# ADVANCED SIGNAL PROCESSING METHODS FOR RESEARCH ON VIBRATION PROPAGATION IN VEHICLE CONSTRUCTION

Rafał Burdzik[1], Radovan Doleček[2]

*Summary: The article provides a discussion on the studies on advanced signal processing methods for research on vibration propagation in vehicle construction. One of the major purpose of vehicle vibration research is evaluation of the human vibration perception in transport. For this purpose it is necessary to analyse the structure of vibration signals in chosen elements of suspension and car body. The scope of the research allows analysis of quantity of vibration isolation by suspension system and distribution of the vibration penetrates into human body by the feet. The presented algorithm of the signal distribution by the stationary and nonstationary conditions allows proper analysis of the signals separately as the stationar and nonstationar signal.*

*Key words: vibration propagation in vehicle, signal processing, human vibration perception.*

## INTRODUCTION

Constant development in automotive industries is directed in numerous engineering directions. Designers and engineers working on alternative engine, combustion, electrical, hybrid or light constructions and increase of passive and active safety (1,2,3-8). There are a lot of efforts put in environmental issues. It is very common to consider the environmental safety only as the combustion emission. The noise and vibration generated by the means of transport are significant important as well. Traffic noise monitoring is regulated by special national law document. For the vibration generated by the means of transport there is a lot of efforts should be make (9-14). Human vibration perception in transport is strongly correlated with comfort and safety (15,16). The paper presents some investigation on propagation of vibration in passenger car construction of suspension and car body.

## 1. RESEARCH METHODOLOGY

The purpose of the research was to analyse the structure of vibration signals in chosen elements of suspension and car body of the passenger car. For the research object the Fiat Panda was chosen, as one of the popular passenger car in UE. The goal of the research was focused on human vibration perception in vehicle. The human perception and vibration sensitivity of organs has been depicted in Fig. 1.

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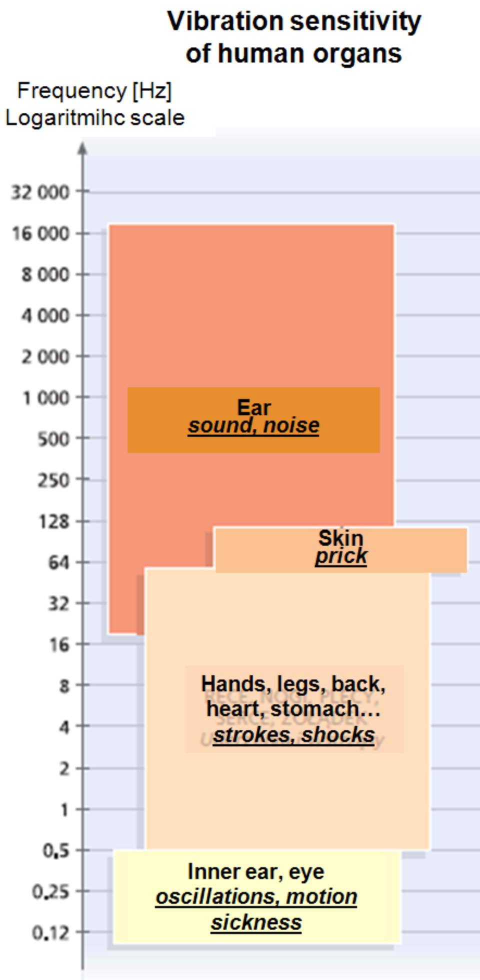


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Fig. 1 – Vibration sensitivity of chosen human organs

The consequences of the impact of vibration on humans are all kinds of adverse effects in the body, resulting from exposure to vibration. Range and process behavior of these changes depends largely on where they penetrate into the body. It is calculated for a car moving at a speed of most popular about 80 km / h, secondary roads, assuming an average wavelength of existing roads, the most energy of the vibration signal is contained in the band up to 20-30 Hz (13).

The active research experiments were conducted on real passenger car. The vehicle was excited to vibration by special kinematic excitation machine. The range of the frequency of the forced was set as dynamic linear increase up to ca. 21 Hz, excitation with constant frequency (ca. 21 Hz) for 5 seconds and excitation frequency decrease down to 0 Hz for 30 second period. This set up allows analysis bands of sprung and unsprung masses resonances.

The scope of the research allows analysis of quantity of vibration isolation by suspension system and distribution of the vibration penetrates into human body by the feet. The research method and measurement points localization has been depicted in Fig. 2.

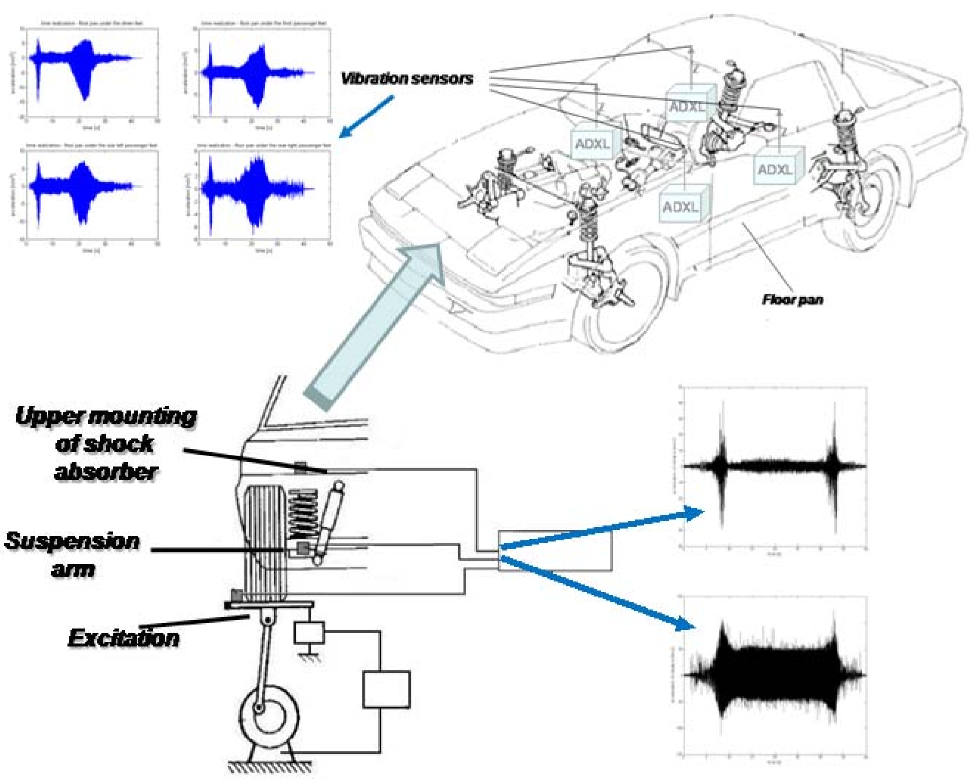


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Fig. 2 – The research method and measurement points

The real object during research has been depicted in Fig. 3.


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Fig. 3 – The object of the research and example of position of vibration sensor

## 2. ANALYTICAL METHODS AND RESULTS

Analysis of the vibration propagation and influence on human body is difficult. It is important to observe the changes of the values and dynamics of the signal. The obtained results are signals with splot of stationary and nonstationary vibrations in Fig. 4 and Fig. 5.

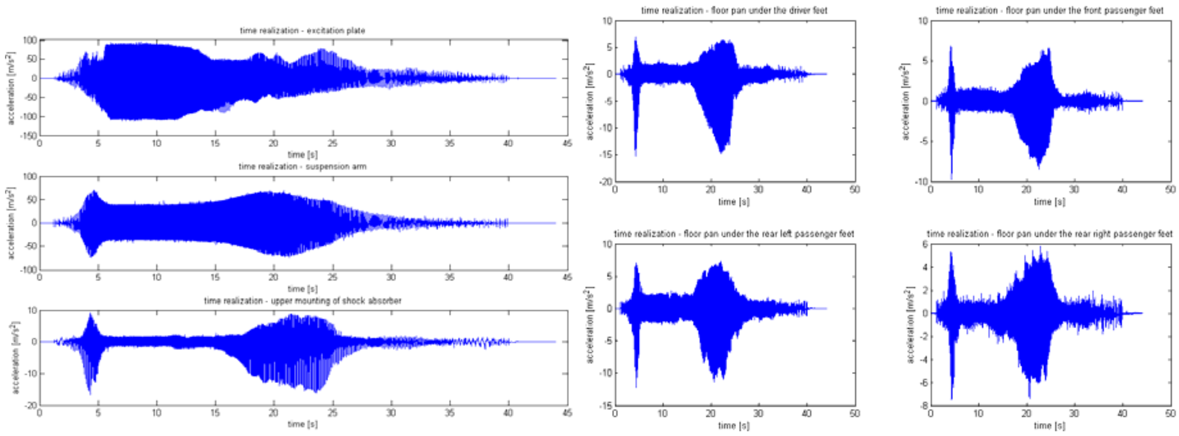

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Fig. 4 – Recorded signals (excitation plate, suspension arm, upper mounting of shock absorber, floor pan: under driver feet, front passenger, rear left, rear right) graphs: X axis – time, Y axis – acceleration

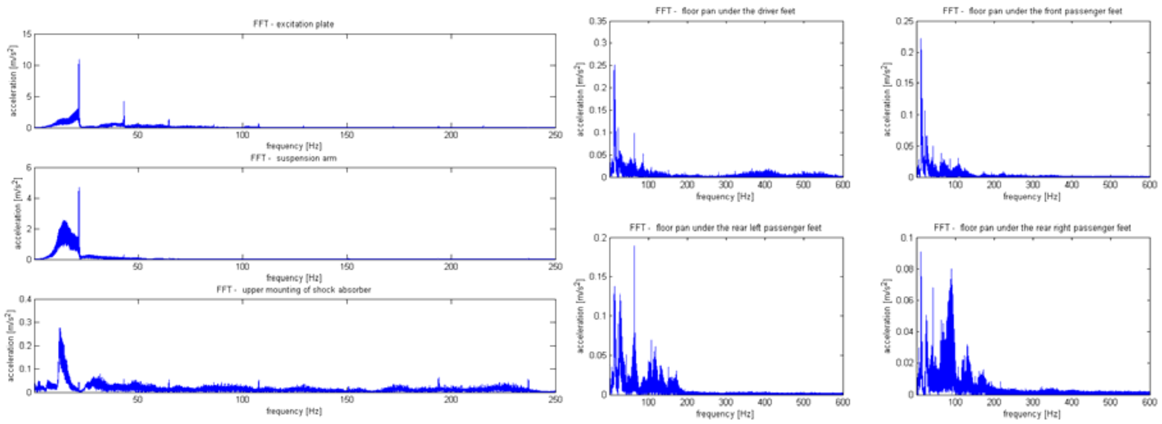

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Fig. 5 – Spectrum of the recorded signals – FFT (excitation plate, suspension arm, upper mounting of shock absorber, floor pan: under driver feet, front passenger, rear left, rear right) graphs: X axis – frequency, Y axis – acceleration

It is well noticeable the resonances as the local increase of the amplitude of vibration, both in time and frequency domains. The quantity of vibration isolation by suspension system was presents as comparison of FFT spectrums between suspension arm (blue line) and upper mounting of shock absorber (green line) registered signals. It can be calculated than energy of the vibration in unsprung masses resonance band (ca. 12-15 Hz) is more than 10 times less in upper mounting than in suspension arm signal. The results have been depicted in Fig. 6.

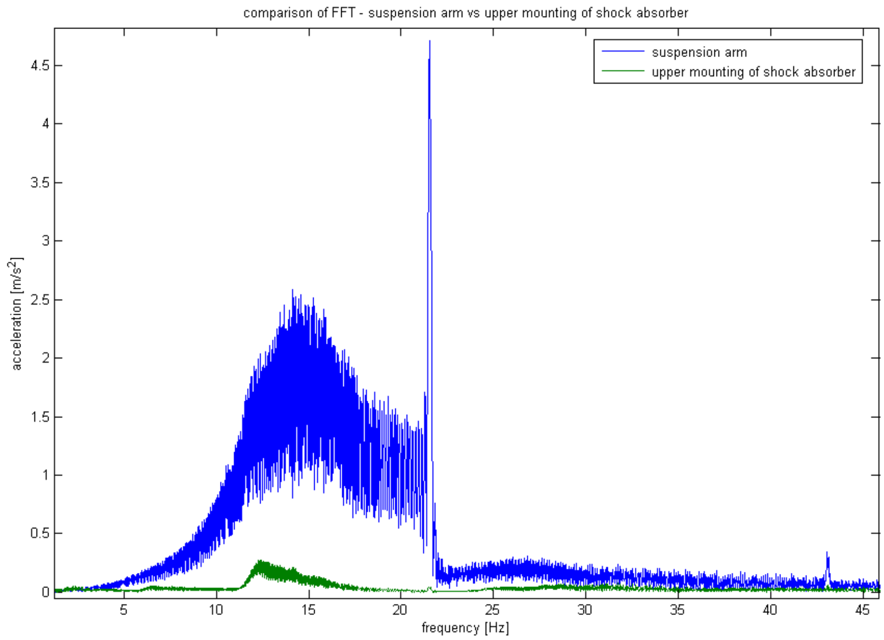


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Fig. 6 – Vibration isolation by suspension system,
graphs: X axis – frequency, Y axis – acceleration

The analysis of the dynamics of the vibration penetrate into the human body by the floor pan has been depicted in Fig. 7, as comparison of the spectrum of the vibration registered on floor pan.

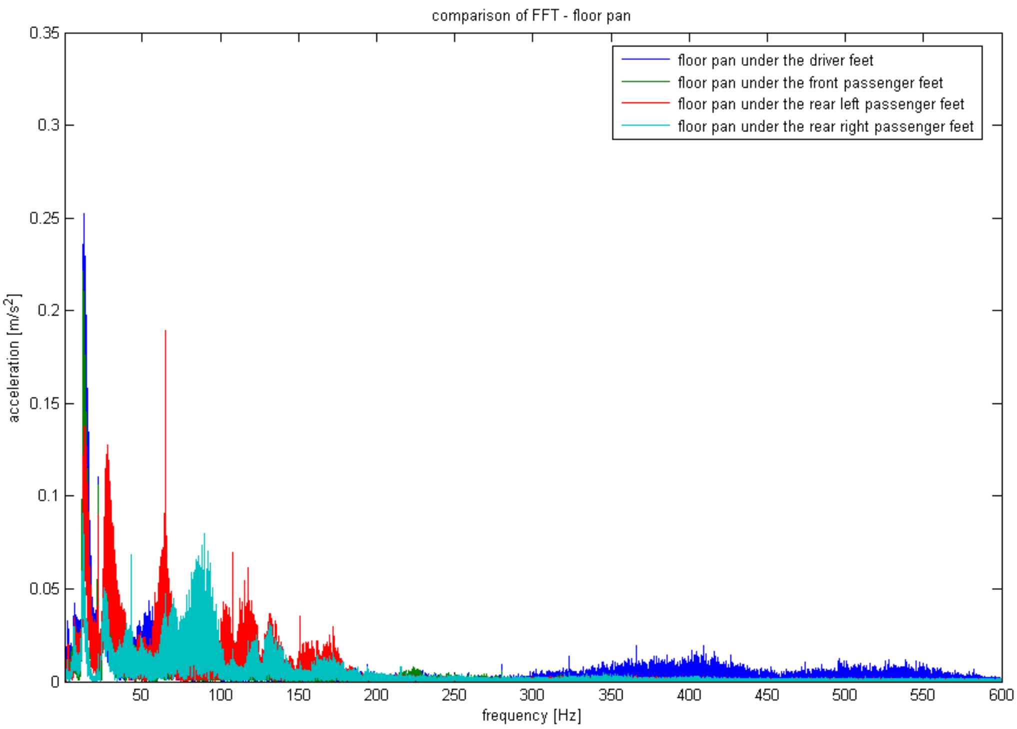


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Fig. 7 – Dynamics of the vibration penetrate into the human body by the floor pan (under driver feet - blue, front passenger - green, rear left - red, rear right - azure),
graphs: X axis – frequency, Y axis – acceleration

The analysis of the dominant frequency bands has been depicted in Fig. 8.

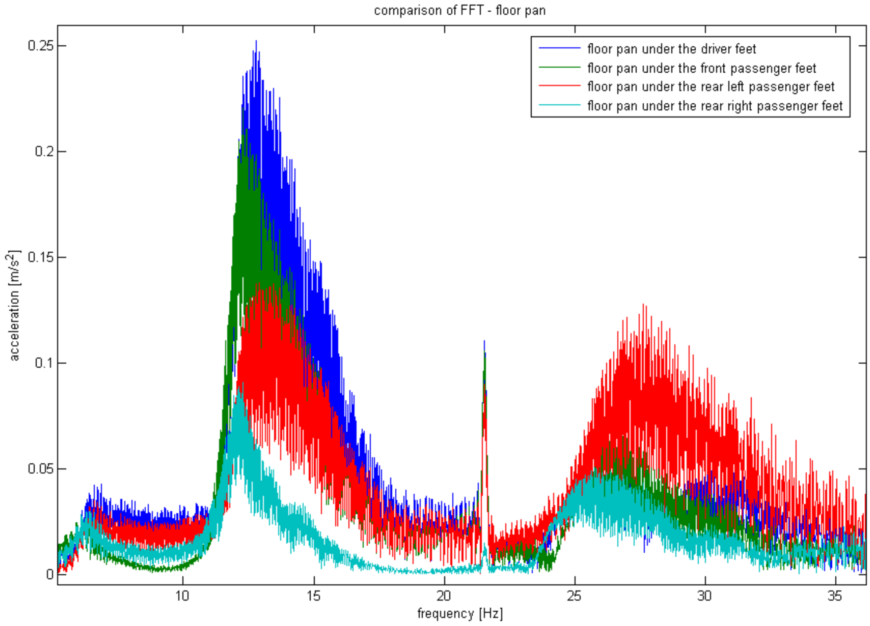


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Fig. 8 – Dominant frequency bands of the floor pan vibrations (under driver feet - blue, front passenger - green, rear left - red, rear right - azure), graphs: X axis – frequency , Y axis – acceleration

For the proper analysis the distribution of the signal has to be made. The author has been developed the algorithm of the signal distribution by the stationary and nonstationary conditions. The divided signals have been depicted in Fig. 9 and Fig. 10.

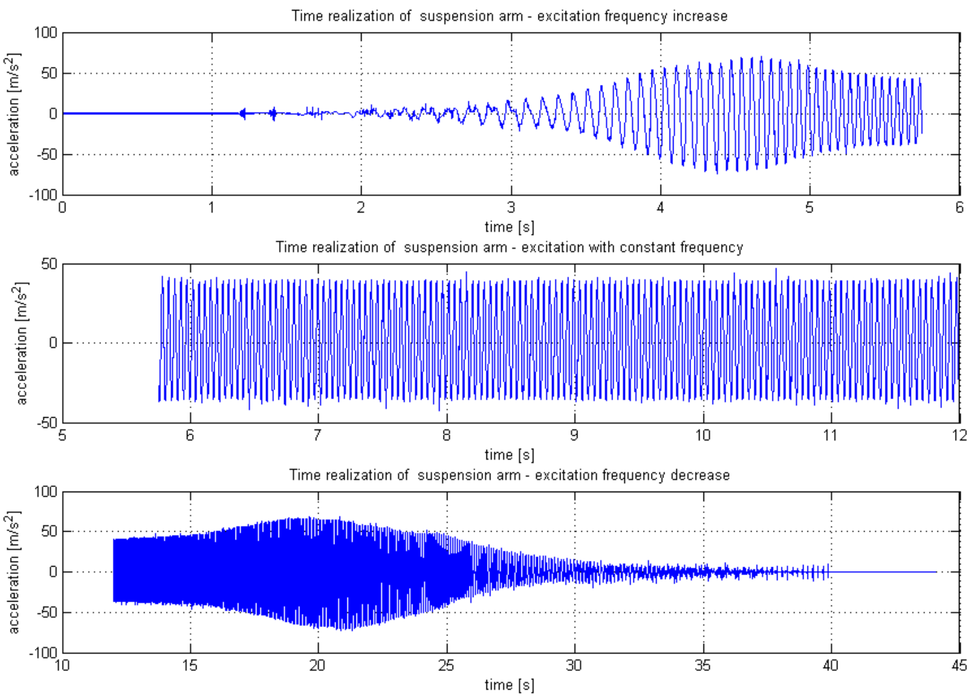


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Fig. 9 – Suspension arm vibration signal distribution by the stationary and nonstationary conditions (excitation frequency increase, constant frequency, frequency decrease), graphs: X axis – time, Y axis – acceleration

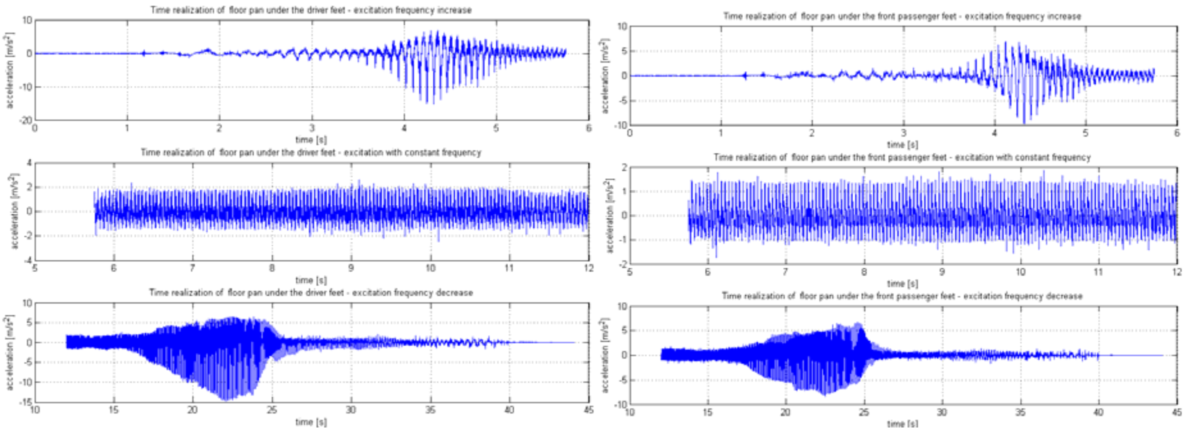


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Fig. 10 – Vibration signal distribution by the stationary and nonstationary conditions (floor pan under driver feet – left, under front passenger feet - right),
graphs: X axis – time, Y axis – acceleration

This methodology allows analysis of the signal with proper transformation. For the increase and decrease of the frequency the signal is nonstationar. The analysis spectrum is very difficult because frequency components are blurry. For the constant frequency the signal is stationar and frequency component are strongly isolated. Some of the results have been depicted in Fig. 11 and Fig. 12. The comparison of the spectrums of the stationary signals of vibration in suspension arm (unsprung masses), upper mounting of shock absorber, floor pan (sprung masses) have been depicted in Fig. 13. It can be observed that stationary signal of unsprung masses is typical harmonic signals without any polyharmonics components. The signals of sprung masses have got many of polyharmonics components.

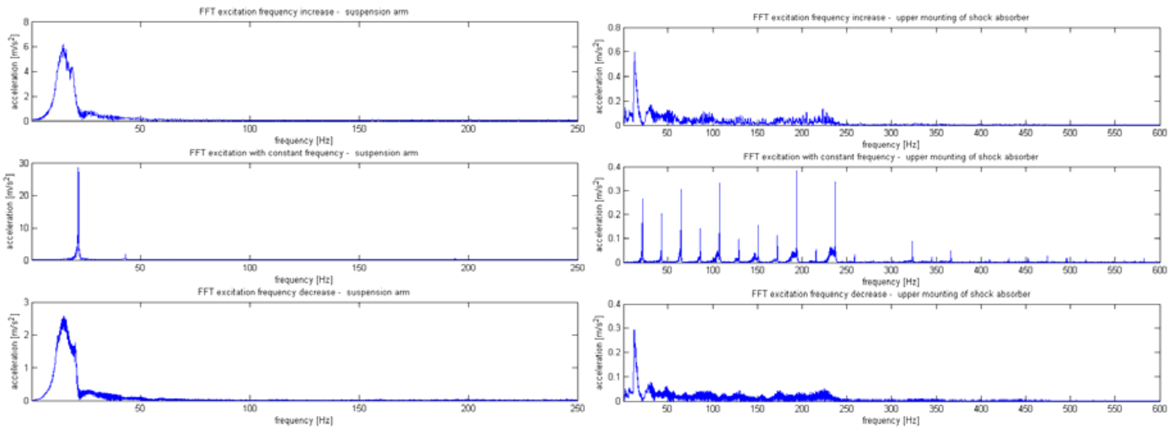


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Fig. 11 – Spectrums of the divided signal by the stationary and nonstationary conditions (suspension arm – left, upper mounting of shock absorber - right),
graphs: X axis – frequency, Y axis – acceleration

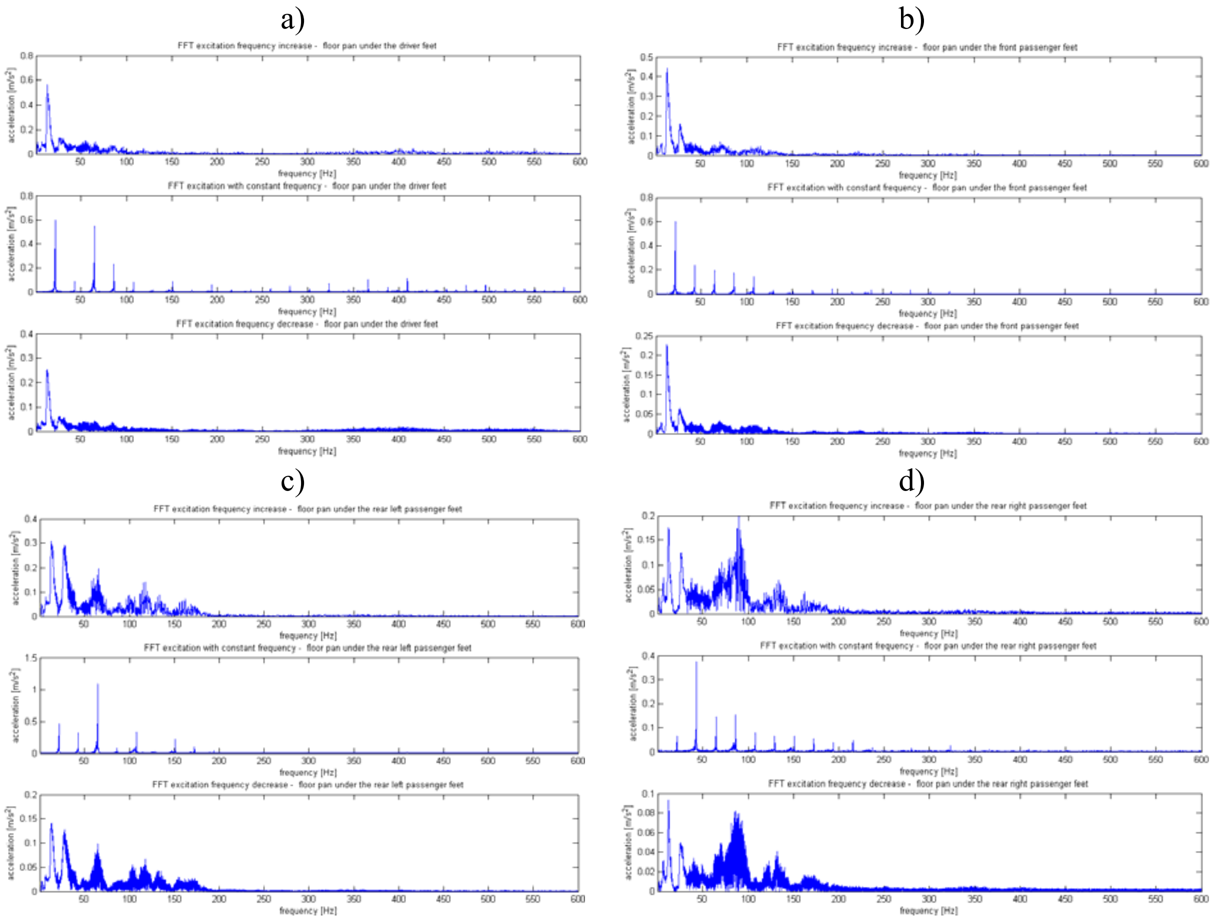


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Fig. 12 – Spectrums of the divided floor pan vibration signal by the stationary and nonstationary conditions (under driver feet - a, front passenger - b, rear left - c, rear right - d), graphs: X axis – frequency, Y axis – acceleration

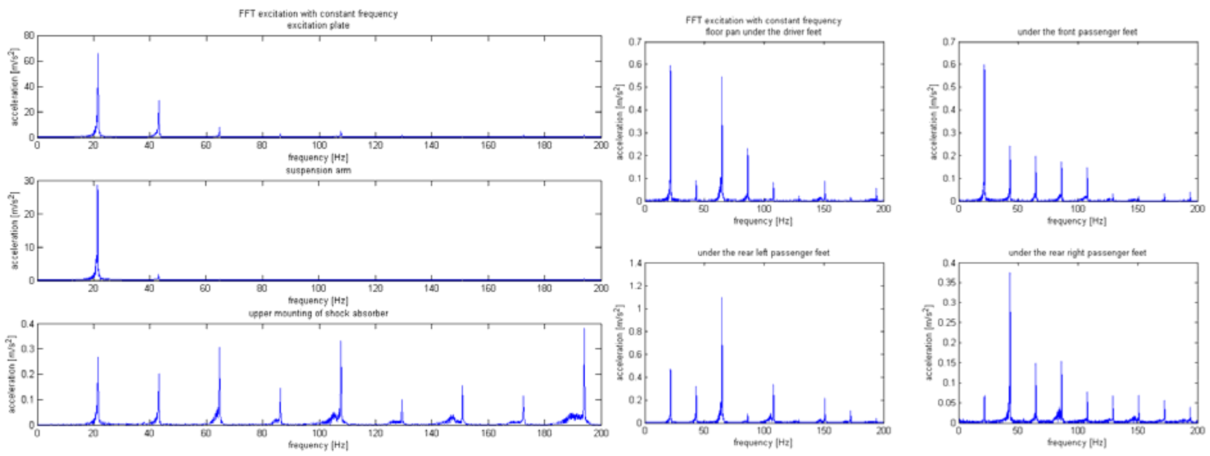


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Fig. 13 – Comparison of the spectrums of the stationary signals of vibration (excitation plate, suspension arm -unsprung, upper mounting of shock absorber – sprung, floor pan - sprung), graphs: X axis – frequency, Y axis – acceleration

The correlation of the dynamics of the nonsationary signals of vibration of the front floor pan have been depicted in Fig. 14 and Fig. 15. It were compared the signals registered during increase and decrease of excitation frequencies. It can be observed that vibration registered under the feet of driver and front passenger are strongly correlated. Especially for unsprung masses resonance (12-15 Hz). Thorough analysis of the spectrums allows observing the resonance of sprung masses. The amplitudes in 1-2 Hz band are higher. Comparison of the sprung and unsprung masses resonances shows that energy of the signal for unsprung masses resonances is more than 5 times higher.

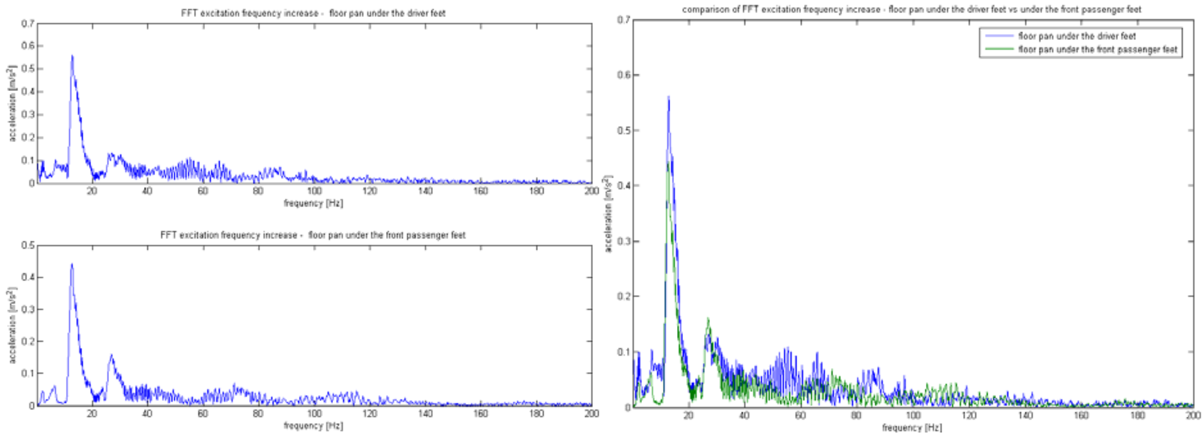


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Fig. 14 – The correlation of the dynamics of the nonsationary signals of vibration of the front floor pan during the excitation frequency increase (under the driver feet – blue, front passenger feet – green),
graphs: X axis – frequency, Y axis – acceleration

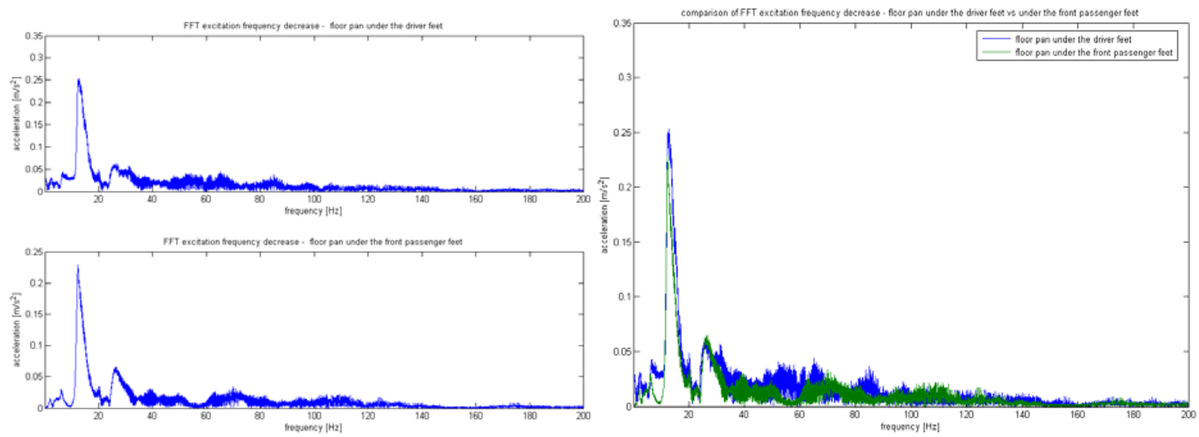


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Fig. 15 – The correlation of the dynamics of the nonsationary signals of vibration of the front floor pan during the excitation frequency decrease (under the driver feet – blue, front passenger feet – green),
graphs: X axis – frequency, Y axis – acceleration

The proper analyses of nonstationary signals are 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). Application of this method allows identifying with good precision the time of the resonance occurs. Some exemplary results of STFT transformation of the vibration registered during the increase frequencies of the excitation in whole vehicle structure have been depicted in Fig. 16.

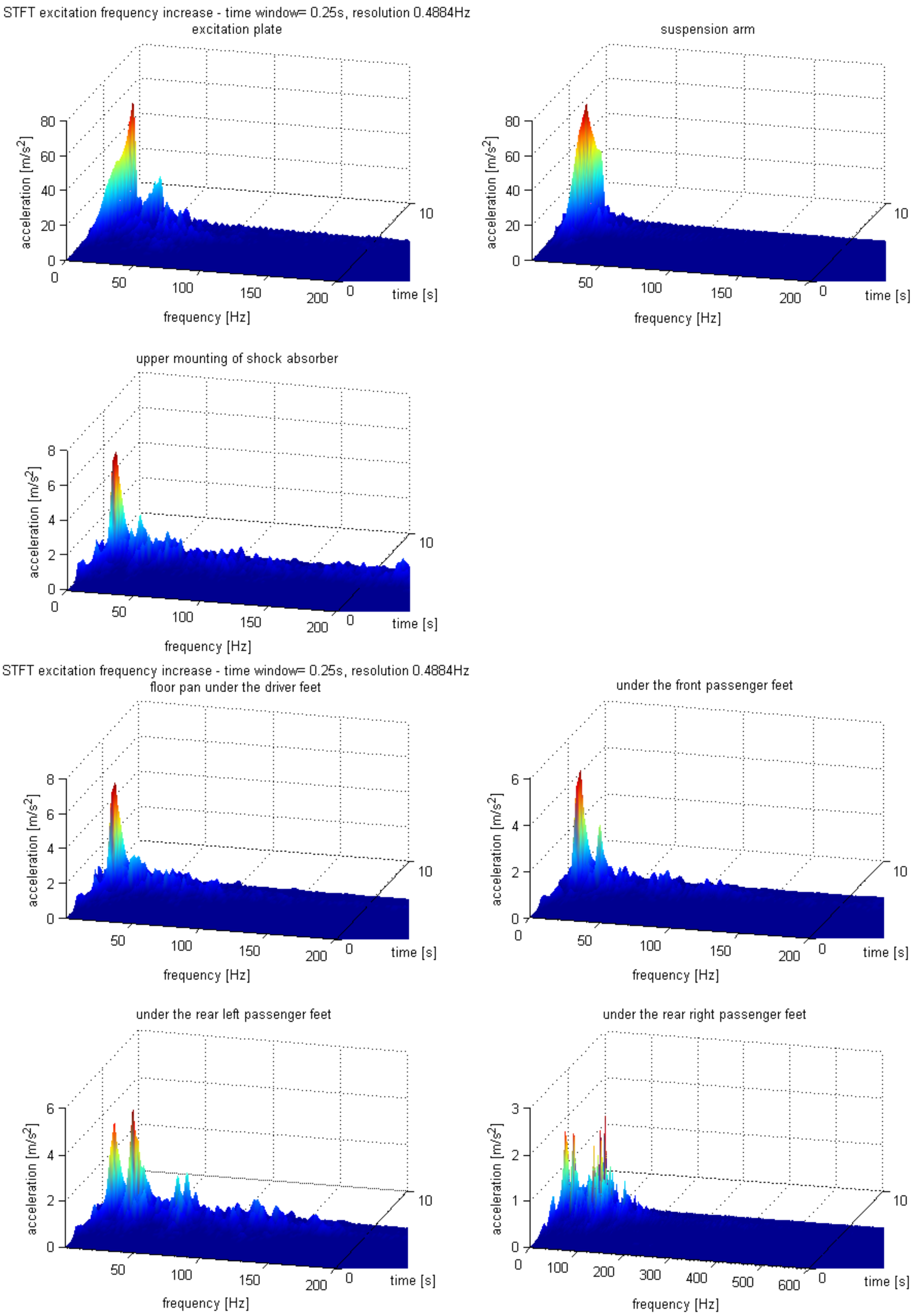


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Fig. 16 – STFT transformations of vibration registered during the increase frequencies of the excitation in whole vehicle structure,
graphs: X axis – frequency, Y axis – time , Z axis – acceleration

## CONCLUSION

The paper presents proposition of methodology on advanced signal processing for research on vibration propagation in vehicle construction. To evaluate the vibration research for the human vibration perception in vehicle it is necessary to analyse the structure of vibration signals in chosen elements of suspension and car body of the passenger car. For the human exposure to vibration the signals registered in places where vibrations are penetrating into the body can be analyzed. The scope of the research allows analysis of quantity of vibration isolation by suspension system and distribution of the vibration penetrates into human body by the feet. The algorithm of the signal distribution by the stationary and nonstationary conditions allows proper analysis of the signals separately as the stationar and nonstationar signal.

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