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COMPARATIVE ANALYSIS OF THE BODY VIBRATIONS OF NEW CARS WITH A SPARK-IGNITION ENGINE WITH AND WITHOUT A SUPERCHARGER

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Abstract

The paper presents the results of tests carried out on two new cars: a Fiat Bravo (model 198, version 54A) with the 1.4BZ 90CV CD spark-ignition engine and the same Fiat Bravo model with the 1.4BZ 120CV CD spark-ignition engine equipped with a supercharging system. The car body vibrations experimentally determined in several specific repeatable points, i.e. behind the front side indicator and behind the passenger handle, were compared. A PSV-400 laser Doppler vibrometer made by Polytec was used to measure vibration velocities. The vibrometer directly measures two quantities: displacement and velocity. In the investigated case, vibration velocity turned out to be the variable supplying better diagnostic information. Vibrations were measured for the car standing on its wheels and for the car jacked up to reduce the influence of the car vibration damping systems on the measurement results. The latter are presented in the form of comparative diagrams. Moreover, the fast Fourier transform was used to determine the frequency distribution. Prior to that the signal was subjected to conditioning operations in time domain, such as parametric windowing and filtering. On the basis of the results the effect of the drive unit on the behaviour of the car body can be assessed for different engine types and rotational speeds. It is shown that the way in which the engine is mounted affects the vibrations of the car.

Key words: *Laser Doppler Vibrometry, vehicle body vibrations, vibration velocity, spark-ignition engine*

1. Introduction

Vibrations, particularly the ones which may affect human health or physical and mental state, are currently a topical issue which is widely discussed, unfortunately mainly in popular magazines. In specialist medical and telecommunications journals the focus is either on the health aspects [1] or the strictly vibrational ones [2] and no attempt is made to explore the phenomenon from the mechanical or mechatronic point of view. Having the comfort of passengers in mind, the authors decided to comprehensively examine the problem.

2. Effect of vibrations on human organism

The effect of vibrations on the human organism has been widely described in the specialist literature [3], focusing on

- the values of the parameters (velocity, displacement, etc.) describing vibrations;
- the way in which vibrations are transmitted to the human body;
- the individual physiological characteristics;

The natural vibrations of most of the human organs range from 3 to 25 Hz. If such vibrations are transmitted to the human body, resonance may arise. This may result in the dislocation of an organ and in the extreme case, in its damage. The exposure of the human organism to general-impact vibrations can be assessed with regard to vibration parameters, such as acceleration, displacement and velocity, according to the criteria

- the harmfulness limit;
- the nuisance limit;
- the comfort limit;

Polish Standard PN-91/N-01354 “Vibrations – allowable accelerations of vibrations having a general impact on the human organism and methods of assessing exposure” sets the limits of vibrations to which the human organism can be exposed. Figure 1 shows vibration accelerations versus allowable exposure time.

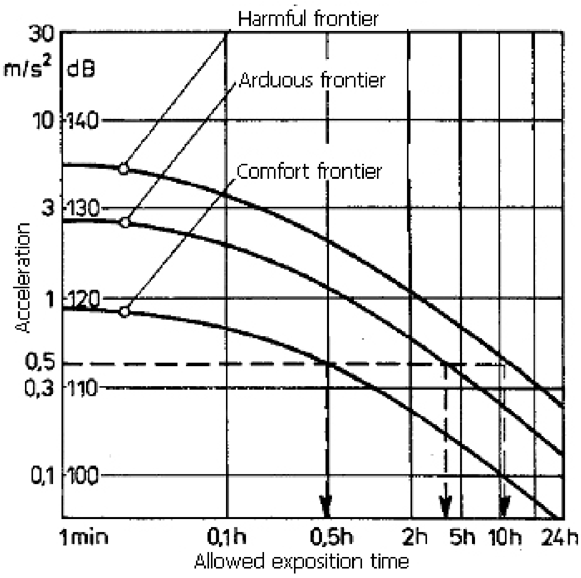

Fig. 1. Allowable acceleration values [3]

It is apparent from figure 1 that the comfort limit (the most representative quantity for the experimental results) is characterized by the lowest acceleration value which becomes extremely annoying after 10 hours. But this long journey by car is nothing extraordinary.

3. Investigated object in light of vibration transmitting components

The structure of a motor vehicle without its plating is shown in fig. 2. The crucial parts and the structure of the individual beams are shown in detail. Test results indicate that the side frame, through which vibrations are transmitted to the measurement sites, is critical. The structure of the particular components is layered as shown in the figure.

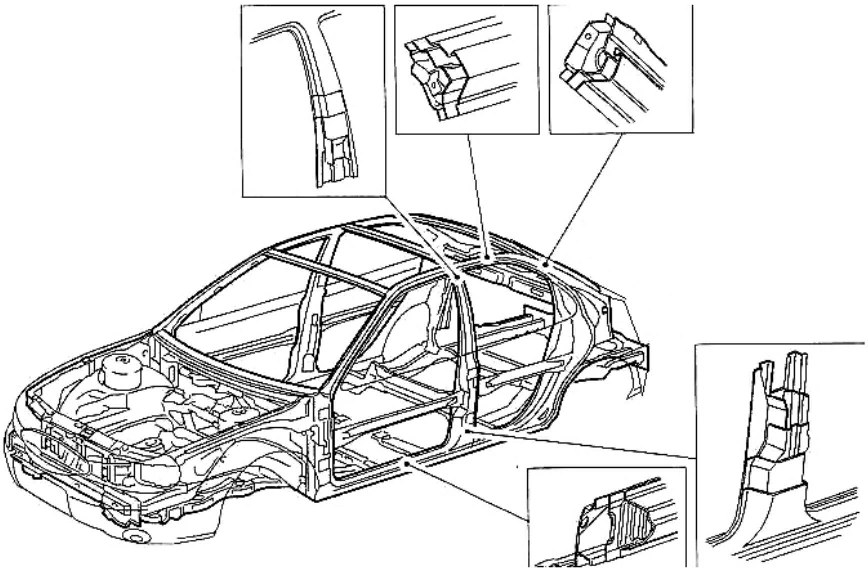

Fig. 2. Investigated object without plating

4. Measurement system and method

Laser Doppler vibrometry (LDV) was used for the investigations. LDV is based on the Doppler effect, which consists in a change in the length of the light wave received by the target if the latter is moving relative to the source.

A laser probe is the transmitting-receiving device. After it is reflected and returns to the scanning head the laser beam hits a lens. This measuring method allows one to directly measure velocity and relative displacement [4]. Any other parameter is a derivative of the above quantities. Velocity is converted into voltage proportional to frequency shift. Displacement is measured by counting the occurrences of areas generating specific wavelengths.

A diagnostic circuit consisting of a Polytec PSV−400 (PSV−I−400) vibrometric probe, an OFV−5000 controller and a PSV−W−400 supervision & acquisition system was used in the experiment. The controller and the supervision system were contained in a dedicated mobile enclosure. Vibration velocity was measured behind the side indicator and behind the rear passenger door handle. The measurements were performed in the neutral gear with and without forcing the crankshaft rotational speed of 2000 min.$^{-1}$. The measurements were carried out for a jacked up car and a car standing on its wheels. The two cars were investigated in the same conditions. Figure 3 shows a photograph of the test rig and the place (behind the passenger handle) on which the laser beam falls.

Fig. 3. Test rig: 1– place from which laser beam is reflected, 2 – method of isolating from base (jacking up), 3 – scanning probe

The results are shown in the form of diagrams in which the measured velocities of the vibrations generated by motor vehicles are compared. The waveforms were registered during 0.5 s long tests being part of the measurement lasting 2 s and involving 2048 samples in each case. Also frequency spectra (obtained through the Fourier transform) are shown in the figures.

5. Measurement results

Figure 4 shows the waveform and the frequency spectrum of engine vibrations measured at idle running behind the passenger handle.

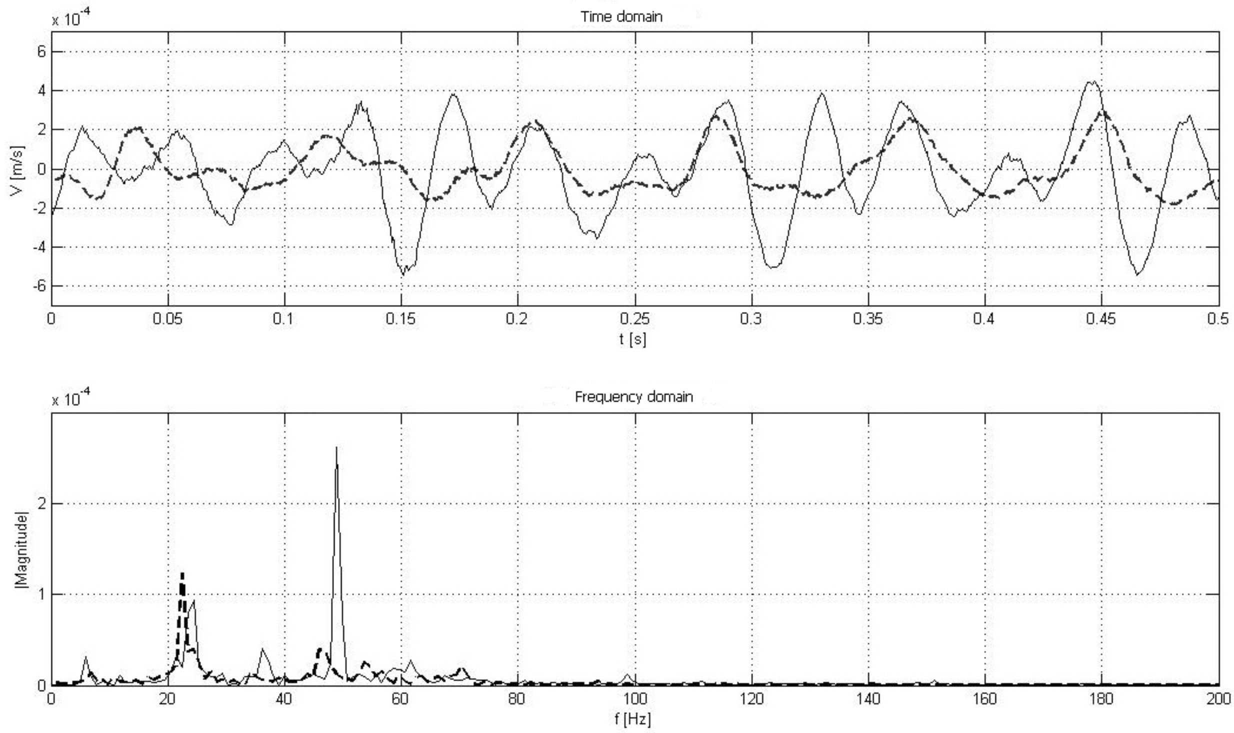

Fig. 4. Waveform and frequency spectrum of vibration velocities measured behind passenger handle for jacked up idle running car; solid line represents car having engine equipped with supercharger

The above analysis was performed for the two compared cars. It should be noted that the measurement of vibrations under the forced crankshaft rotational speed of 2000 min.$^{-1}$ carries an error due to the difficulty in maintaining constant speed during the measurement, especially in the case of the car whose engine is not equipped with a supercharger. This adverse phenomenon can be partially eliminated thanks to the fact that the Fourier transform does not preserve information about the phase of the measured signal [5]. The figure below shows the trace of vibration velocity measured behind the indicator of the car not isolated from the base for the crankshaft rotational speed of 2000 min.$^{-1}$ forced at idle running. It is clearly visible that vibration frequency and signal nonstationarity increase for both the car with an engine supercharger and the one without it.

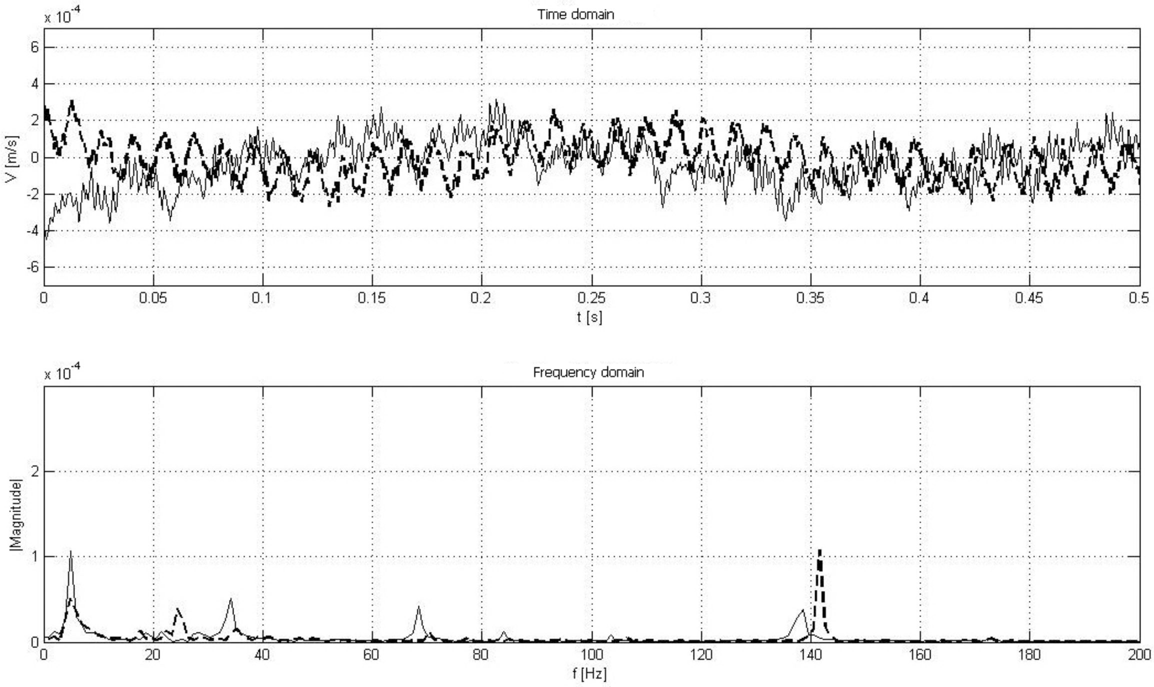

Fig. 5. Waveform and frequency spectrum of vibration velocities measured behind passenger handle for jacked up idle running (2000 rpm) car; solid line is for car having engine equipped with supercharger

The table below shows a comparison of average and maximum vibration velocities for the particular measurements.

Tab. 1. Maximum and average vibration velocities in different states

No.	Description	1,4BZ 90CV CD		1,4BZ 120CV CD	
		V_{max} [m/s]	V_{av} [m/s]	V_{max} [m/s]	V_{av} [m/s]
1.	Measurement behind handle, jacked up idle running vehicle	0.31	-0.0022	0.53	-0.017
2.	Measurement behind handle, jacked up idle running vehicle, forced 2000 min.$^{-1}$	0.35	-0.0038	0.88	-0.019
3.	Measurement behind handle, jacked up idle running vehicle, no speed forcing	0.39	-0.0020	0.54	-0.018
4.	Measurement behind handle, jacked up idle running vehicle, forced 2000 min.$^{-1}$	~~1736~~	~~-12.7~~	0.34	-0.020
5.	Measurement behind handle, not jacked up idle running vehicle, no speed forcing	0.46	-0.00023	0.55	-0.022
6.	Measurement behind handle, not jacked up idle running vehicle, forced 2000 min.$^{-1}$	0.31	-0.0015	0.33	-0.030
7.	Measurement behind handle, not jacked up idle running vehicle, no speed forcing	0.48	0.0031	0.65	-0.017
8.	Measurement behind handle, not jacked up idle running vehicle, forced 2000 min.$^{-1}$	0.41	-0.0046	0.60	-0.020

Measurement 4 (tab. 1) carries a large error due to the factors described earlier. For this reason the measured velocities in this case were not taken into account in the analysis.

6. Conclusions

The following conclusions emerge from the car vibration velocity spectra and waveforms and the values shown in tab. 1:

- the vibration velocities of the car whose engine was equipped with a supercharger are higher in each case;
- the vibration signal under forcing has a nonstationary character (fig. 4) and the signal without forcing is also nonstationary but no large fluctuation of peak values is observed in this case;
- the jacking up of the car, aimed at eliminating the effect of the base, has no methodological justification, as indicated by the properties of the transform and the high values of the dominant harmonics;
- it is very difficult to maintain the forcing, particularly in the case of the car without an engine supercharger. Such a measurement may carry a large error, of which one should be aware in order to avoid analytical errors;
- the two vehicles generate vibrations in the range of human internal organs natural vibrations. In the case of the car with a supercharged engine, the amplitudes of the vibrations are larger;

The aim of the research was to measure the velocities of the vibrations generated by a motor vehicle. The passenger comfort is greater in the case of the car whose engine is not supercharged. But the decision in this regard belongs to the owner since a car with an engine equipped with a supercharger is characterized by better driving properties, such as the ease of maintaining a constant driving speed.

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