RESEARCH OF VIBRATION DISTRIBUTION IN VEHICLE CONSTRUCTIVE

Rafał Burdzik[1], Radovan Doleček[2]

Summary: The article provides a discussion on the studies comprising active experiments conducted on selected structural elements of vehicles, the purpose of which was to analyze the vibration propagation in vehicles construction. The vibration excitation was achieved by applying an engine working on idle gear. The studies were conducted on vibration propagation for different constant rotational velocity. The changes of the signals were observed in time, frequency and simultaneously in time-frequency domains.

Key words: vibration propagation in vehicle, engine vibration, vibration excitation, vibroacoustics.

INTRODUCTION

The vehicle vibration is an unwanted effect. It causes many difficulties i.e. increases in fuel consumption, damages to elements of vehicles and causes vibration of roadside buildings. It is also one of the sources of noise disturbance for people. For driving safety and comfort it is very important what kind and values of vibration transfers from road to car body (1, 2, 3). Large capacity of the information in vibration signals allows creating many research methods and results analysis. Vibroacoustics is the science discipline describes the possibilities of vibration and acoustics signals useful for diagnosing and research purpose. There are a lot of publications showing original methods of vibration signal analysis for many applications (4,5,6,13,14). The main phenomenon useful in vibration research is resonant effect. Resonance vibration amplifies the vibration response more than the level of deflection, stress, and strain caused by static loading. Resonances are determined by the material properties, such as: mass, stiffness, damping properties, boundary conditions of the structure.

In manufacturing of structural components, the type of material used as well as the technology and geometric form are decisive for their service parameters. Considerable emphasis is put on their dynamic properties in designing of machine parts. Tests of dynamic parameters are conducted by application of simulation methods or by active experiments. In this respect, one should stress that a computational model needs an identification procedure which enables its parameters to be adjusted. A model-based description of real components is always a simplification to a certain extent, as it results from factors like the scope of research

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assumed. Therefore, studies of real objects constitute an unparalleled source of knowledge on the vibration.

It is very important to realize that for the driver and passengers exposure to whole-body vibration of the vehicle can affect from short-term body discomfort and inefficient performance to long term physiological damage.

1. ENGINE AS THE VIBRATION GENERATOR

The vibrations of the vehicle body are main problem in ride comfort. Road surface roughness often acts as a major source that excites the vibration of the vehicle running on the ground through the tire/wheel assembly and the suspension system (7, 8). There are many of different vibration sources in vehicles as well. One of those is motor engine.

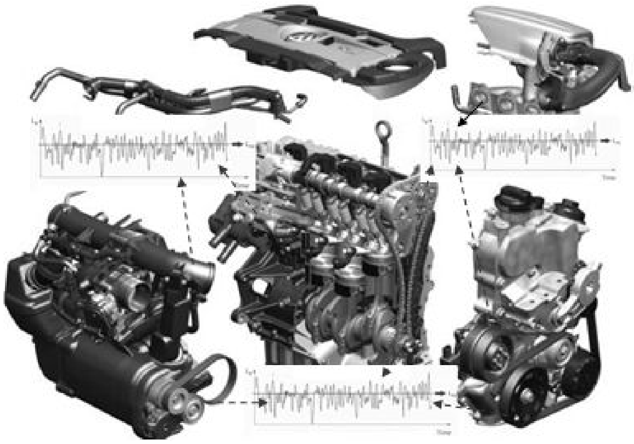

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Fig. 1 – Motor engine as the vibration generator

Before attempting to reduce the vibration levels in a machines or structure of the vehicles by increasing its damping, every effort should be made to reduce the vibration excitation at its source. Motor engine should be considered as one of the vibration generators. Rotating machinery such as motors can generate disturbing forces at several different frequencies such as the rotating velocity and blade passing frequency. Reciprocating machinery such as compressors and engines can rarely be perfectly balanced, and an exciting force is produced at the rotating velocity and at harmonics. There are two basic types of structural vibration: steady-state vibration caused by continually running machines such as engines, air-conditioning plants and generators either within the structure or situated in a neighboring structure, and transient vibration caused by a short-duration disturbance such as a lorry or train passing over an expansion joint in a road or over a bridge.

Consider the vibroacoustic analysis of an internal combustion engine one should take into account the fact, that a high level of nominal vibrations is generated, resulting from the target function realization. Internal combustion engine is an object under the influence of internal and external inputs. Among them there are mainly: burning pressure, the movement of the piston-crank mechanism, inputs from the timing gear system, inputs resulting from the work of the fittings of the engine, inputs transmitted from the motor-car body and the drive transmission system. One of the most important inputs during the work of the piston-crank mechanism are the impacts of the piston by the change of its work direction (9). The level and dynamics of vibration generated by motor-car engine in 3 axis for different rotational velocity have been measured (750 rpm, 1500 rpm, 2000 rpm, 3000 rpm). Some exemplary results have been depicted in Fig. 2.

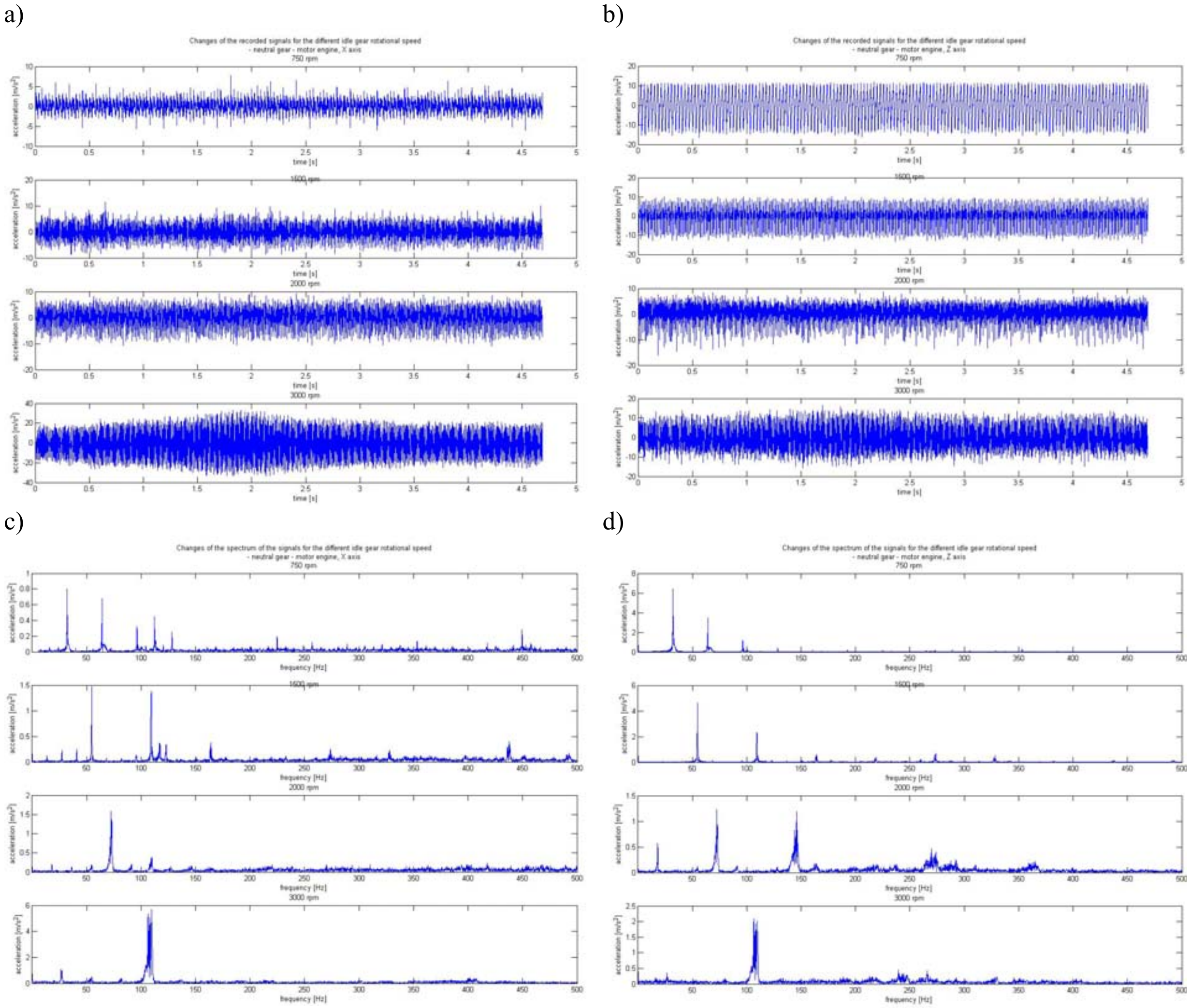

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Fig. 2 – Vibration signals generated by motor-car engine (measurements in X and Z axis), graphs: a), b) X axis – time , Y axis – acceleration ; c), d) X axis – frequency , Y axis – acceleration

2. RESEARCH METHODOLOGY

The studies were structural components of vehicles construction build in suspension and car body. Under the studies in question, active experiments were undertaken featuring measurements of vibration accelerations in a three directions in four selected points the positions of which have been depicted in Fig. 3. It were recorded the vibration in three orthogonal axes (X,Y,Z). The paper presents some results of measurements vibration of motor engine, floor of the car under the driver foots and driver seat. It enables to analyze the way of vibration transfer from the source to driver. Ride vibrations are transmitted to the driver buttocks and back by the seat. The floor panel, pedal and steering wheel transmit additional vibrations to the feet and hands of the driver. These vibrations are producing a level of discomfort for driver.

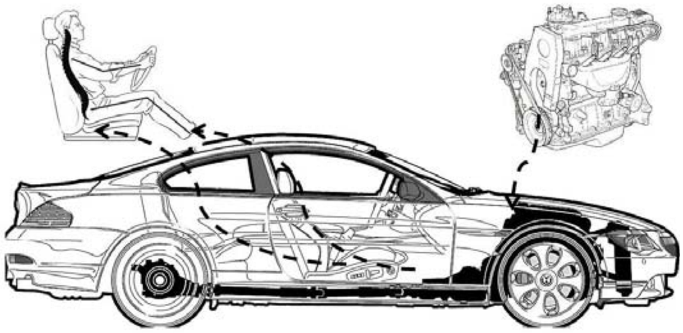

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Fig. 3 – The measurement point position and the vibration propagation from engine to human

Vibration signals x(t), being an effect of a force excitation, obtained by working process of engine, were recorded. The vibrations in the vehicle structure were excited by engine working on idle gear. It enables to consider only the vibration generated by vehicle mechanism without vibration from road roughness during the drive. The experiment was conduct under laboratory conditions to ensure reproducibility of results.

In the studies discussed, a standard measurement track comprising a transducer, an A/C card and a PC was used (Fig. 4).

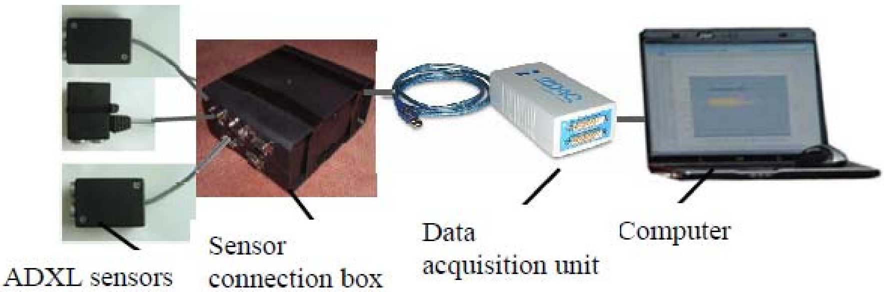

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Fig. 4 – The measurement and the data acquisition system

The results obtained were subsequently processed in the MatLab computational environment. Consequently, specific sets of the time courses recorded for the vibration accelerations were established. Some exemplary measurement result obtained for the engine with constant rotational velocity excitation applied has been depicted in Fig. 5. The established scope of research enables to observe changes of the vibration for idle gear rotational velocity increase. The idle gear rotational velocity founded during research were: 750 rpm, 1500 rpm, 2000 rpm, 3000 rpm.

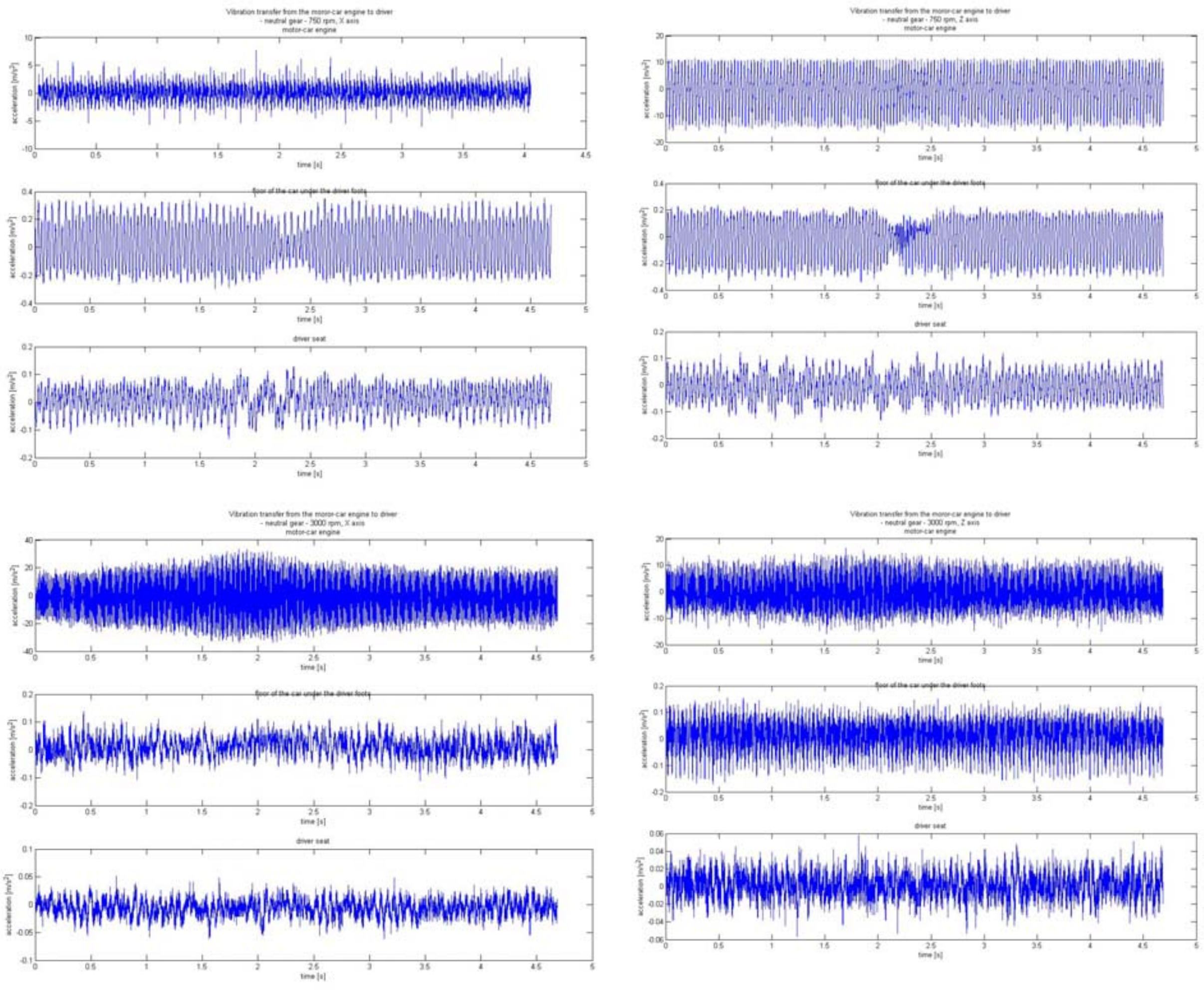

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Fig. 5 – Examples of recorded signals for 750 rpm and 3000 rpm idle gear rotational velocity (measurements in X and Z axis), graphs: X axis – time , Y axis – acceleration

The three orthogonal axes were analysed separately. The comparison of the acceleration of vibration signals allows determine which directions of the vibration propagation is parent. The proposed methodology allows estimate influence of structure and elements on vehicle reduction level of vibration.

3. ANALYTICAL METHODS AND RESULTS

The time courses recorded provided information on the phenomenon in question, however, in order to extract it, application of the appropriate mathematical method proved necessary. The results obtained belong to a group of non-stationary signals the analysis of which forces one to apply time-frequency methods. Simultaneous extraction of information concerning the time-frequency structure of a signal being analysed is possible owing to a Short Time Fourier Transform (STFT). Because of its simplicity mathematical and physical interpretation it is very common used tool. The main weakness of STFT is constant time-frequency resolution which effect on analysis precision for different object dynamics. So it is necessary to seek a trade-off between the window width and the time or frequency resolution in specific applications.

The results of the STFT analysis are the coefficients described by the dependence:

$$S(\omega,b) = \int_{-\infty}^{+\infty} x(t) \cdot w_{\omega,b}(t)dt = \int_{-\infty}^{+\infty} x(t) \cdot g(t-b)e^{-i\omega t}dt \qquad (1)$$

where: ω – analysing frequency, b – window shift, $g(t - b)=const$ – constant width of the subsequently analysed window (rectangular).

For analyse the rectangular window was chosen and to improve the frequency resolution, in a single FFT analysis, a method of completing with zeros was applied.

The vibration signal processing results obtained by application of the STFT for chosen measurement points and different rotational velocity examined have been depicted in Fig. 6.

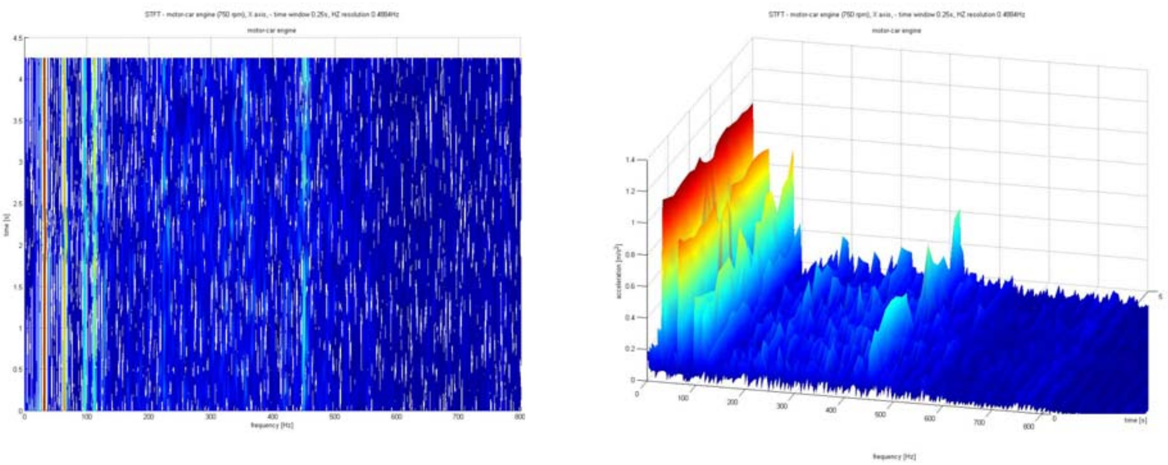

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Fig. 6 – Distributions of STFT obtained for measurement point (motor-car engine), graphs: X axis – frequency , Y axis – time , Z axis – acceleration

The results obtained enable identification of the signal frequency constituents related to the changes of rotational velocity and structural resonances of construction elements of vehicles.

The results of the presented signal processing are spectrums of the signals and a matrix of STFT transformation. It enables qualitative interpretation of vibration propagation in vehicles construction. The qualitative impact assessment was made and presented in (5,10). Some of the results of time-frequency distribution of propagating vibration have been depicted in Fig. 7-10.

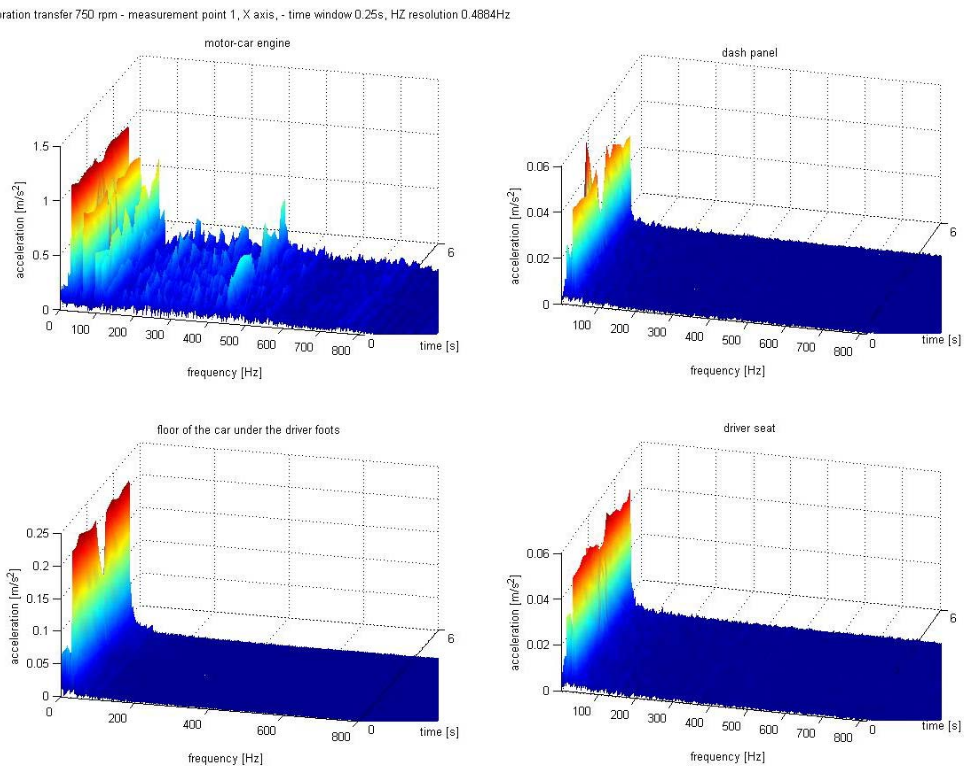

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Fig. 7 – STFT transformations of propagating vibration, from motor-car engine by dash and floor panel to seat (750 rpm, X axis),
graphs: X axis – frequency , Y axis – time , Z axis – acceleration

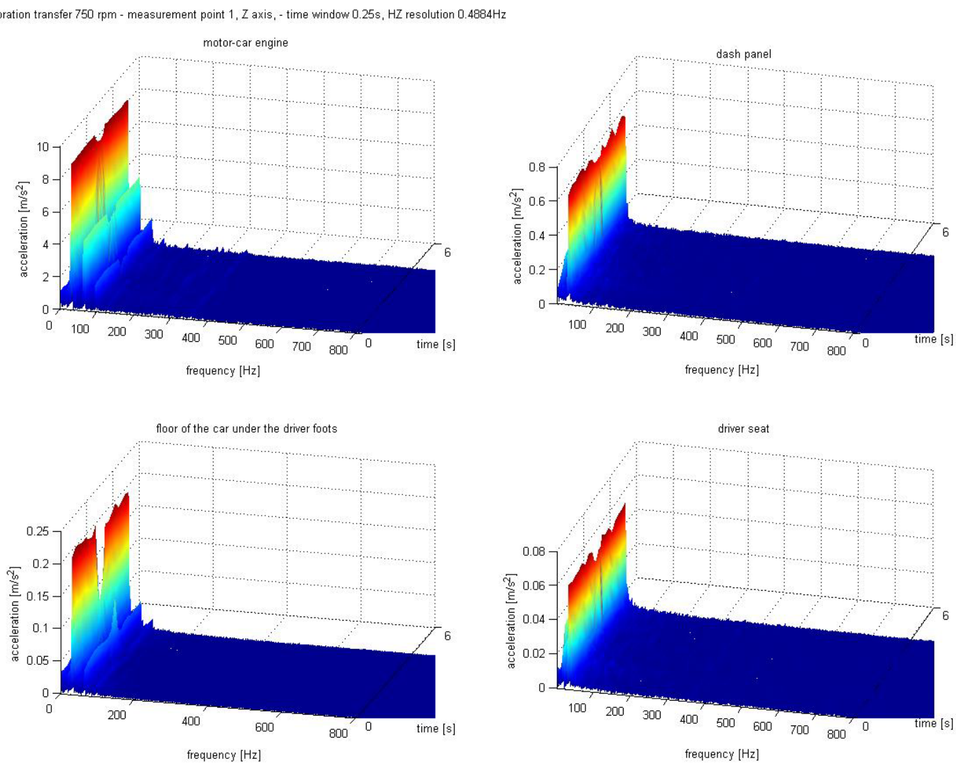

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Fig. 8 – STFT transformations of propagating vibration, from motor-car engine by dash and floor panel to seat (750 rpm, Z axis),
graphs: X axis – frequency , Y axis – time , Z axis – acceleration

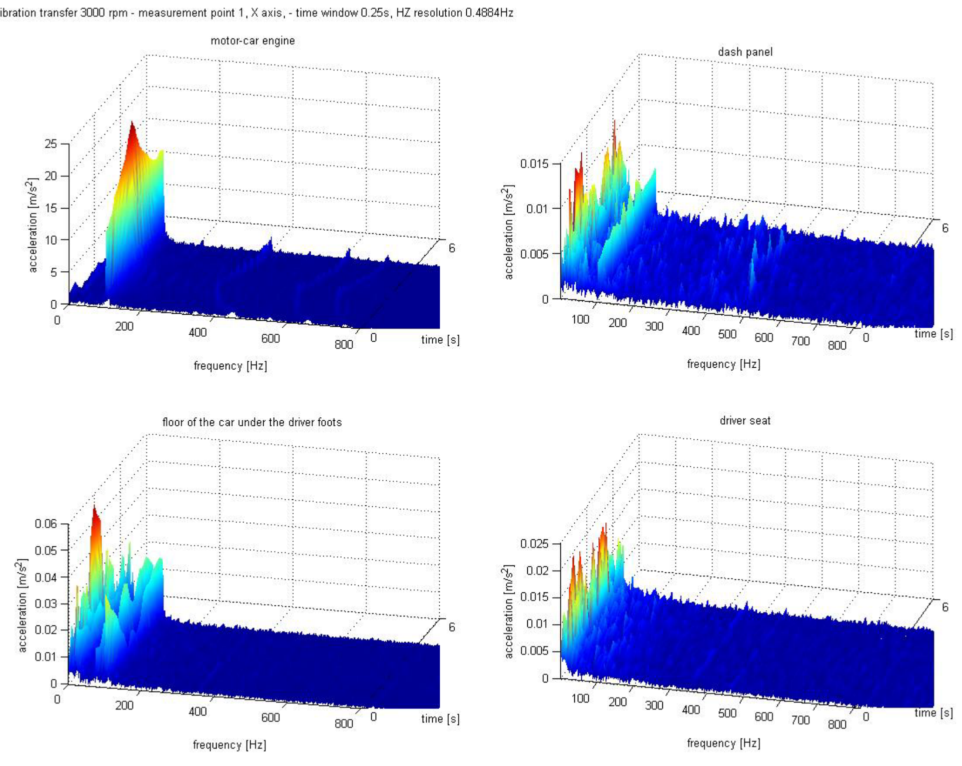

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Fig. 9 – STFT transformations of propagating vibration, from motor-car engine by dash and floor panel to seat (3000 rpm, X axis), graphs: X axis – frequency , Y axis – time , Z axis – acceleration

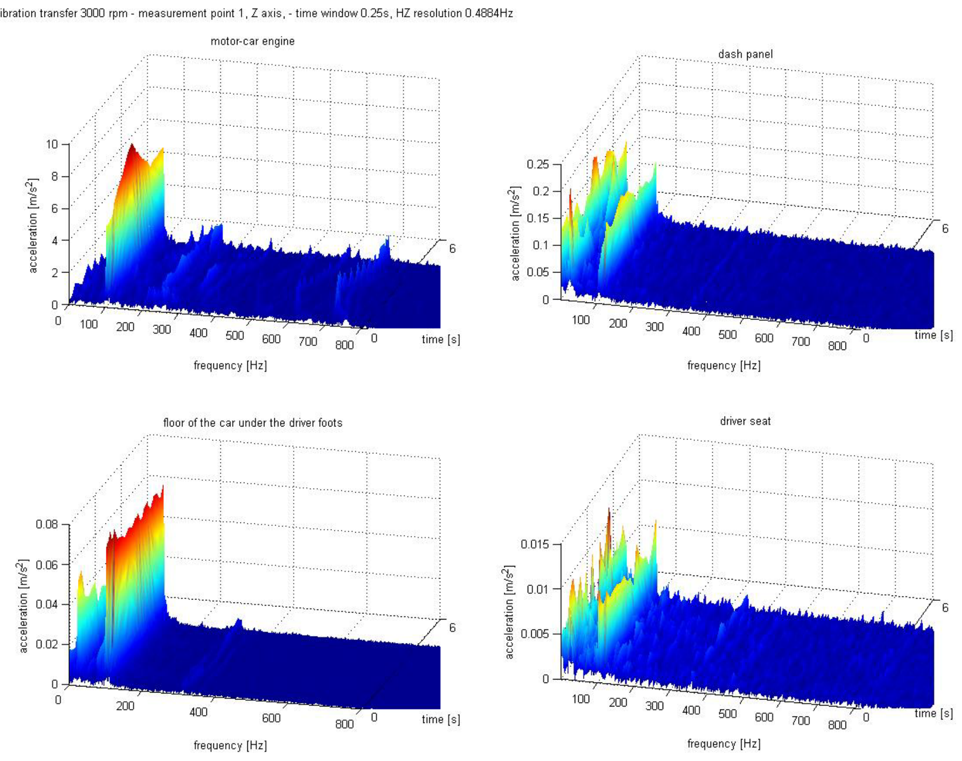

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Fig. 10 – STFT transformations of propagating vibration, from motor-car engine by dash and floor panel to seat (3000 rpm, Z axis), graphs: X axis – frequency , Y axis – time , Z axis – acceleration

CONCLUSION

The results confirm that vibroacoustic methods allow monitoring dynamic parameters of the vehicle. Those methods are very useful for precise observation of the signal realization in time and frequencies domain. Obtained results enabled to analyse of the vibration propagation to car body for different idle gear rotational velocity. Significant levels of the vibration were recorded for the X and Z axes. The vibrations transferred to seat have significant less value. It can be observed that for higher rotational velocity there is more high frequencies vibration but very low values. This proves good vibration isolation in vehicle cab. Based on the results it can be said only for vibration propagation from motor-car engine for now but there are researches continuously conduct on the vehicle vibration. The assembly and structure of car-body are very important in reduction of vibration transferred to driver or passengers. Of course the materials used in vehicles construction are very important as well. Modern technologies applied in manufacture of metallurgical products ensure high material parameters, however, one must never exclude the possibility of a negative impact of the inclusions from scrap processing (11) or changes in the material properties occurring in the course of manufacture or resulting from repair works such as welding (12). It can affect safety and comfort of ride.

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