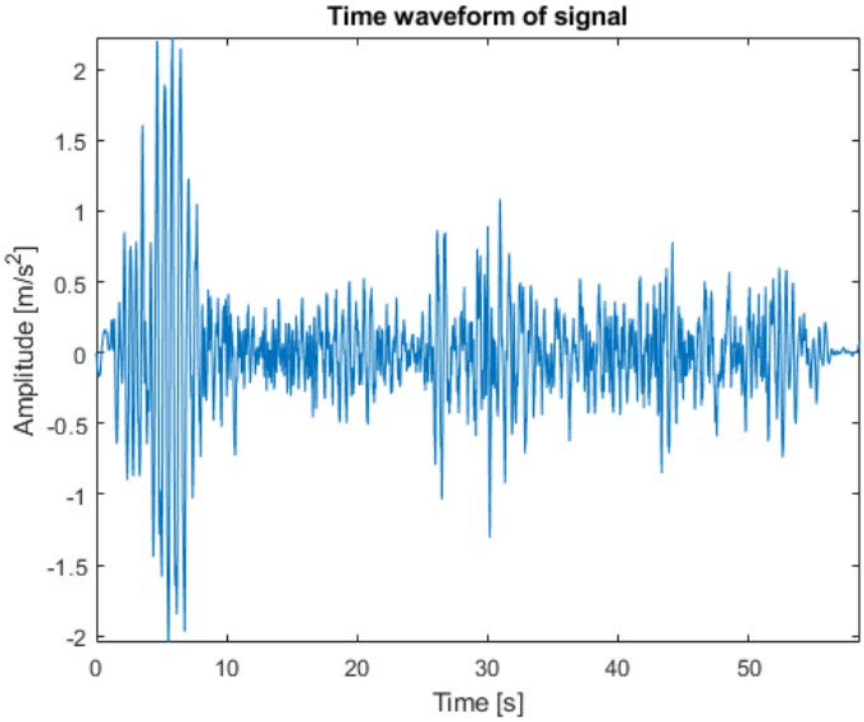

Figure 13: Signal in Side-To-Side (y) Axis Wd Weighted.

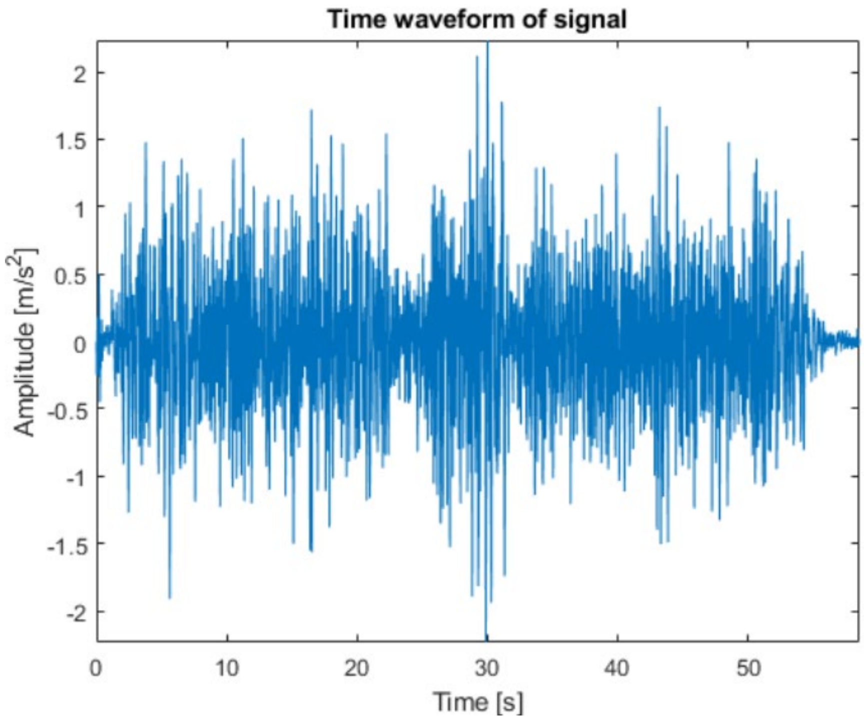

Figure 14: Seat Vibration Signal in Vertical (z) Axis Wd Weighted.

From these signal vectors can be calculated vibration levels, that are simple (average) numbers (Table 1).

Table 1: RMS Levels of Weighted Seat Vibration.

Value	$1.4 \times a_{wx}$	$1.4 \times a_{wy}$	$1 \times a_{wz}$
Magnitude [m.s²]	3.577	4.060	4.873

RMS levels coming from the "experimental mission" show a small influence of fore-aft changes in vehicle motion; a higher influence of side-to-side shaking when passing road roughness; and the highest influence of vertical changes. Several traces were tested for different driving durations, while experimental measurements were made. Longer signal records were better suited to methodology requirements. A recording of about one minute was used as a representative example, due to fairly visible randomness in the time domain.

The results obtained are used to calculate a summary of the person sitting on the seat's exposure to WBV. This method of evaluation can be used for all the cases of WBV previously described.

9.0 CALCULATING DAILY EXPOSURES

Real vibration magnitudes are used to calculate exposure as it would be recorded on the real mission. If we consider 2 hours of driving a vehicle in case/conditions introduced above, the daily exposure, A(8), results (using formulae in Section 5) are found in Table 2.

Table 2: Vehicle Driver's Daily Exposure to Seat Vibration.

Value	A(8)x	A(8)y	A(8)z
Magnitude [m.s²]	1.7885	2.030	2.4365

Several tools are available to evaluate the daily exposure rates of workers. They are based on reliable input information coming from vibration monitoring and reports from personnel.

Some web-based calculators are available that simplify the process of doing daily vibration exposure calculations, e.g.: http://www.hse.gov.uk/vibration/wbv/calculator.htm.

A graph of daily exposure evaluation provide a simple alternative method for looking up daily exposures or partial vibration exposures without the need for a calculator (Figure 15).

Looking at the graph for the A(8) line we find a point, at or just above where the known vibration magnitude value (k.aw)max (see Table 1) and exposure time lines meet (the factor k is either 1.4 for the x- and y-axes or 1.0 for the z-axis i.e., vertical direction).

The green area in the graph indicates exposures likely to below the exposure action value. These exposures must not be assumed to be "safe". There may be a risk of WBV injury for exposures below the exposure action value; some exposures within the green area may cause vibration injury in some workers, especially after many years of exposure.

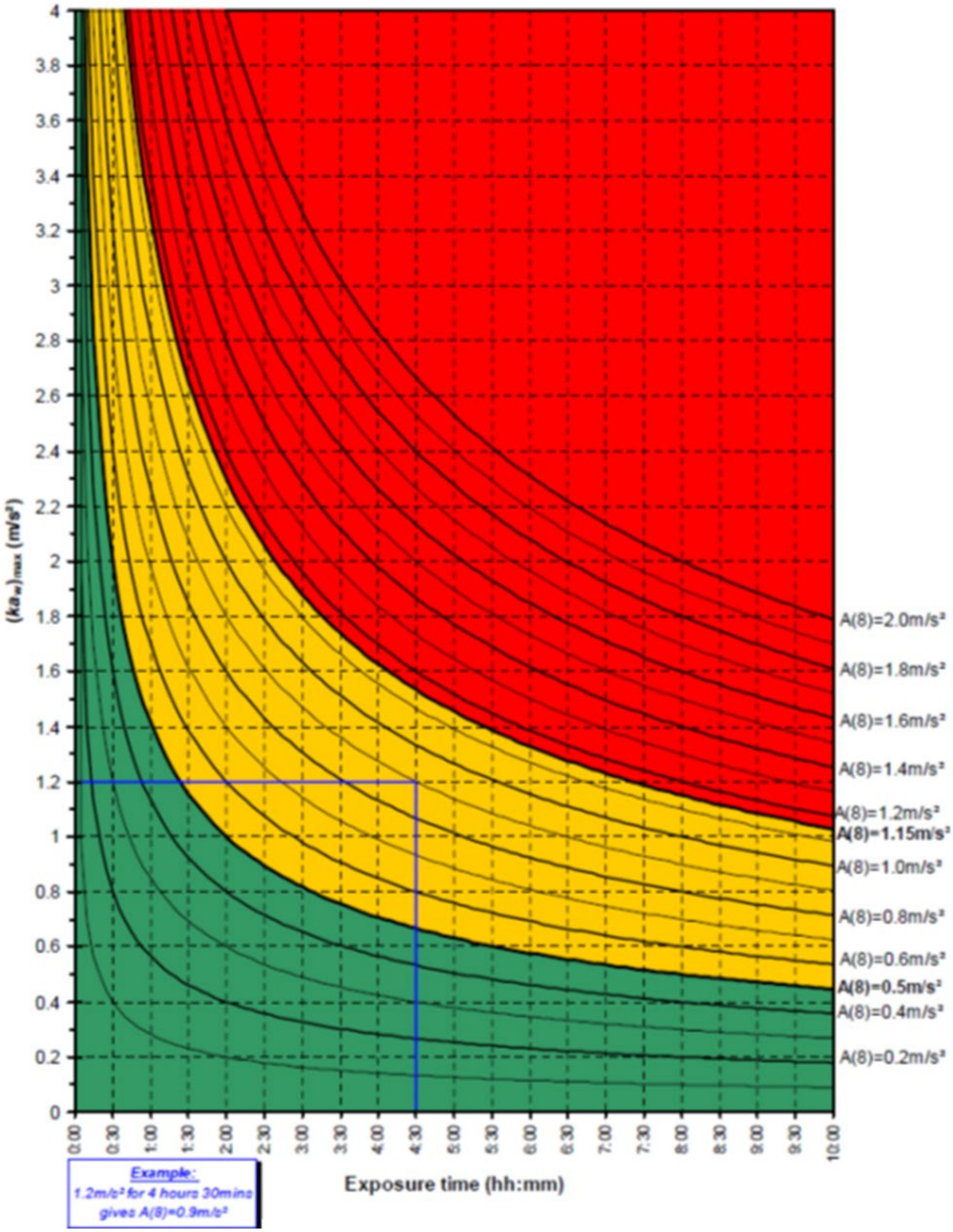

Figure 15: Daily Exposure Graphs [3].

A daily exposure nomogram (Figure 16) provides a simple alternative method of obtaining daily vibration exposures, without using the equations:

1) On the left hand line can be found the point corresponding to the vibration magnitude (use the left scale for *x*- and *y*-axis values; the right scale for *z*-axis values).
2) A line can be drawn from the point on the left hand line (representing the vibration magnitude) to a point on the right hand line (representing the exposure time).

The partial exposures can be read off where the line crosses the central scale.

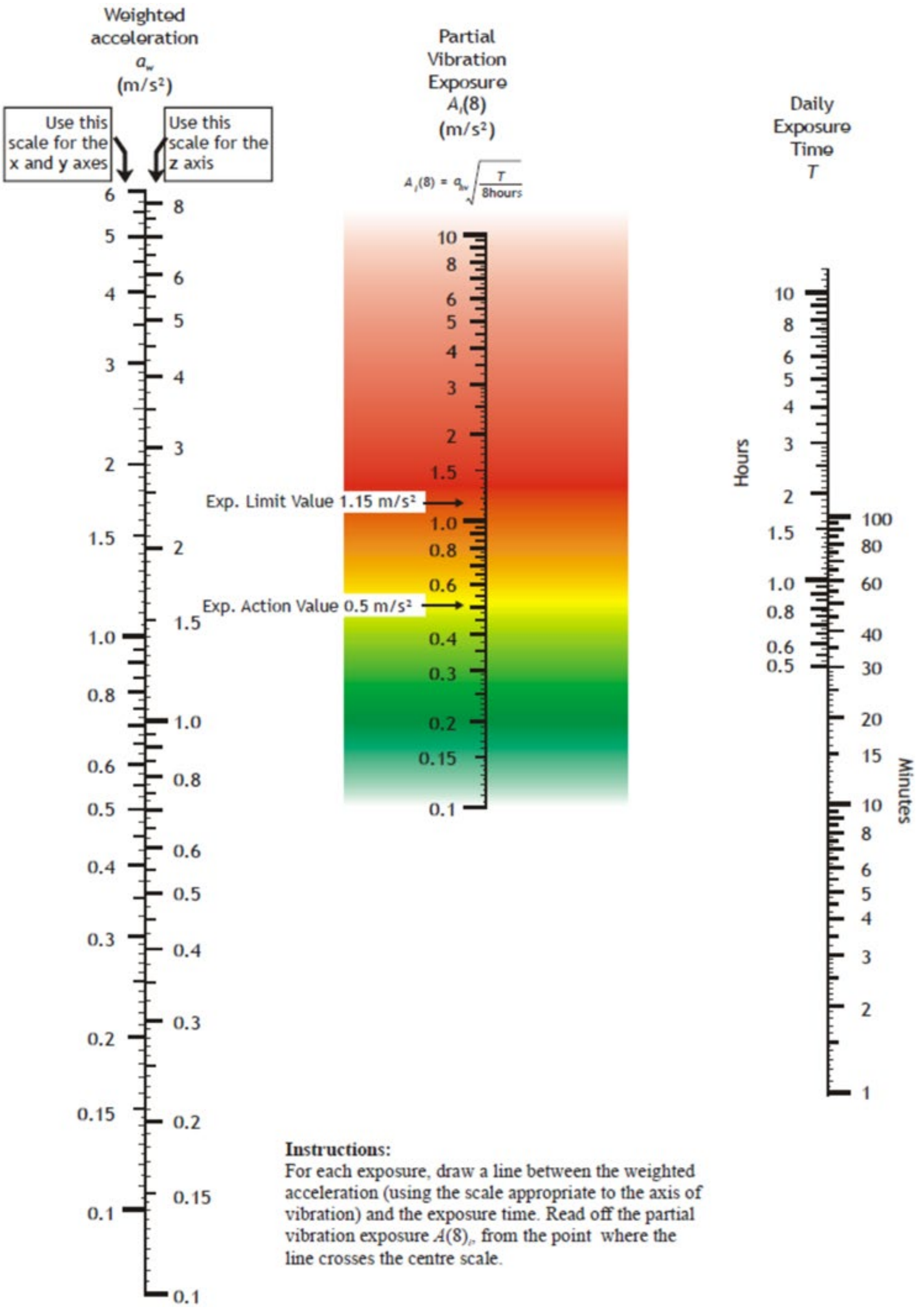

Figure 16: Nomogram for A(8) Values [3].

Whole-body vibration exposure management can be simplified by using an exposure "points" system (Figure 17). For any vehicle or machine operated, the number of exposure points accumulated in an hour ($P_{E,1h}$ in points per hour) can be obtained from the vibration magnitude a_w in m/s² and the factor k (either 1.4 for x- and y-axes or 1.0 for the z-axis) using:

$$P_{E,1h} = 50(ka_w)^2 \tag{3}$$

Exposure points are simply added together, so specialist can set a maximum number of exposure points for any person in one day.

The exposure scores corresponding to the exposure action and limit values are:

- Exposure action value (0.5 m/s²) = 100 points; and
- Exposure limit value (1.15 m/s²) = 529 points.

Acceleration x k (m/s²) \ Daily Exposure time	15m	30m	1h	2h	3h	4h	5h	6h	8h	10h	12h
2	50	100	200	400	600	800	1000	1200	1600	2000	2400
1.9	45	90	180	360	540	720	905	1100	1450	1800	2150
1.8	41	81	160	325	485	650	810	970	1300	1600	1950
1.7	36	72	145	290	435	580	725	865	1150	1450	1750
1.6	32	64	130	255	385	510	640	770	1000	1300	1550
1.5	28	56	115	225	340	450	565	675	900	1150	1350
1.4	25	49	98	195	295	390	490	590	785	980	1200
1.3	21	42	85	170	255	340	425	505	675	845	1000
1.2	18	36	72	145	215	290	360	430	575	720	865
1.1	15	30	61	120	180	240	305	365	485	605	725
1	13	25	50	100	150	200	250	300	400	500	600
0.9	10	20	41	81	120	160	205	245	325	405	485
0.8	8	16	32	64	96	130	160	190	255	320	385
0.7	6	12	25	49	74	98	125	145	195	245	295
0.6	5	9	18	36	54	72	90	110	145	180	215
0.5	3	6	13	25	38	50	63	75	100	125	150
0.4	2	4	8	16	24	32	40	48	64	80	96
0.3	1	2	5	9	14	18	23	27	36	45	54
0.2	1	1	2	4	6	8	10	12	16	20	24

Figure 17: Exposure Points Table (Rounded Values) [3].

10.0 FLOOR AND SEAT VIBRATION CORRELATION

Several problems are addressed in the research described here. The basic task is to establish a method for the efficient evaluation of WBV risk assessment. In cases where a measurement/recording system is available, vibration magnitude can be recorded, using different damping materials under seat frames, floor or handles. The damping material indicates some kind of interface between the vibrating structure and the contact point/area on the human body.

Since the mid-1920s, bus drivers and heavy truck drivers have been known to be equipped with seats with a damping system. Damping systems reduce vibration transfer from machine/structure to man; their success can be measured. Taking such steps can significantly decrease the effects of long-term exposure. At the same time, smaller, daily exposures can be recorded.

Decreasing daily exposure to WBV is the main motivation for doing this research, in which the vibration of the vehicle body and the vibration of the seat are compared. Future research will record signals and calculate correlation. Frequently used vehicles and highly vibrating vehicles will be the focus of interest now that the tools for evaluation are on hand.

11.0 HEALTH SURVEILLANCE AND RISK REDUCTION

Health surveillance is a programme of systematic health checks that identifies early signs and symptoms of illness and allows action to be taken to prevent further progression. Health surveillance is also useful in monitoring the effectiveness of controls.

It is not necessary to record and evaluate vibration signals from an entire fleet of vehicles during the total duration of a mission. However, the person in command should make a decision about health monitoring according to information about the mission, and reports from subordinate personnel, etc. If he/she considers operational conditions to be dangerous due to shaking and vibration, he/she should order health monitoring. The symptoms can take many forms, but personnel demonstrating low power, eyesight, hearing and the appearance of pain in the last part of turns cannot give good results in the field.

11.1 Controls to Reduce the Risk of WBV

The control of vibration risk will ideally be achieved by using machinery and equipment which produces lower levels of vibration, by restricting the duration of exposure, by maintaining equipment, by modifications to the working conditions in order to help prevent an adverse environment and by use of Personal Protective Equipment. Health surveillance and awareness training will also be important.

11.1.1 Precautionary Measures

- Establish who is responsible for managing the control of risk from exposure to WBV or shock.
- Find out what can reduce shock, such as adequate maintenance of vehicles.
- Find out what can reduce vibration, such as limiting speed or good maintenance of machinery suspensions.
- Find out vibration information when purchasing or hiring machinery.
- Provide information and training for operators on how to minimise exposure to WBV and shock and how to recognise and report symptoms.

11.1.2 Selecting or Adapting Suitable Machinery

Several questions should be answered:

- Is the equipment suitable for the intended task?
- Is the equipment properly maintained in accordance with the manufacturer's recommendations?
- Will the machinery cause unnecessary vibration exposure?

- Are the vehicles with low vibration emissions employed?
- Did the supplier inform the user of the WBV emission level? Did the supplier provide additional information about WBV, as necessary, for the machinery to be used safely?
- Is it possible to make technical changes aimed at lowering vibration levels?

Using under-sized or under-powered machinery is likely to increase exposure to WBV and shock. It may be possible to reorganise the extraction process to minimise the use of mobile plant.

Job rotation should only be used to reduce exposure to shocks after other measures have been put in place to minimise shock, as job rotation may increase the number of operators at risk if large shocks are present.

11.1.3 Maintenance and Adjustment of Seats

Machine manufacturers/suppliers must ensure that the seat adjustment controls are readily accessible and easy to use. The same applies to the retrofitting of replacement seats.

Operators should be trained to set seats correctly. Incorrect seat adjustment is frequently the source of poor posture and unnecessary vibration or shock.

Check, lubricate and maintain seat, cab and chassis suspensions in accordance with the manufacturer's instructions.

11.1.4 Training

A competent and skilled machine operator (driver, pilot) who drives in a smooth and controlled manner will often generate lower exposure to vibration than a less skilled operator or someone working under pressure.

It is important to train machine operators and to give them information about:

- The risk of lower back pain in their jobs;
- The factors that are within their control (such as choice of speed and route) and where experience has shown these to be important;
- How to set the seat for good posture and to set the suspension correctly to minimise vibration;
- How to locate and adjust convex mirrors and CCTV so that they can be used without twisting and stretching; and
- How to identify and report faults.

12.0 CONCLUSION

High dynamic load causes fatigue in both machine and man. Vibration measurements allow possible risks to be assessed. Additional information can be achieved from several sources. Targeted information collection and analysis permits effective Structural Health Monitoring (SHM) of the vehicle body and Whole Body Vibration monitoring in personnel. Consequently, health surveillance can be established.

International standards state allowable vibration levels for human support in the vehicle. Vibration signals recorded close to the vehicle seat can help to reveal the sources of unsatisfactory results recorded on the seat, or other support, if used. The possibilities for analysis presented here give just one point of view on the recorded signals. Different methods of analysis can also be employed.

By correlating vehicle body vibration and human body support vibration, experts can evaluate the vehicle seat (support) and optimise its damping versus supporting properties. Future research will help to evaluate vehicle operators' seat quality. It is also possible to connect the current research with medical research that explores human fatigue and/or performance.

13.0 REFERENCES

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Annex A – WORK SCHEDULE CHART FOR THE SUPPORT PROJECT

Work Schedule Chart for the Support Project:

Theory collection.	10/2016 to 12/2017
Measurements preparation.	09/2017 to 08/2018
Evaluation method preparation.	12/2017 to 12/2018
Measurements conducting.	Completed 03/2019
Final report.	Completed 04/2019

Annex B – FACE TO FACE MEETINGS

Name of Travelling Specialist	Place of Meeting	Date
Doc., Ing. Mariana Kuffová, PhD Eng. Stanislav Fábry, PhD	Ottawa, Ontario, CA	November 14 – 18, 2016
Dr. Wieslaw Beres, P. Eng. Dr.Yong (Eric) Chen, P. Eng	Košice, Liptovký Mikuláš, SK	October 16 – 20, 2017
Dr. Viresh Wickramasinghe, P. Eng	Košice, Liptovký Mikuláš, SK	June 13 – 16, 2018
Doc., Ing. Mariana Kuffová, PhD Eng. Stanislav Fábry, PhD	Ottawa, Ontario, Victoria, British Columbia, CA	October 20 – 27, 2018

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Evaluation of In-Vehicle Vibrations and Their Effect on Vehicle Structures and Personnel Health and Performance

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13. Keywords/Descriptors

Damage accumulation	Operational safety
Fatigue of personnel	Structural vibration
Fatigue of structure	Vibration exposure
Health Issues	Vibration monitoring
Mission performance	Whole-body vibration

14. Abstract
The vibratory forces generated during the operation of land vehicles such as Armored Personnel Carriers, Infantry Fighting Vehicles and aircraft including both fixed wing and helicopters, expose both the vehicle to structural vibration and the military personnel inside to Whole-Body Vibration environment. Vibration transmitted to vehicles and their occupants originates from a host of causes, including, road roughness, aerodynamic forces and engine- and powertrain-induced vibration. Vibrations can degrade vehicle performance and may be responsible for damage accumulation that typically leads to mechanical fatigue and subsequent failure of metallic or composite vehicle components. The mechanical vibration transmitted through the structure to the human body increases fatigue, degrades comfort, interferes with mission performance and affects operational safety, in the short term. Long-term exposure contributes to occupational health issues. Based on Standard ISO 2631-1 and Health and Safety Executive, Regulations 2005, The Control of Vibration at Work, we developed a personnel whole-body vibration monitoring procedure based on standards and in-operation measurements.

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