17. The measures of dispersion of vibration energy of vehicle construction

Basing on an analysis of such a vast selection of study results, bearing in mind that the research purpose was to identify sources, propagation and structure of vibrations affecting men in means of transport based on the example of automotive vehicles, a decision was made to extend the studies with an analysis of the vibration energy dissipation across the vehicle structure. It will enable assessment of the damping properties of the vehicle structure and its equipment, and may prove to be a valid source of information to be applied while designing eliminators and dampers of vibrations propagating into the human organism.

When considering the vibration in human-structure relation system (i.e. building, platform, mean of transport) the identification of non-linear or active elements of human participation in structural vibrations has to be studied but the end result is usually seen in two forms: a moderate shift in structure natural frequency and a not so moderate increase in total damping capacity. Damping is energy dissipation and since the desirable end result of human participation is to help control vibration by energy dissipation it is natural to track energy flow in a vibrating human-structure system [32].

The state of art shows many approach to issue of dispersion of energy of vibration, especially in multi-body solid structure. One of the group of methods are based on the assumption that energy in the form of vibration in the structure behaves in the same way as energy in the form of heat. It diffuses from one substructure to another at a rate proportional to the difference in temperature of the substructures, and it is dissipated internally in each substructure at a rate proportional to the temperature of that substructure.

17.1. Methods of analysis of dispersion of vibration energy

Energy propagation and impact in mechanical systems are both closely linked with the phenomenon of energy dissipation and change to its emission forms. With regard to vibration related phenomena, the direct proportionality between the energy and the root mean square value of amplitude of the dynamic vibration course makes it possible to define global measures of propagation in the energy dimension [116]. The general vibration propagation form may be expressed in the following dependence:

$$H = \frac{\int_0^T (x(t))^2 \, dt}{\int_0^T (F(t))^2 \, dt}, \tag{17.1}$$

where: $x(t)$ – forced vibration, $F(t)$ – forcing vibration.

According to Parseval's theorem the result of the Fourier transform is unitary. Thus the integral of the square of a function is equal to the integral of the square of its transform. Therefore the propagation can be defined in the transform domain expression:

$$H_f = \frac{\int_{-\infty}^{\infty} |X(f)|^2 \, df}{\int_{-\infty}^{\infty} |F(f)|^2 \, df}, \tag{17.2}$$

where: $X(f)$ – power spectral density of forced vibration, $F(f)$ – power spectral density of forcing vibration.

The different approach is presented as statistical-energy analysis. When applied appropriately it gives a very simple means of predicting the distribution of mean-square vibration amplitudes among the substructures in response to a known pattern of external driving. A major theoretical problem of statistical-energy analysis is to investigate the approximations implicit in these two fundamental assumptions, and the extent to which they are justified in various practical situations. The assumption that the rate of internal dissipation of energy is proportional to the kinetic energy of the substructure is a familiar idealization [68, 203]. In Rayleigh's language, it amounts to assuming that the dissipation function is simultaneously diagonalizable with the kinetic and potential energy functions. Rayleigh shows that this assumption does not lead to serious problems provided the damping is small [132].

The vibration energy dissipation may also be perceived as a specific case of the entropy phenomenon. Entropy is a measure of the system disorder degree. Following the second law of thermodynamics, if a thermodynamic system spontaneously evolves from one state of equilibrium towards another, its entropy always increases. With reference to the signal theory, entropy is defined as follows:

$$E = -\sum_{i} x_i^2\,(t) \cdot \log\left(x_i^2(t)\right), \tag{17.3}$$

where: $x(t)$ – analyzed signal.

One of the energy entropy symptoms is dissipation which determines the energy form change into heat. This phenomenon clearly intensifies in systems or structures featuring friction forces and viscosity. As a result of the dissipation phenomenon, the oscillating motion energy declines and so vibration damping takes place. Consequently, the relative amount of thermal energy increases in the system and its entropy grows. An interesting engineering application of the said phenomenon can be observed in vibration damping systems based on magnetorheological fluids where, due to relative micro-motions, the oscillating motion power is dissipated through friction into heat [16-18].

17.2. The measures of dispersion of vibration energy of vehicle construction

The notion of vibration energy dissipation is inextricably linked with the wave propagation phenomenon, being most commonly described by means of wave propagation velocity derivatives [110, 113]. What matters more in terms of the vibration related phenomena and their impact on men is the energy-oriented approach. Having established a correlation between energy measures and dynamic properties of vibrations or their TFR distribution, dedicated measures of propagation and dissipation of vibrations in a vehicle structure from the perspective of their impact on the vehicle passengers can be developed.

Basing on satisfactory results of the efficiency assessment for the measures proposed in Section 13.4 with reference to the studies of propagation of vibrations and how they affect the suspension system operating and technical parameters as well as the engine and transmission operating parameters, specific measures of the vibration energy dissipation at structural points of a vehicle were proposed.

The measures developed enable observation and assessment of the energy and amplitude dissipation of vibrations in the domains of time, frequency and TFR. The dissipation measures are correlated with vibration signals of the vibration sources envisaged as input signals. The foregoing measures are defined as follows:

$$D_{RMS_i} = \frac{(X_{RMSsi} - X_{RMSdi})}{X_{RMSsi}}, \tag{17.4}$$

$$D_{S_{RMS}} = \frac{(S_{RMSs} - S_{RMSd})}{S_{RMSs}}, \tag{17.5}$$

where: D_{RMS_i} – RMS directional dispersion factor for i-direction, $D_{S_{RMS}}$ – total RMS dispersion factor, i – direction x, y or z, X_{RMSsi} – root mean square of source vibration signal for i-direction, X_{RMSdi} – root mean square of response vibration signal for i-direction, S_{RMSs} – total root mean square of source vibration signal, S_{RMSd} – total root mean square of response vibration signal.

$$D_{Tabs_i} = \frac{(T_{abs(FFT)si} - T_{abs(FFT)di})}{T_{abs(FFT)si}}, \tag{17.6}$$

$$D_{S_{Tabs}} = \frac{(S_{Tabs_s} - S_{Tabs_d})}{S_{Tabs_s}}, \tag{17.7}$$

where: D_{Tabs_i} – frequency directional dispersion factor for i-direction, $D_{S_{Tabs}}$ – total frequency dispersion factor, $T_{abs(FFT)si}$ – $T_{abs(FFT)}$ of source vibration signal for i-direction, $T_{abs(FFT)di}$ – $T_{abs(FFT)}$ of response vibration signal for i-direction, S_{Tabs_s} – total $T_{abs(FFT)}$ of source vibration signal, S_{Tabs_d} – total $T_{abs(FFT)}$ of response vibration signal.

$$D_{TabsTFR_i} = \frac{(T_{absTFRsi} - T_{absTFRdi})}{T_{absTFRsi}}, \tag{17.8}$$

$$D_{S_{TabsTFR}} = \frac{(S_{TabsTFR_s} - S_{TabsTFR_d})}{S_{TabsTFR_s}}, \tag{17.9}$$

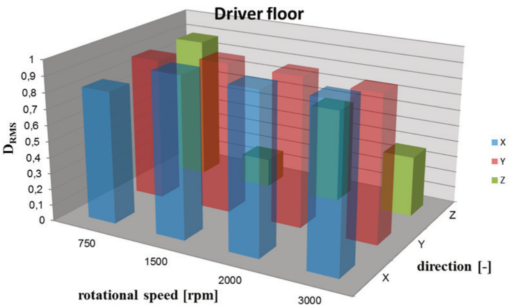
where: $D_{TabsTFR_i}$ – TFR directional dispersion factor for i-direction, $D_{S_{TabsTFR}}$ – total TFR dispersion factor, $T_{absTFRsi}$ – T_{absTFR} of source vibration signal for i-direction, $T_{absTFRdi}$ – T_{absTFR} of response vibration signal for i-direction, $S_{TabsTFR_s}$ – total T_{absTFR} of source vibration signal, $S_{TabsTFR_d}$ – total T_{absTFR} of response vibration signal.

The methodology of determining partial measures for the calculation of the vibration energy dissipation coefficients was already described in detail in Chapter 13.

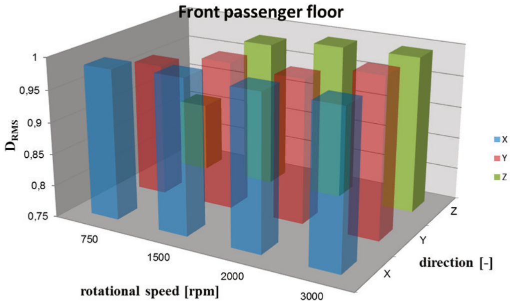
17.3. Dispersion of floor panel vibration generated by the engine and power transmission system

In order to verify the efficiency of the measures proposed for the vibration dissipation in a vehicle structure, analytical experiments were conducted, comprising assessment of the susceptibility of the said measures to changes of the input function parameters. The source of vibrations was assumed to be the engine and the transmission. The studies included two experiments. In the course of the first one, the engine rotational speed was changed when running idle. In the second one, on fixed rotational speed, the gear ratio was changed by engaging successive gears. Time courses, spectra and TFR distributions of the vibration signals envisaged for the experiments were discussed in Chapters 13 and 14.

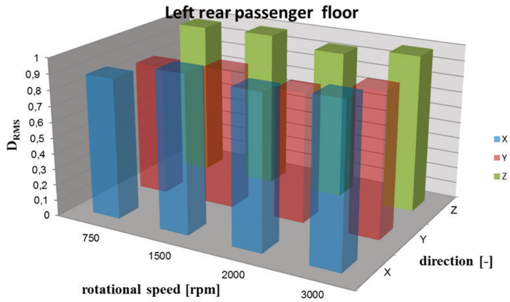
The results obtained in the course of the first experiment for the vibrations recorded on the vehicle floor panel were compared and collated in the bar graphs provided in the Figs. 17.1-17.4.



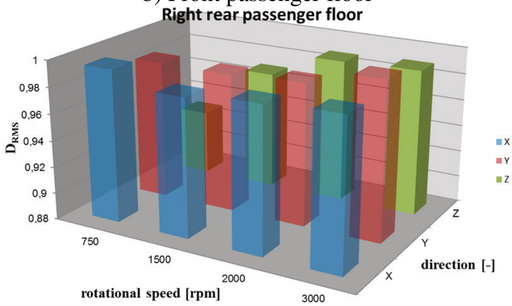
a) Driver floor



b) Front passenger floor

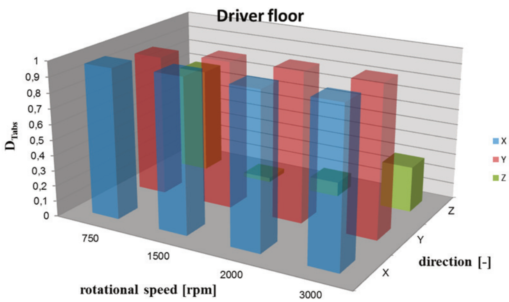


c) Left rear passenger floor

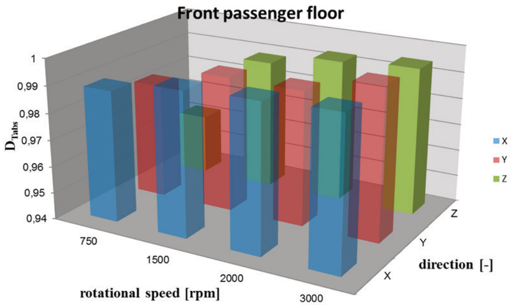


d) Right rear passenger floor

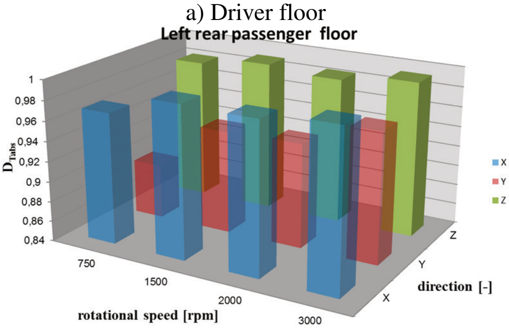
Fig. 17.1. Comparison of RMS directional dispersion factor of floor panel vibration for different engine rotational speed



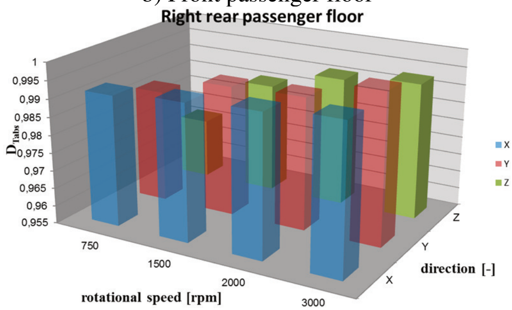
a) Driver floor



b) Front passenger floor



c) Left rear passenger floor



d) Right rear passenger floor

Fig. 17.2. Comparison of frequency directional dispersion factor of floor panel vibration for different engine rotational speed

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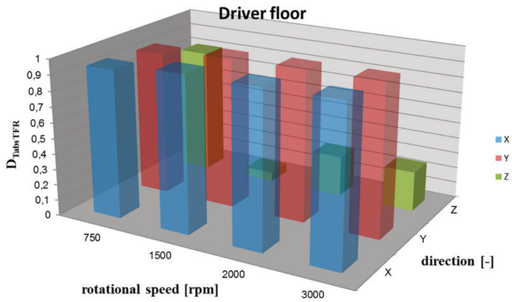
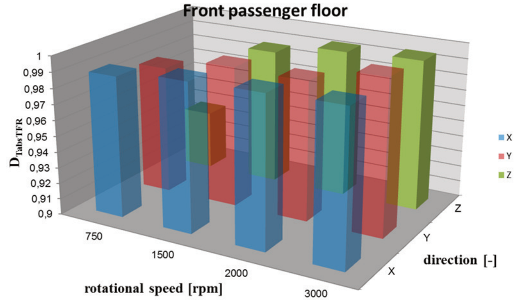
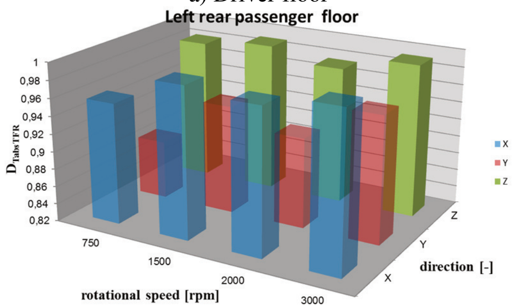


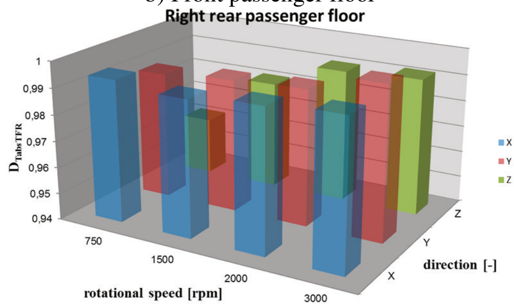
a) Driver floor



b) Front passenger floor

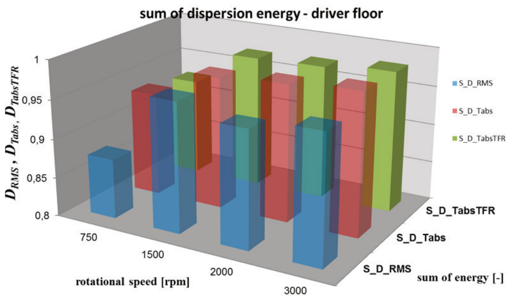


c) Left rear passenger floor

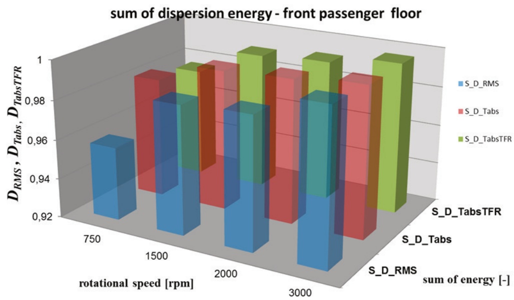


d) Right rear passenger floor

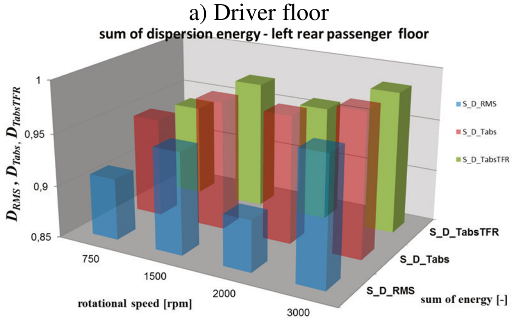
Fig. 17.3. Comparison of TFR directional dispersion factor of floor panel vibration for different engine rotational speed



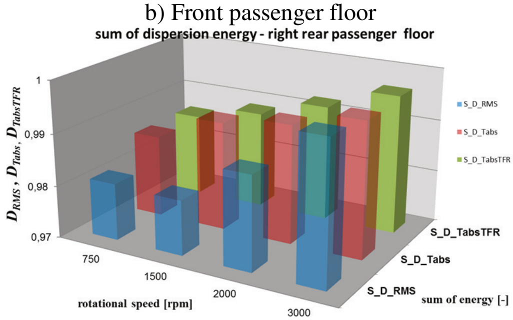
a) Driver floor



b) Front passenger floor



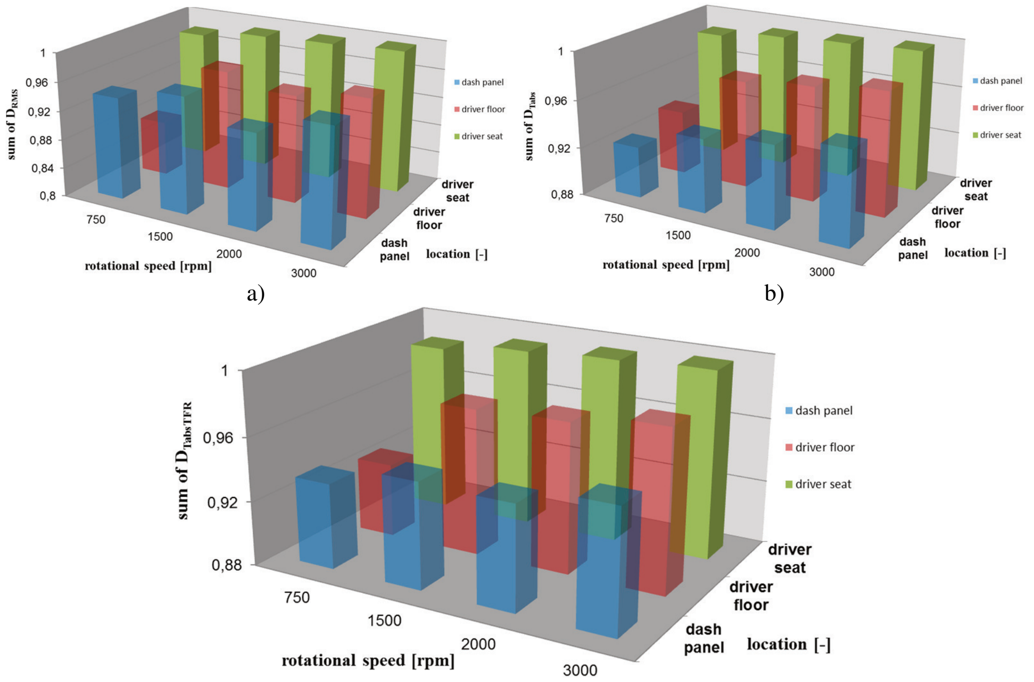
c) Left rear passenger floor



d) Right rear passenger floor

Fig. 17.4. Comparison of total energy directional dispersion factors of floor panel vibration for different engine rotational speed

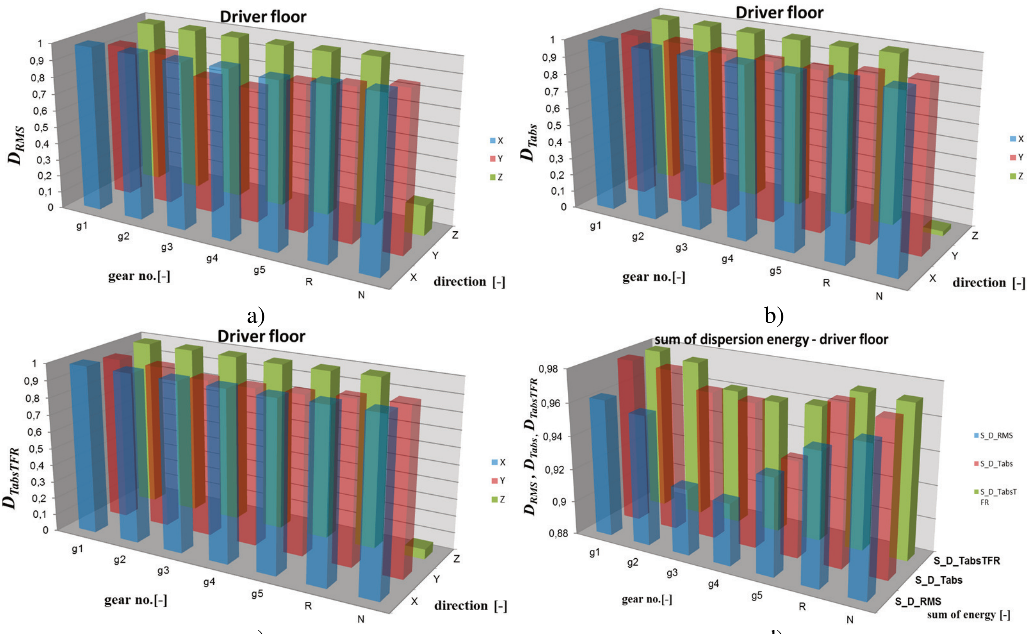
For the purpose of analysis the vibration dispersion factors at the path of propagation into human body via dash panel, floor panel and seat the comparison was collected in Fig. 17.5.



a) b) c)

Fig. 17.5. Comparison of total vibration dispersion factors at the path of propagation into human organism for different engine rotational speed

The results of second investigation on influence of gear ratio on dispersion of vibration on floor panel under the driver's feet are shown in Figs. 17.6 and 17.7.



a) b) c) d)

Fig. 17.6. Comparison of directional and total vibration dispersion factors of floor panel under the driver's feet for different gear ratio (gear no.)

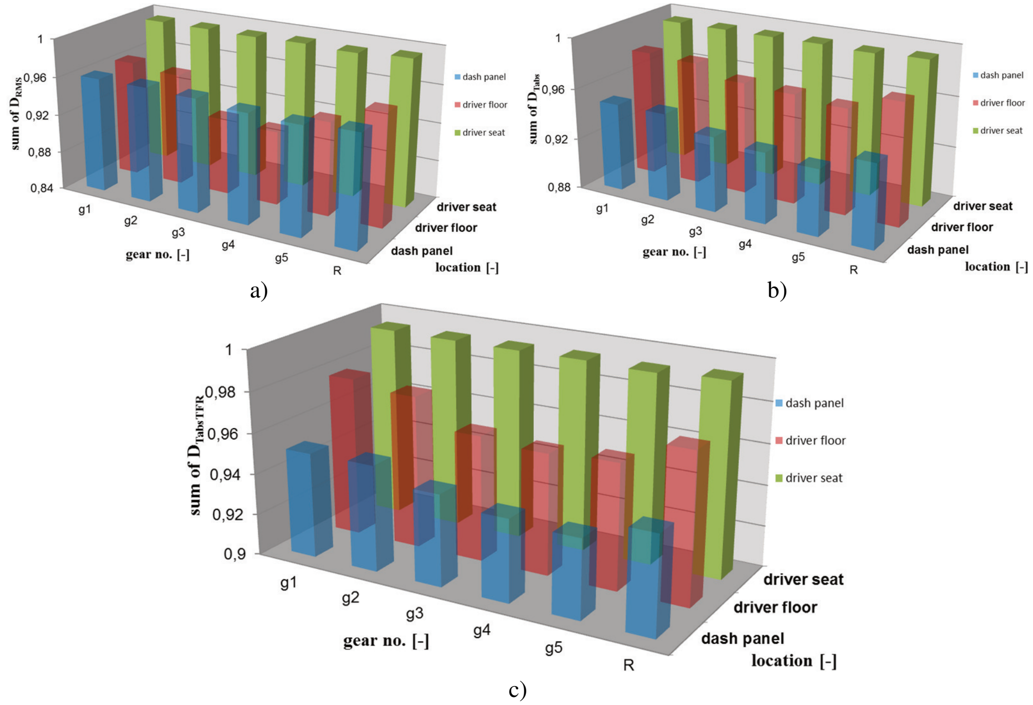


Fig. 17.7. Comparison of total vibration dispersion factors at the path of propagation into human organism for different gear ratio (gear no.)

The measures of vibration dissipation in automotive vehicles were defined and verified. They enable the vibration propagation and damping to be analysed and assessed by application of simple energy measures in the domains of time and frequency. The measures envisaged can also be used in experimental studies, which were confirmed by the results of validation experiments. Directional distributions of the coefficients mentioned make it possible to determine the vibration damping characteristics and the directional propagation, whereas by comparing the values obtained at the selected structural points in the propagation path, the dynamics of vibration damping or suppression as well as determine the most exposed locations can be assessed.

All the vibration energy dissipation coefficients proposed may assume the maximum value of 1, which implies that the entire vibration energy generated by the source dissipate, and that the vibration is completely suppressed at the given measurement point. Low values imply some small dissipation, whereas negative values prove that the vibration energy measured at the given point is larger than the one generated by the source. In this kind of case the vibration can be reinforced or interfered by other sources.