16. Influence of vehicle technical condition and power transmission system on evaluation of human exposure to whole body vibration penetrated via feet

The statistics reported in western European countries imply that the number of people exposed to general vibrations come to 4-7 % of all working persons [79]. Studies [96] devoted to work-related risk of exposure to general mechanical vibrations in professional environments provide numbers of people exposed to vibrations broken into 6 NDN classes. They mention the following professional groups as the ones most endangered by general vibrations: drivers of locomotives and other traction vehicles – 10.211 persons, drivers of motor and delivery trucks – 7.811 persons, bus drivers – 5.740 persons, tractor drivers – 4.053 persons, fork-lift truck operators – 1.603 persons, loading machine operators – 1.607 persons, excavating machine operators – 1.513 persons, bulldozer operators – 1.325 persons, operator of other heavy gear – 772 persons and operator of road machinery – 728 persons. As regards vehicle drivers, they correspond to 15-30 % of all persons employed. With reference to European data (4-7 %) or results of national studies (ca. 0.5 %), the share of people exposed to vibrations in means of transport is far larger [96].

The occupants of means of transport assess the ride discomfort on the grounds of the accelerations to which they are exposed. The harmful effects of vibrations generated by any means of transport on the human body chiefly depend on the vibration amplitude and frequency. In most cases, a measure of the health risk and danger is based on the fact whether the vibration volume exceeds a specific limit that is determined experimentally. Important is also the duration of exposure, especially in the situation of increasing amount of time spent by people when riding vehicles [197].

All research described in previous chapters were focused on identification of vibration sources and paths of propagation in vehicle. The scope of the research included investigation on influence of chosen operating parameters of investigated sources on vibration propagation into the vehicle structure in locations where vibration penetrate into the human organism. Thus the influence of technical condition of suspension elements, vehicle operating parameters, engine rotational speed and gear ratio on evaluation of human exposure to whole body vibration can be performed.

There are many publication, documents, standards describing human exposure to vibration but the state of art on influence of mechanical systems conditions or operating parameters of machine on human exposure to vibration is much fewer in numbers of publications. Some interesting investigation on influence of chosen driving parameters on vibration comfort according to Human-Vehicle-Road (HVR) model and vibration exposure metric described in the ISO 2631 are presented in [127]. In a wide variety of transport environments the vibration transmitted through seats is associated with discomfort [197]. Seats can either reduce vibration discomfort or increase vibration discomfort [88]. The paper [88] presents results of the study on determine how factors, as age, gender, physical characteristics, backrest contact, and magnitude of vibration affect seat transmissibility.

The chapter presents some results of different methods evaluation of exposure to WBV for different suspension technical condition and power transmission system operating parameters.

16.1. Human exposure to Whole-Body vibration

Mechanical vibrations are among the harmful physical factors occurring in working environments. Overloading an organism with vibrations contributes to development of non-specific pathological processes, also known as the head-arm vibration syndrome, which has been entered into the list of professional diseases. The nature and the location of health effects depend on the penetration point and propagation of vibrations in the organism.

The prediction of spinal stress is a prerequisite for a quantitative assessment of the health risk of the lumbar spine. Repetitive peak compressive forces are assumed to be responsible for fatigue failure of vertebral endplates [169-171]. The processing of predicted compressive forces in the time domain enables the calculation of a dose measure characterising the probability of fatigue failure. One procedure for the quantification of health risk described in ISO 2631-5.

Although the human body dampens most vibration frequencies transmitted through the operator-seat interface, WBV between 1 Hz and 20 Hz results in resonance of the spinal column, pelvis, internal organs and soft tissues. Health effects associated with short term WBV include muscle fatigue, discomfort, distorted motor performance, headache, loss of balance, motion sickness, increased heart rate, hyperventilation, decreased cognitive functions, as well as, diminished speech and vision. An even greater concern arises from chronic health effects associated with regular exposure to WBV, which include: spinal degeneration, spinal disc disease, disc failure, sciatic pain, herniated discs, low back pain, and gastrointestinal disorders.

16.2. The standards of WBV for means of transport

These standards comprise a very broad area of standardization with a small, but important, portion of it directly related to shock and vibration. ISO TC 108/SC 2 (Measurement and Evaluation of Mechanical Vibration and Shock as Applied to Machines, Vehicles, and Structures) is involved with the vibration of ships, and ISO 4867, 4868, and 6954 specifically address the measurement and reporting of vibration onboard ships. Much of the U.S. participation in this work is contributed by members of the Society of Naval Architects and Marine Engineers (SNAME). ANSI S2.16 covers the measurement and acceptance criteria for the vibratory noise of shipboard equipment, and ANSI S2.25 covers the evaluation and reporting of hull and superstructure vibration in ships. ISO TC 108/SC 2 is also involved with vibration of land-based vehicles, and ISO 8002, 8608, and 10326 are specifically related to the evaluation and reporting of the vibration associated with either land-based vehicles or road surface profiles. ISO TC 20 (Aircraft and Space Vehicles) is involved with standards related to aerospace vehicles in general, and a number of ISO technical committees exist that generally cover specific types of land-based vehicles, e.g., construction, agricultural, and off-road vehicles. The U.S.TAG for ISOTC 20 and the U.S.TAGs for many of the ISO technical committees on land-based vehicles in general are administered by the Society of Automotive Engineers (SAE).The CEN document CEN EN 1032 on testing mobile machinery has been published, and CEN TC 231 with respect to testing mobile machinery to determine whole-body vibration and vibration emission values. CENTC 231 maintains liaisons with CEN TC 144 and CEN TC 1 51 on tractors and agricultural machines, and construction equipment, respectively.

Human exposure to shock and vibration, as the program of work on human exposure to shock and vibration is assigned to ISO TC 108/SC 4 (Human Exposure to Mechanical Vibration and Shock). ISO TC 108/SC 4 maintains liaisons with about a dozen ISO technical committees and subcommittees including ISO TC 43 (Acoustics), as well as with other organizations such as the European Committee of Associations of Manufacturers of Agricultural Machinery (CEMA), the International Maritime Organization (IMO), and the International Union of Railways (UIC). There are a number of ISO and ANSI standards on exposure to whole-body and hand-arm vibration including standards covering occupants of fixed-structures, single shocks, guidance on safety aspects of tests and experiments, transmissibility of gloves and resilient materials, and terminology.

According to technical report of European Commission Quality of Life and Management of Living Resources [142] most of these procedures ignores the fact that only one time series of compressive force exists as a result of the superposition of different components. Hence, any sufficient dose of peak values can be based on one time series only and not on peak values of several non-existing components. The origin of this error is the approach described in [142]. The models used in ISO 2631-5 has been previous described by Seidel in [6]. The existing methods for the quantification of health risk caused by WBV require time series of internal forces acting on lumbar vertebral endplates. The later research of Siedal presented in [170] assumed that this model cannot be considered as verified. Many aspects of a critical analysis and discussion of the very first results of research conducted under Morrison [142] underlying ISO 2631-5, were interpreted and published in [169]. The possible underestimation of health risk described in publication of Siedel deserves special attention. Variable postures, anthropometric characteristics, spinal geometry, and individual spinal tolerance were identified as important factors that codetermine the effects of occupational WBV on health. A re-analysis of the paper [140] led to the conclusion that the exponent derived from this study [6] should not be used for the dose calculation, because the pronounced non-linearity of the stress-strain relationship. It does not permit the calculation of a correct equivalent stress.

The European Directive (2002) states an extremely high limit value for whole-body vibration (WBV) in z-direction without any limitation of an energy-equivalent evaluation. The consequence is a very dubious assessment of health effects, especially for WBV containing high peak values and/or short daily exposure times [90].

Unlike ISO 2631-5 (2004), the FIOSH-approach considers additionally significant variables like posture, body mass and body height, body mass index (BMI), disc area, disc level. Combinations of body mass, body height and BMI were chosen in order to provide representative characteristics of European drivers. It offers the possibility to predict the health risk for different shares of the exposed population as a contribution to subsequent decisions on tolerated risks [11]. There are further differences between the FIOSH-approach and the method described by ISO 2631-5 (2004). A variable static stress is predicted instead of the “constant c representing the static stress due to gravitational force” in ISO 2631-5, R factor equation. Another consequence is the variable dynamic stress predicted for different anthropometric characteristics. The FIOSH-approach also offers the possibility to use different exponents for the dose calculations. The procedure was developed to assess the health risk related to whole-body vibration (WBV) based on the results of model calculations and using the prediction of cumulative fatigue failure of vertebral endplates caused by compression as criterium. The procedure permits the consideration of individual exposure conditions, posture and personal characteristics which are reflected by different finite element models [76].

Since 2002 the implementation of the provisions of Directive 2002/44/EC of the European Parliament and of the Council on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration) were presented. In 2007 as the annex 19 to final technical report of European Commission Quality of Life and Management of Living Resources, programme Key Action 4 – Environment and Health Risks of Occupational Vibration Exposures, prediction of spinal stress in drivers from field measurements were published.

16.3. The model of vibration spine response – ISO 2631

Despite of discussion presented above the most popular standards for measurement and evaluation of human response to whole-body vibration are ISO 2631-1 (1997) and ISO2631-5 (2004). ISO 2631 – Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration, was prepared by Technical Committee ISO/TC 108, Mechanical vibration and shock, subcommittee SC 4, Human exposure to mechanical vibration and shock. It is consists of the following parts:

– Part 1: General requirements,

– Part 2: Vibration in buildings (1 Hz to 80 Hz),

– Part 4: Guidelines for the evaluation of the effects of vibration and rotational motion on passenger and crew comfort in fixed-guideway transport systems,

– Part 5: Method for evaluation of vibration containing multiple shocks.

For the assessment of the effects of vibration on health, it is proposed to use the frequency-weighted RMS of ISO 2631-1 based on translational motion of the each axis on the seat surface. ISO 2631-1 also suggests that if the crest factor is less than 9, the weighted RMS is normally sufficient for evaluation of vibration. On the other hand, ISO 2631-5 provides the additional guidance on assessment of vibration containing multiple shocks. ISO 2631-5 focused on the lumbar response in humans exposed to whole-body vibration. Although the assessment point on humans differ depending on the ISO standard indices, it is necessary to compare effects of vibration on health by the current standard (ISO2631-1) with that by the multiple shocks standard (ISO2631-5).

In ISO2631-5 recommendations, the vibration effects to the human body are evaluated by compression stress in the lumbar spine. The frequency-weighted spinal stress is calculated.

In the x- and y-axes, the spinal response is approximately linear and is represented by a single-degree-of-freedom (SDOF) lumped-parameter model. The lumbar response is calculated from equation:

$$a_{lk}(t) = 2\varsigma\omega_n(v_{sk} - v_{lk}) + \omega_n^2(s_{sk} - s_{lk}), \tag{16.1}$$

where: ς – critical damping ration ($\varsigma = 0.22$), ω_n – natural frequency, k – X or Y axes, s_{sk}, s_{lk} – displacement time histories in the seat and in the spine, v_{sk}, v_{lk} – velocity time histories in the seat and in the spine.

In the z-direction, the spinal response is non-linear and can be represented by a recurrent neural network (RNN) model. Lumbar spine z-axis acceleration is predicted by using the following equations:

$$a_{lz} = \sum_{i=1}^{7} W_j u_j(t) + W_8, \tag{16.2}$$

$$u_j(t) = \tanh\left[\sum_{i=1}^{4} w_{ji} a_{lz}(t-i) + \sum_{i=5}^{12} w_{ji} a_{sz}(t-i+4) + w_{j13}\right], \tag{16.3}$$

where: w_{ji} – connection weights are given in Table 2 in the draft of ISO 2631-5, W_j – z-axis model coefficients are given in Tables 1 in the draft of ISO 2631-5, a_s –seat acceleration, a_l – lumbar spine acceleration, $a_{lz}(t-i)$ – feed back delayed output, a_{sz} – z-axis seat acceleration.

The RNN model for the z axis presented in ISO 2631-5 was trained using vibration in the range of –20 m/s^2 to 40 m/s^2 and 0.5 Hz to 40 Hz with frequency sampling 160 Hz. As the model is non-linear, this constitutes the range of the applicability of this part of ISO 2631-5.

16.4. WBV evaluation

The vibration evaluation base on many methods and equations for assessment of health effects and risk. The section shows chosen equation of WBV evaluation.

The vibration evaluation according to ISO 2631 shall always include measurements of the weighted root mean square acceleration. This method evaluates the vibration transmitted to the body through the supporting surfaces. The standard defines the total vibration value of weighted RMS acceleration for all directions in respective position.

The method of determining the vibration exposure and discomfort is the use of a measure defined as the vector sum of squared (or RMS) acceleration values for particular vibration axes (components), with extracting the root thereof. For the purpose of research goal the weighting factors for directions of floor panelvibration were used as 1.4 for horizontal directions. This approach is based on the running RMS method ($MTVV$). However it takes into account dominant direction of the vibration, instead of occasional shocks and transient vibration by use of a short integration time constant. The vibration magnitude is defined as a maximum transient vibration value (A_{wmax}), given as the maximum in time of root mean square acceleration $a_d(t)$. The A_{wmax} is expresses as:

$$A_{w\max} = \max\{1.4RMS(a_x), 1.4RMS(a_y), RMS(a_z)\}, \tag{16.4}$$

where: RMS – root mean square of vibration signal, a_x – acceleration of vibration in X axis, a_y – acceleration of vibration in Y axis, a_z – acceleration of vibration in Z axis.

For the long term exposure to vibration, i.e. work shift period as 8 hour, the daily exposure to vibration $A(8)$ is expressed as:

$$A(8)_l = \sqrt{\frac{1}{T}\sum_{i=1}^{n} X_{RMSd_i} t_i}, \tag{16.5}$$

where: $A(8)_l$ – daily (8 hour) exposure to vibration, X_{RMSd_i} – root mean square of vibration signal in i-direction, t_i – time of exposure to vibration in separate direction (minutes), T – total time of exposure to vibration $A(8)$ is calculated for 8 hours (480 min.).

The crest factor is defined as the modulus of the ratio of the maximum instantaneous peak value of the frequency – weighted acceleration signal to its RMS value. The peak valueshall be determined over the duration of measurement. The crest factor may be used to investigate if the basic evaluation method is suitable for describing the severity of the vibration in relation to its effects on human beings. For vibration with crest factors below or equal to 9, the basic evaluation method is normally sufficient.

The guidelines by BS 6841 [33] suggest for motions with high crest factors (greater than 6) the vibration dose value must be used. Vibration dose value is a fourth power relation between acceleration and exposure duration. Vibration dose value is used to evaluate the time-dependency, for the effects of vibration on health, for all durations up to 24 hrs ($T = 86400$ s).The vibration dose value is defined as:

$$VDV = \left[\int_{t=0}^{t=T} a^4(t)dt\right]^{1/4}. \tag{16.6}$$

Alternatively, the vibration dose value might be calculated from the RMS acceleration using the "estimated vibration dose value", expressed as:

$$eVDV = [(1.4X_{RMS})^4 t]^{1/4}. \tag{16.7}$$

The ISO 2631 [100-105] standard defines methods for calculation of acceleration dose and average daily acceleration dose. There are expressed as:

$$D_k = \left[\sum_i A_{ik}^6\right]^{1/6}, \tag{16.8}$$

$$D_{kd} = D_k \left[\frac{t_d}{t_m}\right]^{1/6}, \tag{16.9}$$

where: D_k – acceleration dose, D_{kd} – average daily acceleration dose, A_{ik} – is the ith peak of response acceleration $a_{lk}(t)$, $k - x$, y or z axis, t_d – is the duration of the daily exposure, t_m – isthe period over which D_k has been measured.

The peaks are picked up in both the positive and negative directions for x- and y-directions. Otherwise, for z-direction, only positive peaks shall be counted. Eq. 16.6 can be used when the total daily exposureis represented from a single measurement period. Whenthe daily vibration exposure consists of two or more periodsof different magnitudes the average daily accelerationdose can be calculated by Eq. 16.7.

The ISO 2631 allows to assess the vibration health effects by use of a biomechanical model described in previous section. Thus the equivalent static compressive stress and its daily equivalent dose are calculated as follows:

$$S_e = \left[\sum_{k=x,y,z} (m_k D_k)^6 \right]^{1/6}, \tag{16.10}$$

$$S_{ed} = \left[\sum_{k=x,y,z} (m_k D_{dk})^6 \right]^{1/6}, \tag{16.11}$$

where: S_e – equivalent static compressive stress, S_{ed} – daily equivalent static compressive stress dose, $k - x$, y or z axis, D_k – is the acceleration dose in the k-direction, D_{kd} – is the average daily acceleration dose in the k-direction, m_x – is the stress weighting factor for x-direction ($m_x = 0.015$ MPa), m_y – is the stress weighting factor for x-direction ($m_x = 0.035$ MPa), m_z – is the stress weighting factor for x-direction ($m_x = 0.032$ MPa).

The FIOSH-Approach of risk assessment requires another equations for calculating compressive stress dose in term of dynamic conditions. Based on transformation into dynamic compressive stress all peak-to-peak values are related to the disc area of the lumbar level. The dynamic peak-to-peak compressive stress is expressed as:

$$P_{dyn} = \frac{C_{dyn}}{A \cdot 100}, \tag{16.12}$$

where: C_{dyn} – is the dynamic peak-to-peak values of the compressive force (in Newton) due to vibration acting on the lumbar level, A – is the area of the endplates at the lumbar level and for one of three categories (small, medium, large) (in cm^2).

The dynamic compressive stress dose and daily compressive stress dose for disc level are calculated as follows:

$$S_j = \left[\sum_{k=1}^{s} {P_{dyn_k}}^{exp} \right]^{1/exp}, \tag{16.13}$$

$$S_{ed} = \left[\sum_{j=1}^{r} S_j^{exp} \frac{t_{dj}}{t_{mj} \cdot 2} \right]^{1/exp}, \tag{16.14}$$

where: S_j – the compressive stress dose for the exposure j and disc level l, S_{ed} – daily compressive stress dose for disc level, j – is the exposure condition, t_{dj} – is the duration of the daily exposure to condition j, t_{mj} – is the period over which S_j has been calculated based on the measurement.

This daily compression dose does not consider the extent of the simultaneously acting static peak-to-peak compressive stress that could be taken into account, e.g., by Goodman's law [171].

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The static compressive stress is considered in the calculation of the risk factor R, expressed as:

$$R = \left[\sum_{i=1}^{q} \left(\frac{S_{ed} nd^{1/exp}}{S_{ui} - P_{stat}} \right)^{exp} \right]^{1/exp}, \tag{16.15}$$

where: S_{ui} – is the ultimate (subscript u) strength of the lumbar spine for a person of age $(b + i)$ years that can be predicted by two different regression equations and considering the share of the population that shall be covered by the prediction (50 or 95 percent), b is the age at which the exposure starts, P_{stat} – is a constant representing the static compressive stress acting on disk level l during acertain posture, i – is the year counter, nd – is the number of exposure days per year, exp – is the exponent chosen by the user, default is 6.

R factor is a quantity that predicts the risk of fatigue failure of the vertebral endplate due to repeated compressions, if it reaches or exceeds the value 1. It can also be designated as ‘equivalent static compressive stress’, because it is equivalent to the static compressive stress that would cause failure, if the value 1 is reached.

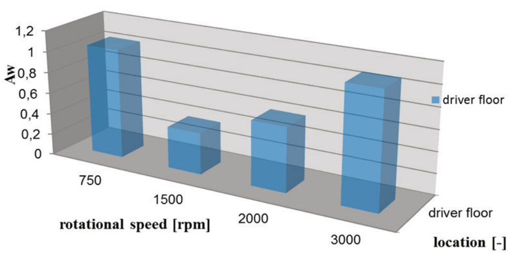
16.5. Investigation on influence of vehicle technical condition and power transmission system on evaluation of human exposure to whole body vibration via feet

All of methods for assessment of vibration exposure are dedicated to the measurement of vibration signal on the seat surface. The second surface of whole-body vibration penetration into human organism are the area of floor panel contact to human’s feet. Thus the research were conducted on implementation of chosen evaluation methods for assessment of exposure to vibration penetrated via feet of seating person.

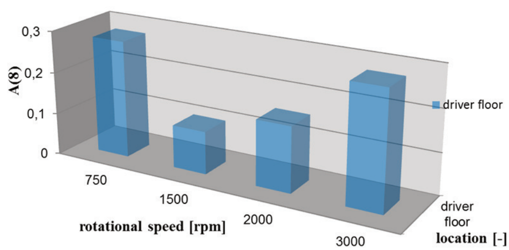
The results described in the book show influence of chosen operating parameters of vibration sources on its propagation into the vehicle structure in locations where vibration penetrate into the human organism. Thus the experiments were performed on influence of technical condition of suspension elements, vehicle operating parameters, engine rotational speed and gear ratio on evaluation of human exposure to whole body vibration. For each case the vibration of floor panel in location of occupant’s feet were registered. The chapter presents the results obtained for vibration penetrated to the feet of driver.

As the energy total estimators it were compared results of the parameter value of vibration dominant effective weighted vibration acceleration A_{wmax} and daily exposure parameter $A(8)_l$. The influence of engine rotational speed and gear ratio on evaluation of human exposure to whole body vibration have been presented as the distribution of these exposure estimators and it is presented in Figs. 16.1-16.2.

For the complex analysis of WBV exposure of driver by areas of possible penetration of the vibration into driver body the estimators of exposure were calculated basing on the vibration signals measurement on the front dash panel and floor panel in location where driver’s feet can be located during driving (Fig. 16.3). The third measurement point was located on driver seat, as it is suggested in ISO 2631.



a)



b)

Fig. 16.1. Influence of engine rotational speed on vibration exposure, expressed as a) A_{wmax} and b) $A(8)$

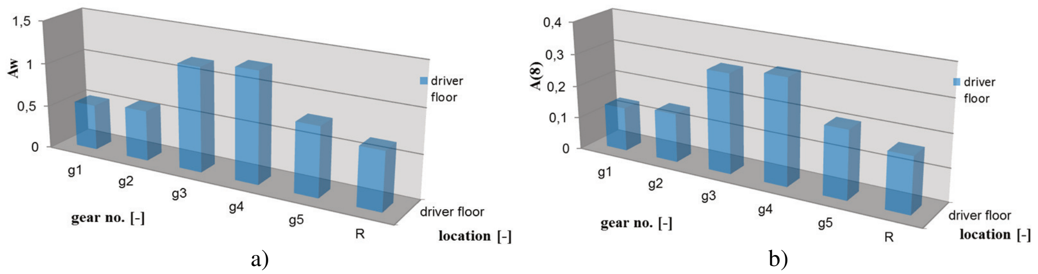


Fig. 16.2. Influence of gear ratio on vibration exposure, expressed as a) A_{wmax} and b) $A(8)$

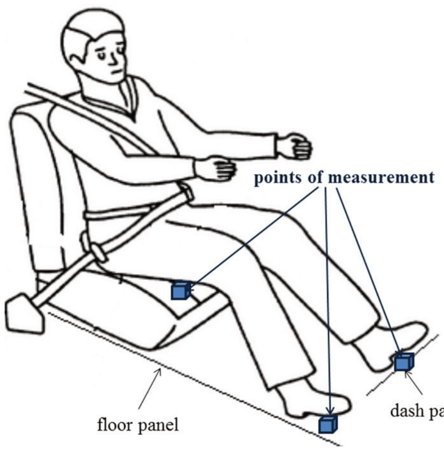


Fig. 16.3. The localization of points of measurement for evaluation of exposure to WBV

The comparison of estimators of exposure to WBV for vibration transferred through floor panel, dash panel and seat are shown in Figs. 16.4-16.5. It shows the influence of operating parameters of power transmission system on exposure to WBV.

When analysing a human exposure to whole-body vibration the methods of quantifying vibration containing multiple shocks in relation to human health is used. For the evaluation of vibration acceleration dose and average daily acceleration dose affecting to the driver the D_k and D_{kd} were compared for different engine rotational speed and gear ratio, as gear number position. Adverse effects on the lumbar spine are the dominating health risk. Therefore the analysis is concerned with the lumbar spine response. For the spine response calculating the presented in section 16.4 model was used. The calculation of acceleration dose and equivalent and daily static compressive stress S_e and S_{ed} for the assessment of health effects were done.

The example of results obtained for engine rotational speed 750 rpm and 3000 rpm or 1st and 5th gear with constant rotational speed is shown in Figs. 16.6-16.9.

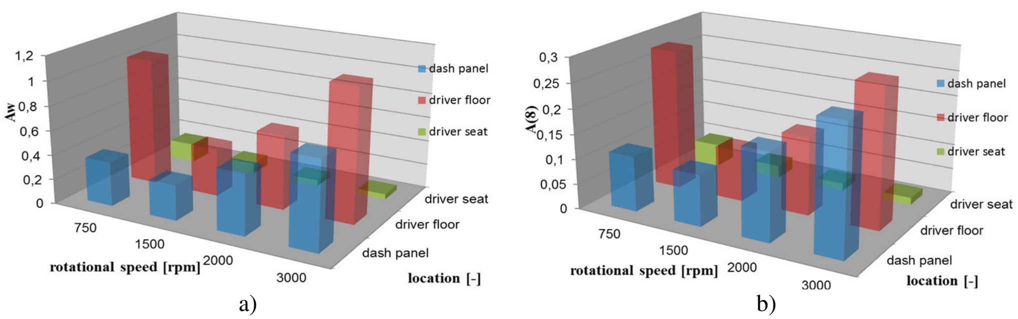
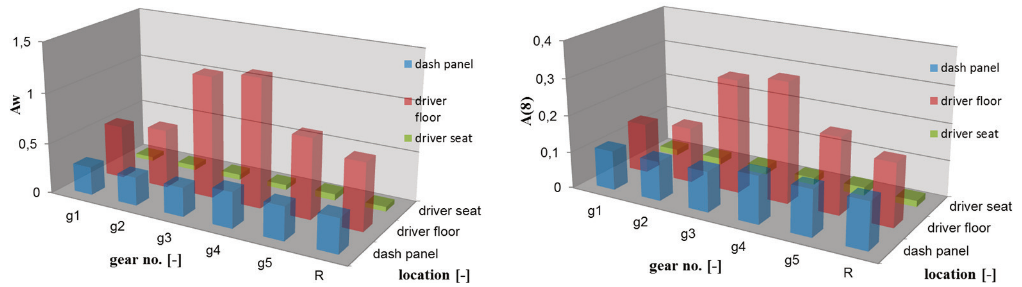
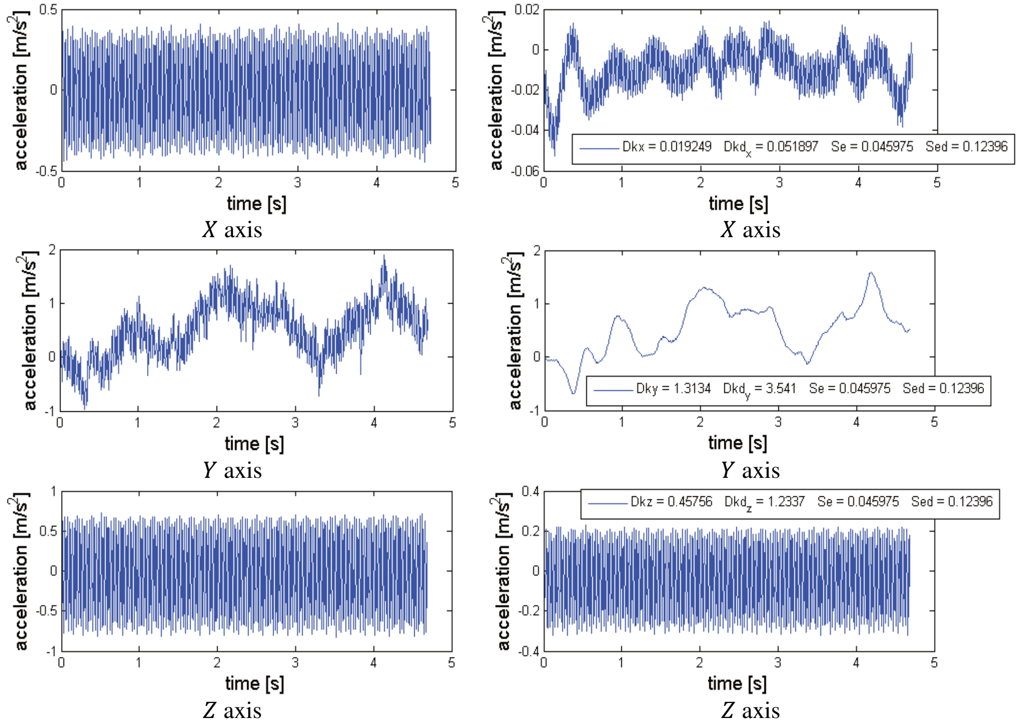


Fig. 16.4. Comparison of influence of engine rotational speed on vibration exposure, expressed as a) A_{wmax} and b) $A(8)$, calculated for vibration of dash panel, floor panel and driver seat



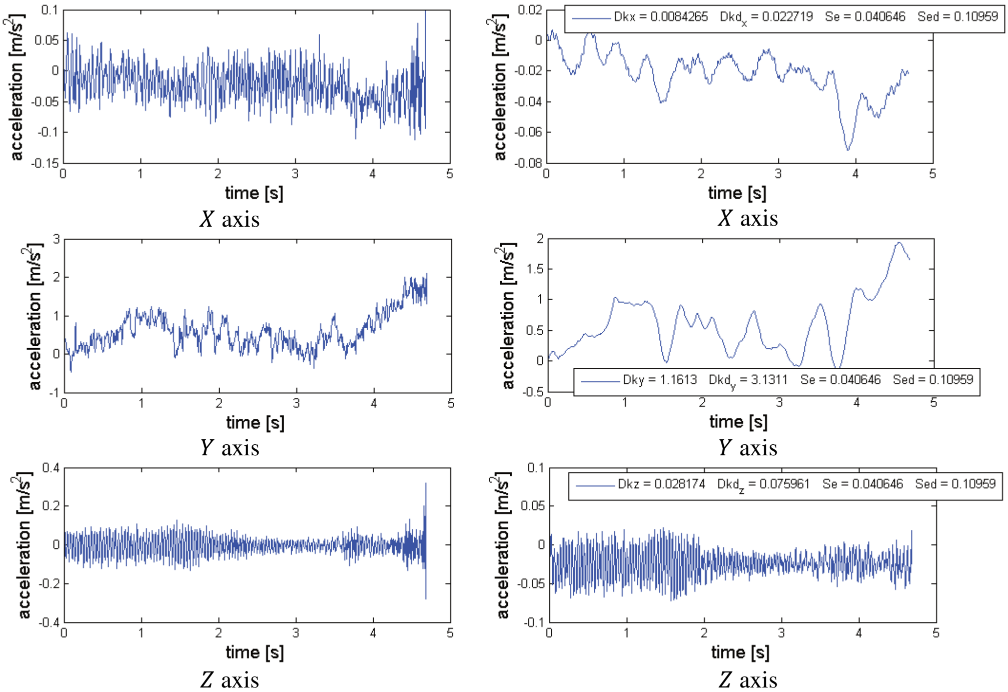
a) b)

Fig. 16.5. Comparison of influence of gear ratio on vibration exposure, expressed as a) A_{wmax} and b) $A(8)$, calculated for vibration of dash panel, floor panel and driver seat



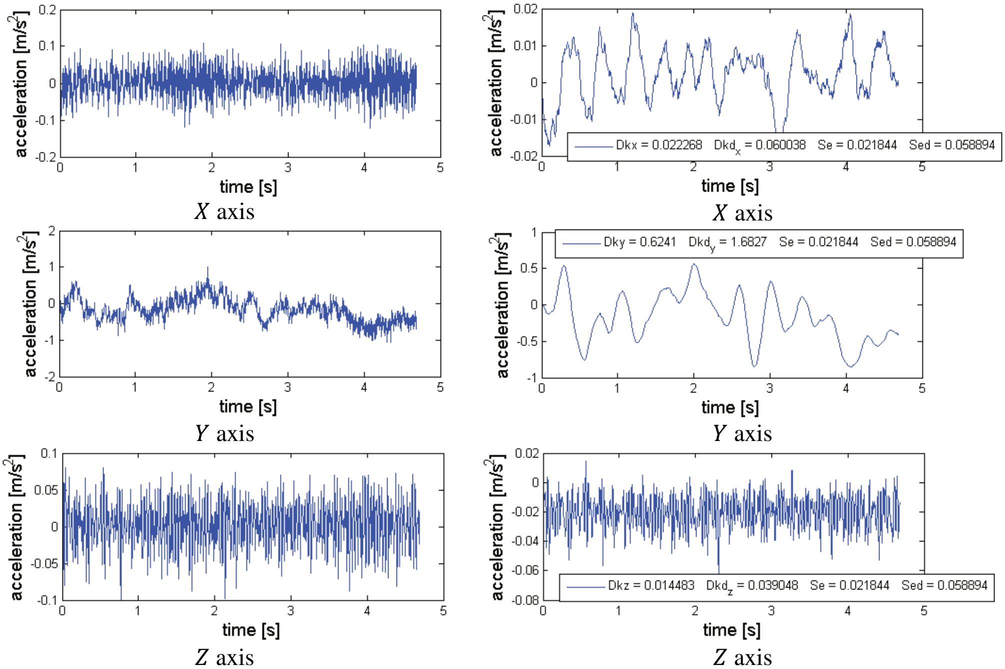
a) Vibration signal a) Response in the Spine

Fig. 16.6. a) Vibration of floor panel under driver's feet for 3 orthogonal axes and b) lumbar spine response for 750 rpm engine rotational speed



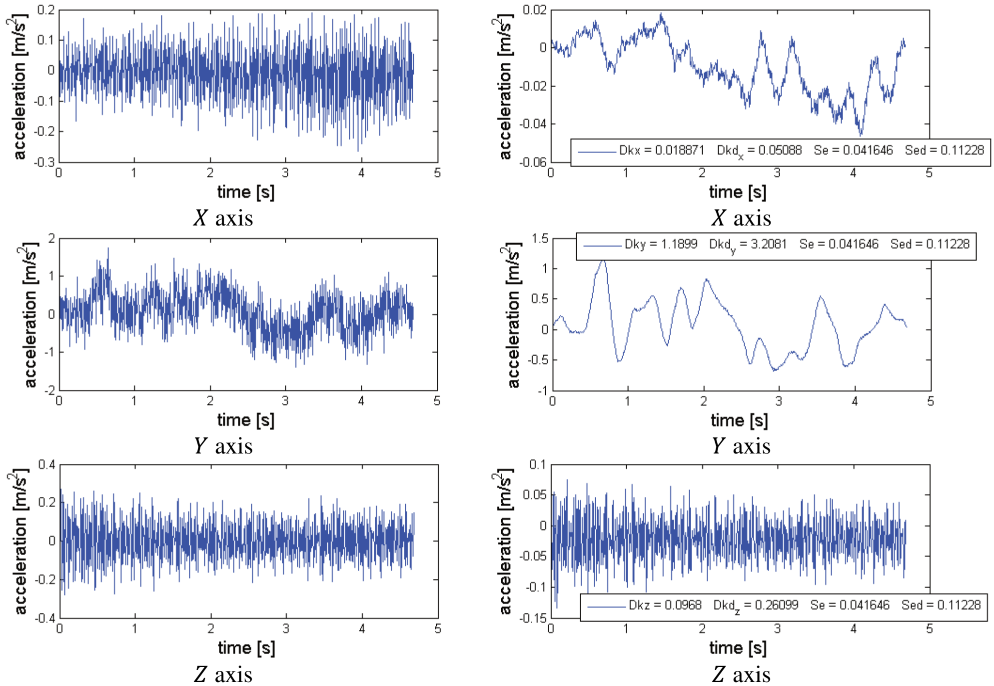
a) Vibration signal a) Response in the Spine

Fig. 16.7. a) Vibration of floor panel under driver's feet for 3 orthogonal axes and b) lumbar spine response for 3000 rpm engine rotational speed



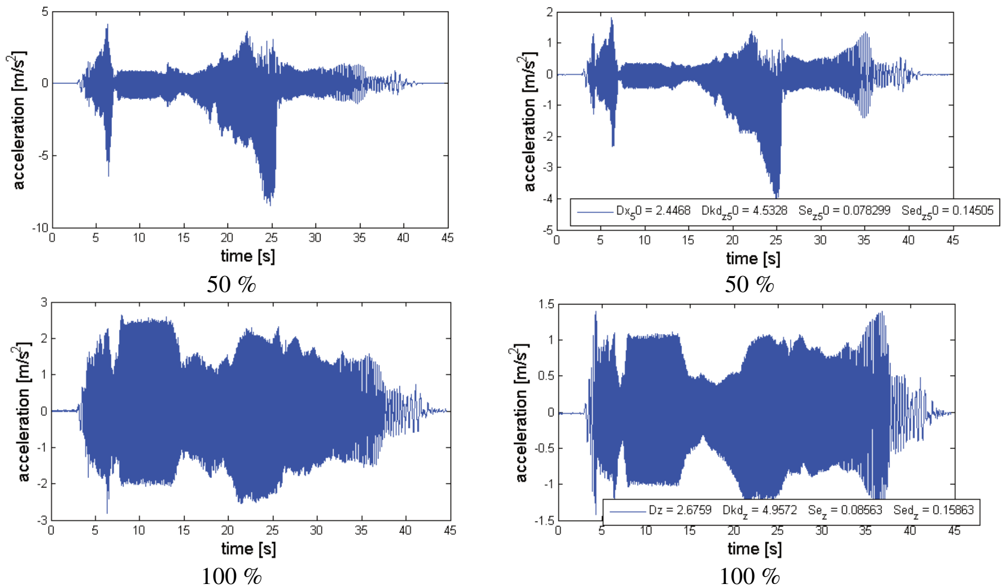
a) Vibration signal a) Response in the Spine

Fig. 16.8. a) Vibration of floor panel under driver's feet for 3 orthogonal axes and b) lumbar spine response for 1th gear, 1500 rpm



a) Vibration signal a) Response in the Spine

Fig. 16.9. a) Vibration of floor panel under driver's feet for 3 orthogonal axes and b) lumbar spine response for 5th gear

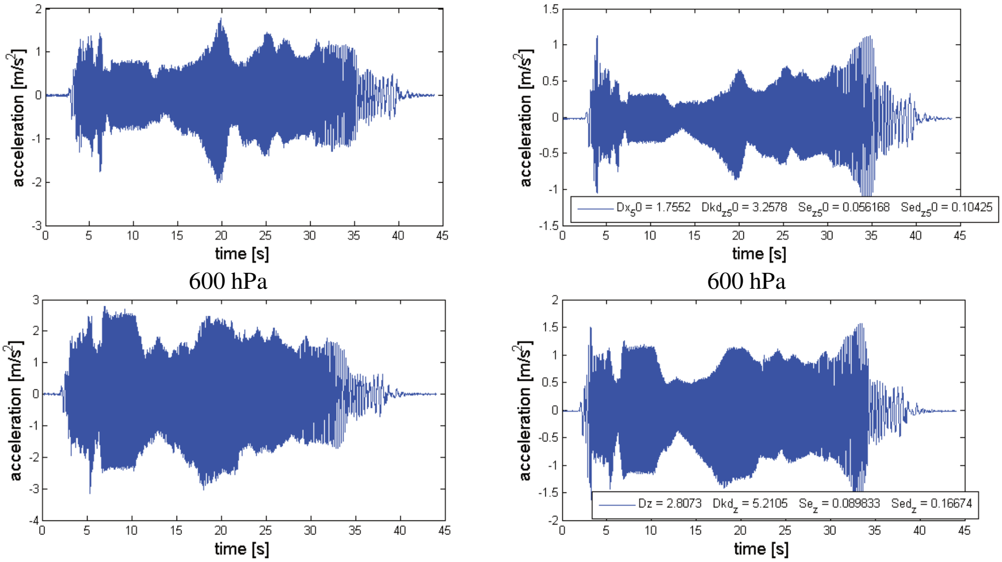


a) Vibration signal b) Response in the Spine

Fig. 16.10. a) Comparison of vibration of floor panel under driver's feet for *z*-axis and b) lumbar spine response for shock absorber with 50 % and 100 % volume of fluid

Basing on the result of research on influence of technical condition of shock absorber and pressure in tires on vibration propagation, described in previous chapters, the analitical experiment on lumbar spine response modeling for these parameters were performed. For the ground excitation simulated in the laboratory research by use the vibration shaker the forces are acting to the wheel in vertical direction. Thus the result of floor panel vibration under driver's feet and lumbar spine response for z-direction was calculated.

The example of results obtained for shock absorber with 50 % and 100 % volume of fluid or 600 hPa and 2600 hPa of tire pressure level are shown in Fig. 16.10-16.11.



600 hPa | 600 hPa

2600 hPa | 2600 hPa

a) Vibration signal | b) Response in the Spine

Fig. 16.11. a) Comparison of vibration of floor panel under driver's feet for z-axis and b) lumbar spine response for tire pressure 600 hPa and 2600 hPa

The values of vibration acceleration doses and equivalent static compressive stress for different operating parameters of vehicle were collected in Table 16.1.

Table 16.1. The values of vibration acceleration doses and equivalent static compressive stress for different operating parameters of vehicle

Vehicle parameter	Value / axis		D_k	D_{kd}	S_e	S_{ed}
Engine rotational speed	750 rpm	X	0.0192	0.0519	0.0460	0.1240
		Y	1.3134	3.5410		
		Z	0.4576	1.2337		
	3000 rpm	X	0.0084	0.0227	0.0406	0.1096
		Y	1.1613	3.1311		
		Z	0.0282	0.0760		
Gear no.	1th	X	0.0223	0.0600	0.0218	0.0589
		Y	0.6241	1.6827		
		Z	0.0145	0.0390		
	5th	X	0.0189	0.0509	0.0416	0.1123
		Y	1.1899	3.2081		
		Z	0.0968	0.2610		
Volume of shock absorber fluid	50 %	Z	2.4468	4.5328	0.0783	0.1450
	100 %	Z	2.6759	4.9572	0.0856	0.1586
Tire pressure level	600 hPa	Z	1.7552	3.2578	0.0562	0.1043
	2600 hPa	Z	2.8073	5.2105	0.0898	0.1667

The chapter presents experimental approach to exposure to WBV penetrated through floor panel via feet into human organism. The different methods for evaluation were compared for assessment influence of vehicle technical condition and power transmission system on human exposure to whole body vibration. For the purpose of comparison of total energy estimators it were collected results of the parameter value of vibration dominant effective weighted vibration acceleration A_{wmax} and daily exposure parameter $A(8)_l$. The exposure to vibration occurring for idle gear rotational speed is higher than for 1500 rpm and 2000 rpm. The increase of these estimators due to the idle gear were registered for the 3000 rpm and more. For the successive gear number and gear ratio the maximum exposure can be observed for 3rd and 4th gear. The comparison of estimators of exposure to WBV for vibration transferred through floor panel, dash panel and seat show the level of the exposition to the vibration for feet located on dash or floor panel and for the lumbar spine on the seat.

The attempts to use the acceleration dose and equivalent static compressive stress for the assessment of health effects of WBV transferred from floor panel according to methods from ISO 2631-5 has been successful. The vibration measurement requirements included in ISO 2631-1 are measure in 3 orthogonal directions on driver seat. The presented calculation was for measurement on floor panel, but it is still corresponded with WBV and adverse effects on the lumbar spine. According to ISO 2631-5 assessment of adverse health effect at lifetime exposure are acceptable where S_{ed} is below 0.5 and very danger when it is above 0.8. The results obtained, with notification that the results of shock absorber and tire pressure are only for the vertical vibration, shows huge impact of damping parameters and tire stiffness on of human exposure to vibration in passenger car. If the horizontal vibration (x, y axis) is counted the probability of an adverse health effect will be very high. The influence of engine rotational speed and gear ratio are also significant and above 0.8. The S_{ed} difference between 1st and 5th gear is twice higher.