Proposal to use vibration analysis steering components and car body to monitor, for example, the state of unbalance wheel

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Abstract. The results of road tests of car VW Passat equipped with tires of size 195/65 R15, on the influence of the unbalancing front wheel on vibration of the parts of steering system, steering wheel and the body of the vehicle have been presented in this paper. Unbalances wheels made using weights of different masses, placed close to the outer edge of the steel rim and checked on the machine Hunter GSP 9700 for balancing wheels. The recorded waveforms vibration steering components and car body, at different constant driving speeds, subjected to spectral analysis to determine the possibility of isolating vibration caused by unbalanced wheel in various states and coming from good quality asphalt road surface. The results were discussed in terms of the possibility of identifying the state of unbalancing wheels and possible changes in radial stiffness of the tire vibration transmitted through the system driving wheel on the steering wheel. Vibration analysis steering components and car body, also in the longitudinal direction, including information from the CAN bus of the state of motion of the car, can be used to monitor the development of the state of unbalance wheel, tire damage or errors shape of brake discs or brake drums, causing pulsations braking forces.

1. Introduction

Almost every driver met with an unpleasant effect of vibration of the steering wheel angle, occurs particularly clearly in a narrow speed range, dependent on the size of the tires. The causes of the vibrations can be: dynamic unbalance wheel or tire shape errors of the rim (or both simultaneously), the variable radial stiffness of the tire at its periphery and damage the tire structure (usually visible as a local bulging of the tire) or errors shape of brake discs or brake drums, causing pulsations braking forces. Currently available apparatus for balancing wheels are equipped with special roller pressed against the rotating tire whereby, in the so-called "Road test", are defined radial force pulsation. The variable on the circumference of the radial force may be due to geometrical faults of the tire (also in case of damage to its structure), or other locally radial stiffness as a manufacturing fault. The inspiration for testing was an article by Krzysztof Prażnowski from the Department of Road Vehicles and Agricultural Opole University of Technology, presented at the conference KONMOT 2014 and published in the monograph "Research of the vehicle" [1].

2. Research object and measuring apparatus

Road tests were carried out using the car VW Passat B5 Fl Variant 1.9 TDI of the year 2003, which is in good condition and equipped with Firestone Firehawk tires 195/65R15 91T and steel wheels rim.

The air pressure in the tires was typical of partial load of the vehicle - in front of 0.23 MPa and 0.21 MPa in the rear.

The study used the following measuring devices [4]:

- unit of Racelogic VBOX 3i to measure traffic parameters of gait and self-decoding and recording linear velocity wheels of the vehicle CAN bus,
- acceleration sensors HBM B12/200 Hottinger Baldwin Messtechnik for measuring the vertical acceleration knuckle right front wheel, the body above of the tested wheel and tangential acceleration in a rotating motion of the steering wheel,
- dynamometric steering wheel CMS WA1111 Kistler for measuring the rotation angle of the steering wheel and the torque on the steering wheel,
- analog – digital converter Spider 8 Hottinger Baldwin Messtechnik,
- computer with Catman software.

Both synchronized measurement channels (VBOX and Spider 8 with a computer and acceleration sensors and wheel dynamometric) recorded the measured values with a frequency of 100 Hz. The view of where and how to place acceleration sensors and recorders measurement, are shown in figures 1 and 2. Operating wheel unbalance with additional weights (introducing deliberate unbalance of the wheel) was determined using the unit Hunter GSP 9700.

(a) (b)

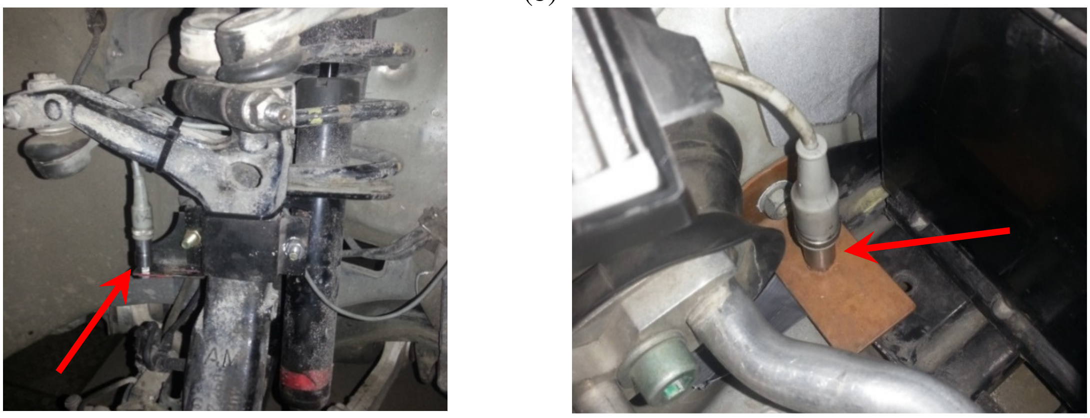

Figure 1. The view of where and how to place acceleration sensors on the front right suspension stub axle (a) and car body above this suspension (b). Sensors indicated by red arrows.

(a) (b) (c)

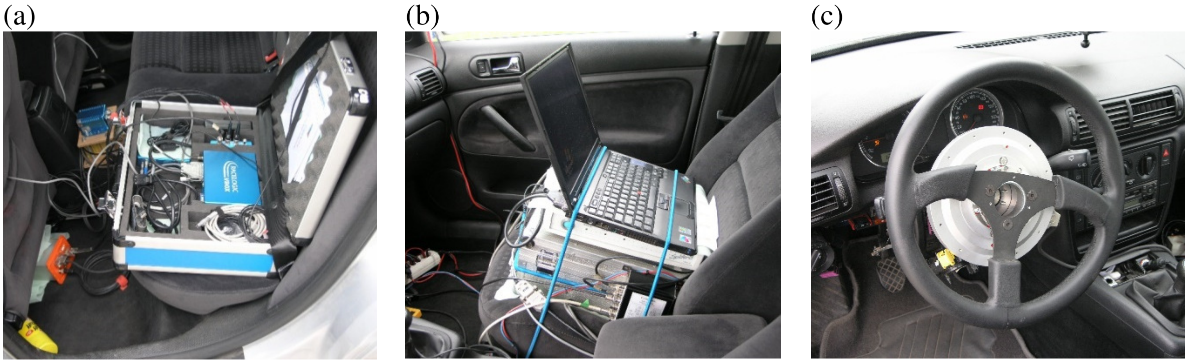

Figure 2. View recording equipment measured values: left - VBOX device (a), and the right - Spider 8 with a computer (b) and dynamometric steering wheel CMS WA1111 Kistler (c).

3. Methodology of research

Road tests the vehicle was carried out in the northern section of the ring road of Krakow, on the asphalt surface in very good condition. Measured values recorded when the vehicle standstill and the engine stopped or running, and next then very slowly increasing the velocity and the selected constant velocity. In the first stage of the study used correctly balanced all wheels and further stages of increased imbalance of the front right wheel by placing weights on the rim glued with masses respectively: 10 grams, 20 grams, 30 grams, 40 grams and 60 grams. Location and method of fixing weights shown in figure 3. For individual states unbalance wheel set "operating wheel imbalance" on the Hunter GSP 9700. Measurement results of stand unbalance the wheel for a few selected states, shown in table 1.

Figure 3. View how to place weights on the rim to the wheel unbalance and a view of the computer screen devices Hunter GSP 9700.

Table 1. Results of measurements balancing the wheels on the machine Hunter GSP 9700.

Additional weight on the wheel rim (grams)	The value of the weight balancing wheel (grams)	
	On the outside of the rim	On the inside of the rim
0 (prior to testing)	0	0
10	0	0
20	10	0
30	25	0
60	50	0
0 (after tests)	15	0

4. Presentation and analysis of results of road research

The following figures 4 and 5 show timing waveforms of vertical acceleration on the pivot of the front right wheel, the car body above this wheel and linear acceleration around the steering wheel for the car standing with the stopped engine (figure 4) and with running engine at minimum rotary speed (four-cylinder diesel engine). Running the engine with the crankshaft speed approx. 830 ÷ 840 1/min caused the vibration of the car body with vertical acceleration approx. ± 0.2 m/s^2, the stub axle vertical accelerations up to approx. ± 0.5 m/s^2, and linear peripheral steering wheel vibration - to approx. ± 0.1 m/s^2.

Figure 6 shows the frequency spectrum of acceleration measured on stub axle of front right wheel, on the car body above this wheel and linear vibration on the circumference of the steering wheel when car was stopped with the engine running at the crankshaft rotary speed approx. 830 ÷ 840 1/min. The vibration frequency of the stub axle and the steering wheel approx. 28 Hz corresponds to main frequency resulting from the combustion load in a four-cylinder four-stroke internal combustion engine, and the frequency of approx. 44 Hz is the second harmonic of the vibration. Frequency approx. 14 Hz is an additional harmonic resulting from vibrations the powertrain.

At higher speed the engine crankshaft vibrations generated by the engine and transmitted to the car body and part of the steering system are smaller. Despite this, in the following analysis includes vibration of the engine.

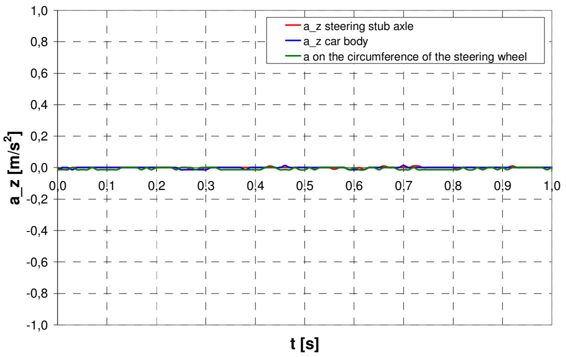

Figure 4. Timing acceleration when the car was stopped with no running engine.

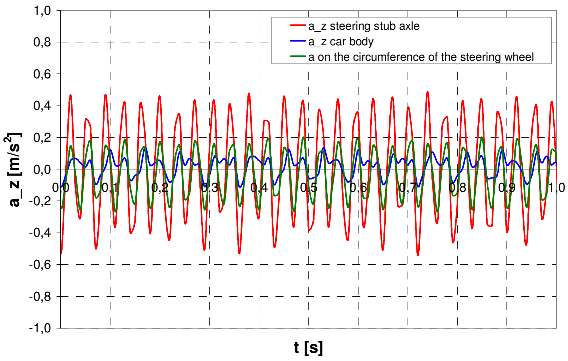

Figure 5. Timing acceleration when the car was stopped with running engine at minimum crankshaft speed (approx. 830 ÷ 840 1/min).

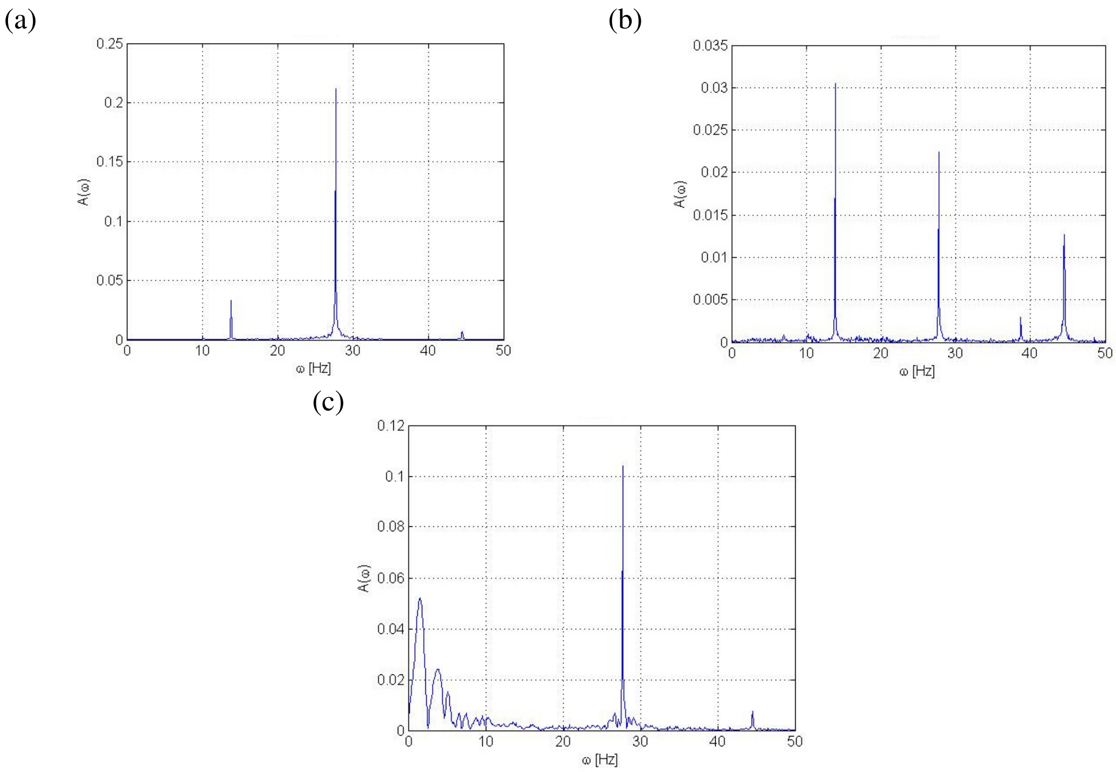

Figure 6. The frequency spectrum of acceleration measured on stub axle of front right wheel (a), on the car body above this wheel (b) and linear vibration on the circumference of the steering wheel (c) when the car was stopped with the engine running at the crankshaft speed approx. 830 ÷ 840 1/min.

Irregularities of road surface cause vibration of the elements of wheels suspension, which are transmitted to the car body and elements of the steering system, including the steering wheel. The driver can identify the wheel imbalance primarily on the basis of vibration of the steering wheel, but initial tests showed that the low mass unbalance of the front wheel, approx. 10 ÷ 20 grams, steering vibration are small enough that they cannot be observed by the driver. Vibration of stub axle of wheels make a dynamic load of the suspension and steering system and accelerate and increase their destruction, and therefore identify the occurrence of vibrations caused by wheel imbalance is very important.

For the above-described conditions of unbalance wheel, below shows the tests results at velocity approx. 100 km/h. On the figure 7 and 8 show time waveforms of the vibration elements of the steering system and the car body for the two states of the wheel unbalance resulting from the placement of the total mass of the weights 10 and 60 grams. Acceleration waveforms recorded at stub axle of the one front wheel, the car body above this wheel and on the steering wheel was subjected to spectral analysis. The results of this analysis for several unbalance state of wheel are shown in the figures 9 ÷ 12.

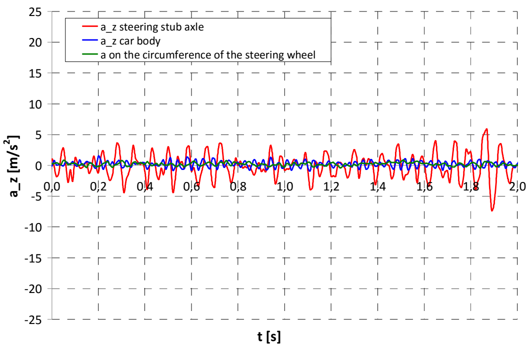

Figure 7. Timing for the acceleration of the elements of the steering system and the car body while driving at velocity approx. 100 km/h and engine crankshaft rotary speed approx. 2070 1/min, with unbalance wheel mass 10 g.

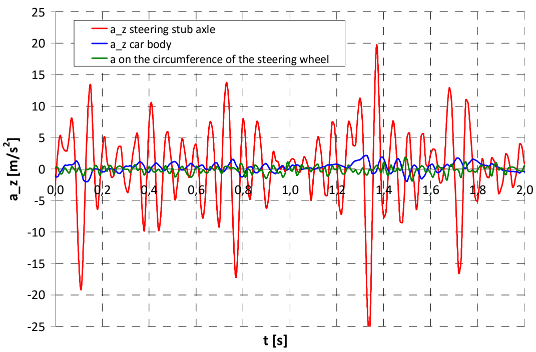

Figure 8. Timing for the acceleration of the elements of the steering system and the car body while driving at velocity approx. 100 km/h and engine crankshaft rotary speed approx. 2070 1/min, with unbalance wheel mass 60 g.

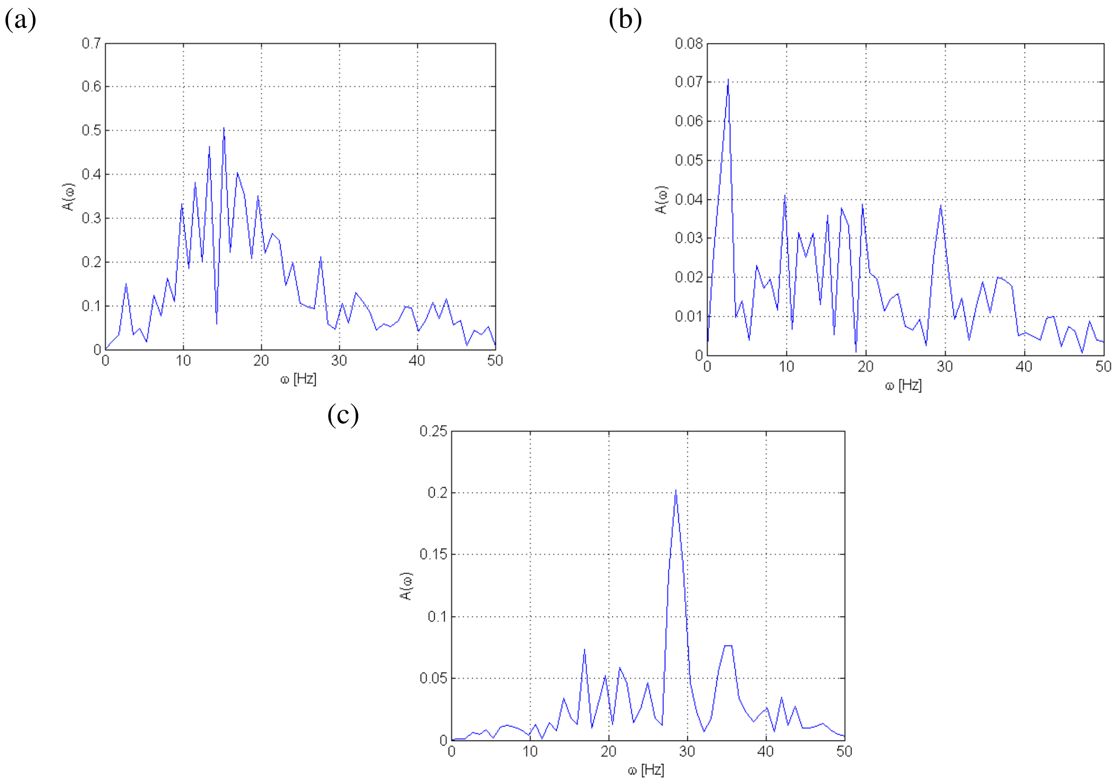

Figure 9. The frequency spectrum of acceleration measured on stub axle of front right wheel (a), on the car body above this wheel (b) and on the circumference of the steering wheel (c) while driving at velocity approx. 100 km/h and engine crankshaft rotary speed approx. 2070 1/min, with unbalance wheel mass 10 grams.

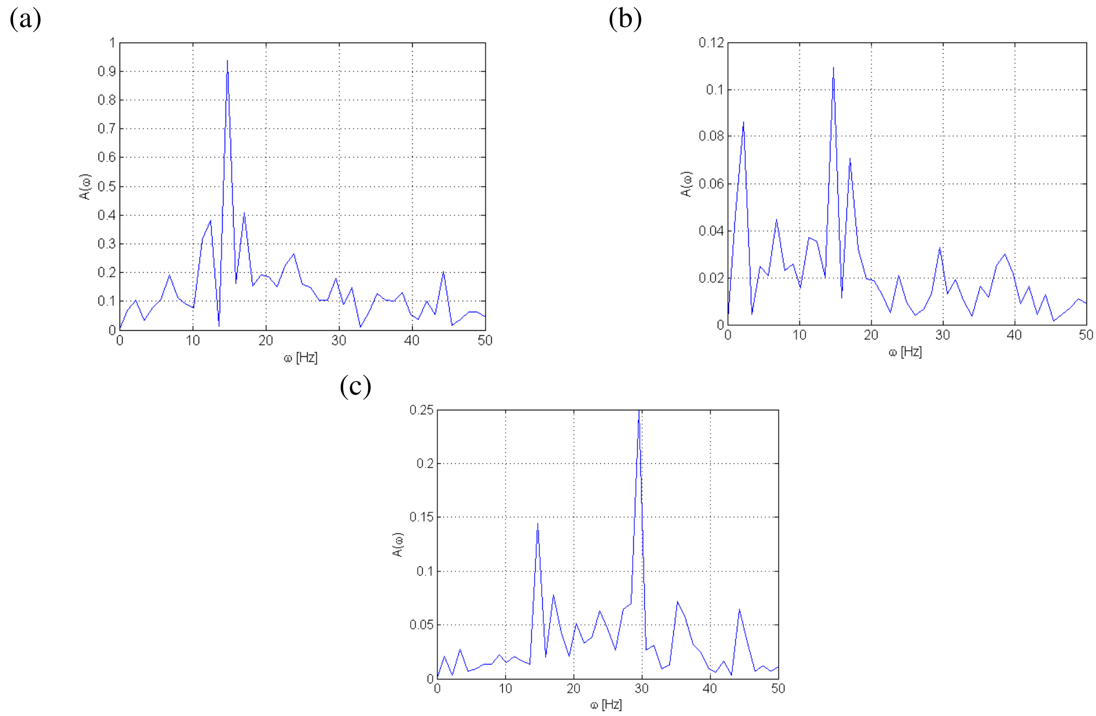

Figure 10. The frequency spectrum of acceleration measured on stub axle of front right wheel (a), on the car body above this wheel (b) and on the circumference of the steering wheel (c) while driving at velocity approx. 100 km/h and engine crankshaft rotary speed approx. 2070 1/min, with unbalance wheel mass 20 grams.

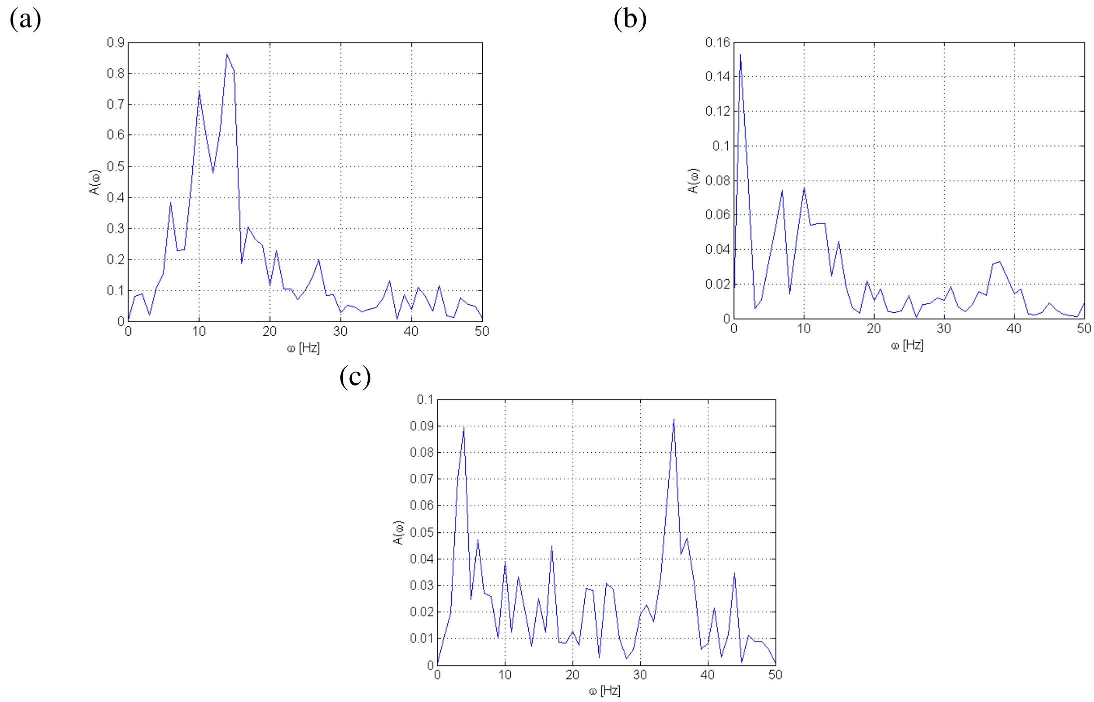

Figure 11. The frequency spectrum of acceleration measured on stub axle of front right wheel (a), on the car body above this wheel (b) and on the circumference of the steering wheel (c) while driving at velocity approx. 100 km/h and engine crankshaft rotary speed approx. 2070 1/min, with unbalance wheel mass 40 grams.

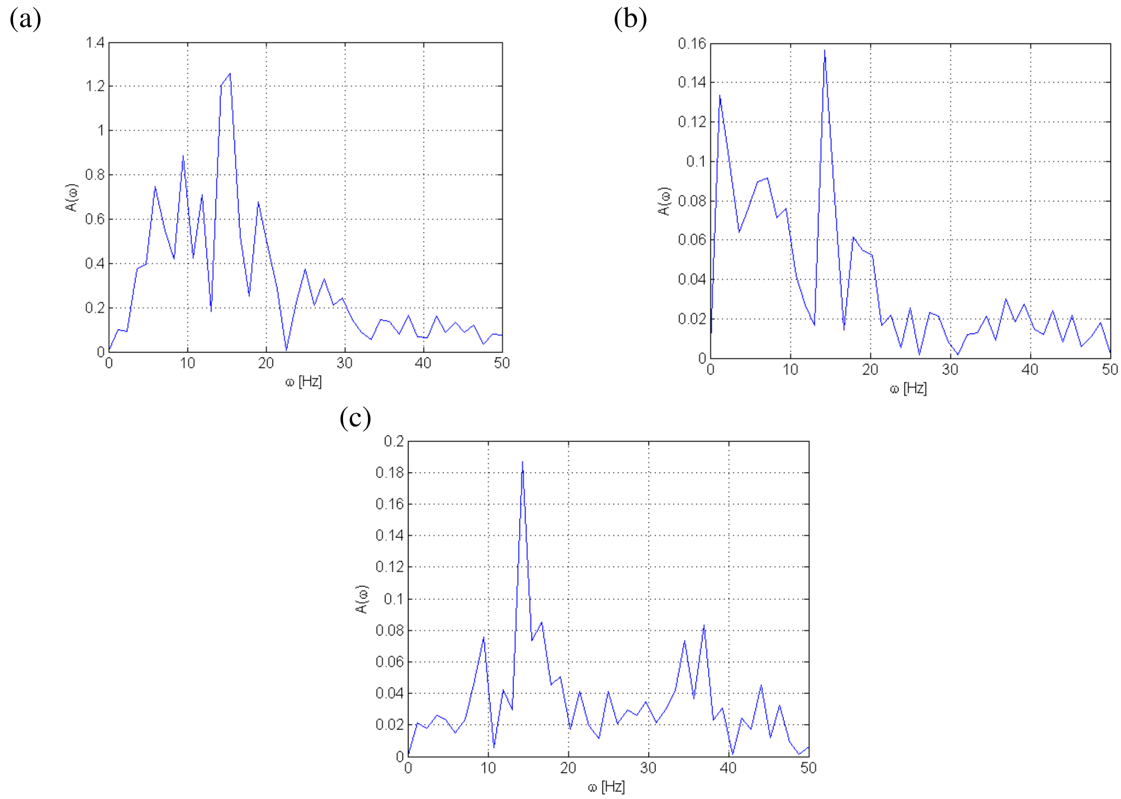

Figure 12. The frequency spectrum of acceleration measured on stub axle of front right wheel (a), on the car body above this wheel (b) and on the circumference of the steering wheel (c) while driving at velocity approx. 100 km/h and engine crankshaft rotary speed approx. 2070 1/min, with unbalance wheel mass 60 grams.

Preliminary analysis of the frequency spectrum of a wheel imbalance of 10 grams, when driving at a velocity approx. 100 km/h is indicative of the vibration of the steering wheel and a low value for a relatively broad frequency spectrum, without the dominant frequency. This points to the predominant influence of uneven road surface vibration and the wheel body [3, 5]. For comparison, figure 13 shows time waveforms of acceleration measured on stub axle of front right wheel, the car body above this wheel and on the circumference of the steering wheel and the frequency characteristics for all balanced wheels of the car. Comparison of the data shown in figure 9 and 13 indicates that the imbalance approx. 10 g cannot be correctly identified by the vibration stub axle and car body. Only the steering wheel vibration indicate the dominance of the frequency of approx. 28 Hz, which corresponds to twice the frequency resulting from the rotation of the wheels of the car traveling at approx. 100 km/h. Such domination vibrations of a similar frequency do not have road tests with a well-balanced all wheels (figure 13).

The results of spectral analysis for waveforms recorded at the wheel imbalance greater than 10 grams indicate the presence of such distinct vibration steering stub axle wheel, chassis and steering wheel, that the identification of these vibrations is possible. As part of this work introduces an imbalance of one wheel driven, but it is necessary to check identification method of vibration for the other wheels and more wheels improperly balanced. The basis for evaluation of vibration coming from the chassis of the car must be to identify the state of the road surface. It may be possible only after recognize that the vehicle is moving at a very good and flat road surface. Then it is possible to record and analyse acceleration coming from the wheels of the car. This analysis should be correlated with the speed of the car and performed in the frequency range relevant for vibration wheels. In the case of vibrations from at least two wheels, the analysis is more complex and needs to be affiliated with the identification of the change in the wheels speed and the frequency of vibration caused by driving on a curve.

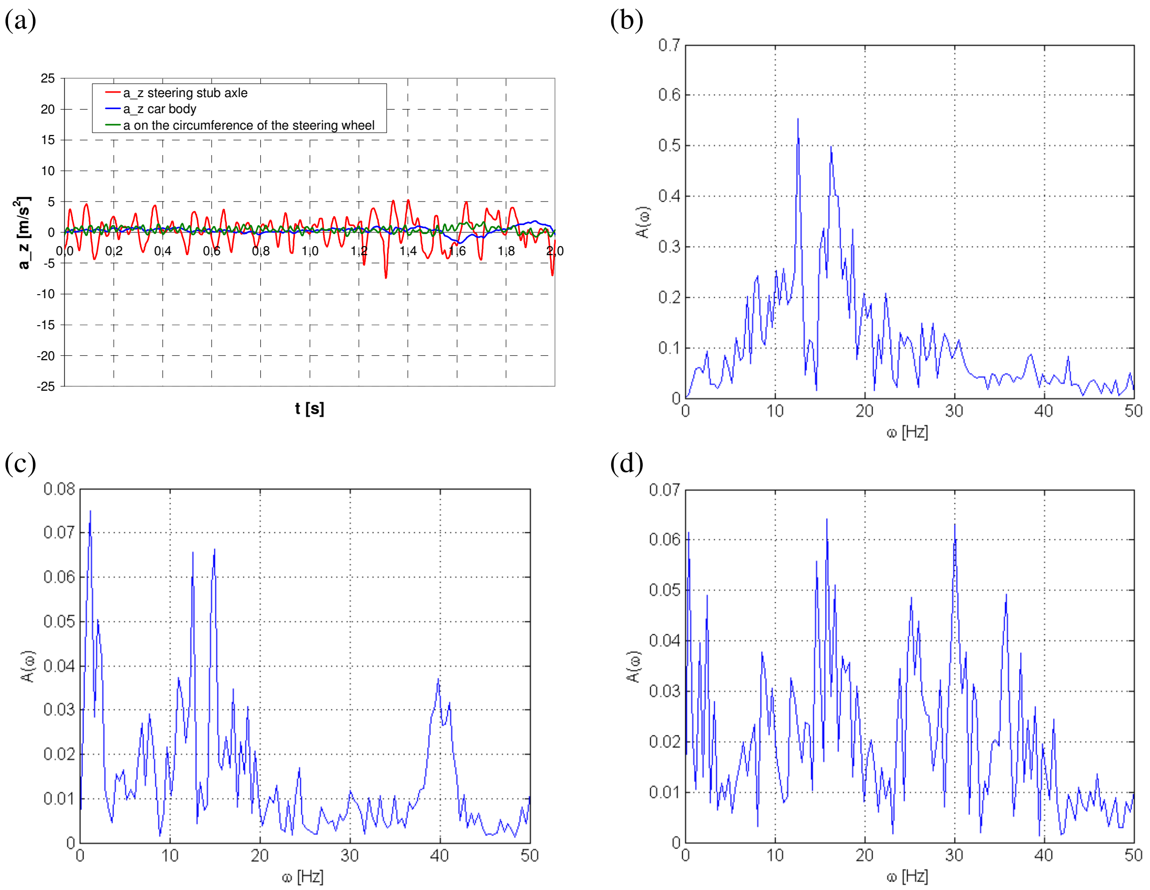

Figure 13. Timing for the acceleration of the elements of the steering system and the car body while driving at velocity approx. 100 km/h with well-unbalanced all wheels (a) and the frequency spectrum of acceleration measured on stub axle of front right wheel (b), on the car body above this wheel (c) and on the circumference of the steering wheel (d).

Installing the acceleration sensor on the stub axle wheel is technically possible, as the speed of wheel sensor ABS system. Much better working conditions can have an acceleration sensor mounted in the car body or steering wheel. Analysis of the signals recorded by means of the steering wheel dynamometer Kistler indicates that the signals of the rotation angle of the steering wheel and the torque on the steering wheel are not suitable for identification described vibration steering components, are in fact affected by manoeuvres carried out by the driver. Figures 14 and 15 show the spectral analysis of signals with an angle of rotation of the steering wheel and the torque on the steering wheel obtained when driving at a speed of approx. 100 km/h with an unbalance of the front right wheel weight 10 and 60 grams. In this signals is not a frequency described above, typical for rotating unbalance wheel at velocity approx. 100 km/h.

Therefore, in order to develop a system for measuring and analysis of vibrations caused by the wheels e.g. imbalance of wheels, should be designed the measuring system with acceleration sensors. These sensors, made in the MEMS technology, are cheap and generally available. Appropriate software will analyse the quality of the road surface on which the vehicle is currently moving and if appropriate vibration forced by rough roads are small, analyse these vibrations in order to determine whether they are caused by abnormal condition of the tires, their imbalance or abnormal shape which may indicate damage tire construction, can be made.

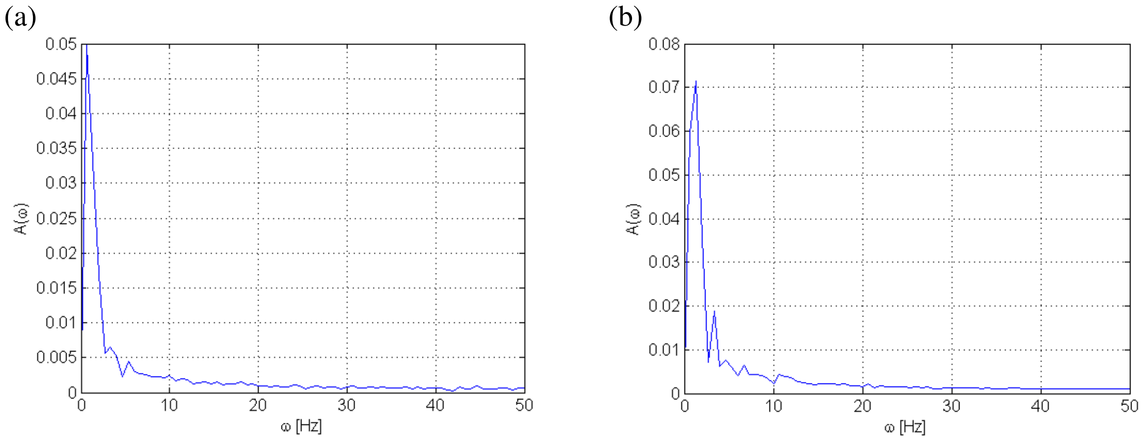

Figure 14. The frequency spectrum of the rotation angle of the steering wheel (a) and the torque on the steering wheel (b) by means of the steering wheel dynamometer Kistler while driving at velocity approx. 100 km/h and unbalance of the front right wheel mass 10 grams.

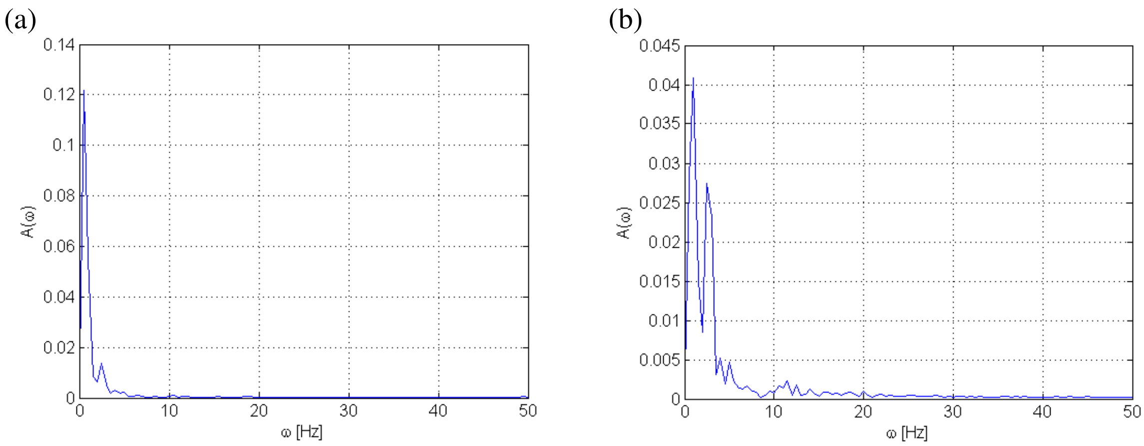

Figure 15. The frequency spectrum of the rotation angle of the steering wheel (a) and the torque on the steering wheel (b) by means of the steering wheel dynamometer Kistler while driving at velocity approx. 100 km/h and unbalance of the front right wheel mass 60 grams.

Measurements of acceleration the car body and parts of steering system in the vertical and longitudinal directions and accelerations on the circumference of the steering wheel and their spectral analysis, the knowledge of the actual speed on the basis of data from the CAN bus of the car, allow the development of a software analysing the data and forming monitor abnormal states of tires or improper effect wear of brake discs and brake drums (now rarely used). This monitor can help to increase the stability of the suspension of the car wheels and durability of tires and to maintain an optimal driving comfort.

5. Conclusion

The development of electronics in vehicles contributes to the development of surveillance systems the correct condition of the vehicle, such as the last monitors air pressure in the tires. The article proposes the use measurement and analysis acceleration of components of steering system and car body to identify the vibration caused by improper balancing wheels. Showing the acceleration waveforms recorded by

sensors placed on the steering stub axle of the front wheel of a passenger car, on the car body and on the circumference of the steering wheel for velocity approx. 100 km/h and all-wheel properly balanced and alternatively the front right wheel improperly balanced. Analysis of recorded accelerations indicates the possibility of diagnosing the state of the tires in terms of improper balance or change the shape associated with structural damage to the tires on the road with a very good and flat surface. Small vibrations can be identify although the average driver may not yet sense them on the steering wheel.
The proposed method of recording and analysing vertical acceleration including the vibrations in the longitudinal direction, can be also used to identify the pulse braking forces, e.g., caused by improper shape of disc brake. The knowledge of the actual acceleration chassis elements of vehicle and velocity on the basis of data from the CAN bus, allow the development of a software analysing the data and forming monitor abnormal states of tires or improper effect wear of discs brake. This monitor can help to increase the stability of the suspension of the car wheels and durability of tires and to maintain an optimal driving comfort.

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