COMPARATIVE ANALYSIS OF THE BODY VIBRATIONS OF NEW CARS EQUIPPED WITH THREE DIFFRENT TYPE OF ENGINES

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Abstract: *The paper presents the results of comparisons tests carried out on one model (Fiat Bravo model 198 produced in 2010) of new cars equipped with three types of engine: Version 54A with the 1.4BZ 90CV CD spark-ignition engine, Version 54G with the 1.4BZ 120CV CD spark-ignition engine equipped with a supercharging system and Version 54W with the* 1,6D 105CV *diesel engine. 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.*

Keywords: *LASER DOPPLER VIBROMETRY, VEHICLE BODY VIBRATIONS, VIBRATION VELOCITY, SPARK-IGNITION ENGINE*

1. Introduction

Mechanical vibration is a phenomenon consisting in the conversion of kinetic energy into potential energy, which is further converted into kinetic energy, etc., until the phenomenon dies out [1 - 3]. The measurement of mechanical vibrations depends on the system's number of degrees of freedom (DOF).

Since a mechanical system, such as the combustion engine, has an enormous number of DOFs, vibration diagnostics is highly complicated. In order to avoid a huge number of computations, physical systems are interpolated to systems with a known number of DOFs. In such systems the components with the smallest mass are represented by deformable constraints while components with a larger mass are represented by material particles or rigid bodies [3].

For (vibroacoustic kind of) vibration, measurements the system is assumed to be continuous, which means that the number of freedom points is determinate and that it is necessary to change over from discretization based on differential equations to continuity based on integral calculus [4]. Therefore one can say that vibroacoustic vibration measurement is approximation already at the detection level where system discretization is approximated by continuity.

Moreover, now is very modern to consider of vehicle vibration in ergonomic aspect – in this case in effects of vibration on human health. The effect of vibrations on the human organism has been widely described in the specialist literature [6], focusing on:

1. The values of the parameters (velocity, displacement, etc.) describing vibrations.
2. The way in which vibrations are transmitted to the human body.
3. 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:

1. The harmfulness limit.
2. The nuisance limit.
3. The comfort limit.

2. Investigated objects

Three vehicles: Fiat Bravo Model 198 54A cars with respectively engine: 1,6 105CV CD, 1.4BZ 90CV CD and 1.4BZ 120CV CD were tested. The latter engine model was equipped with a supercharging system. The specifications of the tested cars with the two different engines are shown in the tab. below.

Tabele. 1: *Comparison of tested engines specifications*

Specification	Type of engine		
	1.6 105CV CD	1.4BZ 90CV CD	1.4BZ 120CV CD
Engine cubic capacity	1598 cm3	1368 cm3	1368 cm3
Engine horsepower rating	105 hpm	90 hpm	120 hpm
Engine mounting	front crosswise	front crosswise	front crosswise
Type of camshaft	OHC	OHC	OHC
Cylinders	bank	bank	bank
Number of cylinders	4	4	4
Number of valves per cylinder	4	4	4
Weight	1320 kg	1205 kg	1260 kg

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 fig. 1.

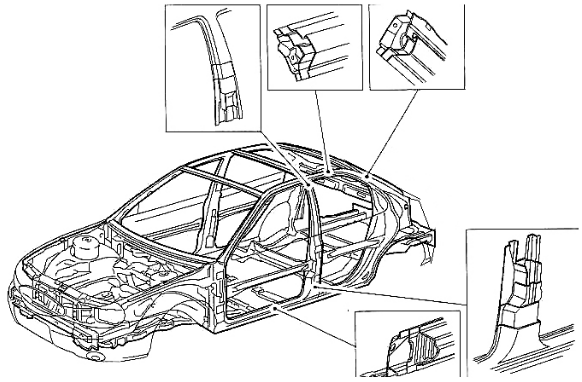

Fig. 1 *Investigated object without plating*

3. Measurement system and methodology

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.

Properties of vibroacoustic signals, often wrongly considered to be synonymous with vibro-acoustic vibrations are widely described in the literature [1 – 10]. Nevertheless, till nowadays, definition of vibroacoustic signals and vibroacoustic vibration has not been unified. It is assumed that the vibroacoustic vibrations are narrower expression, on one specific medium. The vibroacoustic signals phrase refer to the total signal issues, i.e. both vibrations and activated discrete representation of these vibrations and in particular the variables of their characteristic. Note complex level of vibration diagnosis, as the physical system, has a large number of degrees of freedom. To avoid the large number of calculations, physical systems are interpolated to such, in which the number of df is known. In these systems, the elements of lowest mass are assumed to be deformable, while the heavier elements is taken as material points or rigid solids [4]. One of the most quoted literature [2] defines vibroacoustic signals as a general dynamic phenomena; that take place in machines, equipments (devices) and special constructions. These phenomena are vibration, noise, air and sound material and the medium pulsation in workspaces machines. They occur in a wide frequency range from very low, almost zero, a very high level of MHz. Vibroacoustic vibrations are often mistakenly used as a synonym for dimensions characterizing them. There are the following physical dimensions used to quantitatively describe the process of vibration [5]:

1. Displacement.
2. Relative displacement.
3. Velocity.
4. Relative velocity.
5. Acceleration
6. Harmonic movement phase

Dimensions characteristic for vibroacoustic vibrations are measured with different methods, from which should be distinguished piezoelectric accelerometry and recently more and more popular laser vibrometry. The measuring method is closely related to the measured value. For accelerometry, the directly measured dimension is relative acceleration, and in the case vibrometry, the displacement and the relative velocity. Other dimensions are measured in diagnostic systems, but are the result of transformation of the basic value. Performing measurements of vibroacoustic vibration, it is assumed that the system is continuous, which indicates determined number of points of freedom and also the need to move from the discretization, based on differential equations for continuity, based on the account integral [8].

The principle of operation is shown in the fig. 2. The generated wave of the frequency f_0 is sent to both the photodetector and in the object direction oscillating with fd frequency. In the path directed toward the object, is Bragg module and its position in the head is set up to gain (at an integer multiplicity of wavelength). Summation signal is sent to the detector.

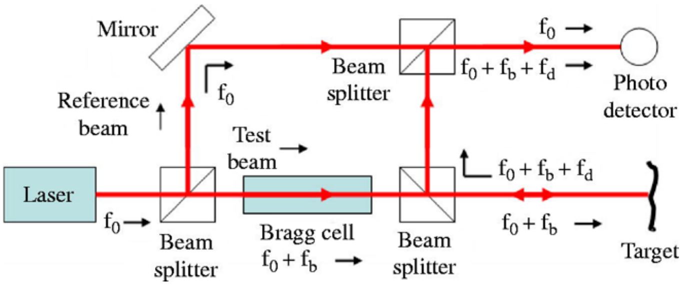

Fig. 2 *LDV system [11]*

In the experiment below, laser head with neon – helium laser was used. The beam path length of the reference is constant in time (as occurs in the head secured so that thermal effects are negligible). However, changing the optical length to the analyzed object, causes a frequency shift of the diagnostic beam (according to the Doppler effect). The study was performed using vibrometry, which parameters are shown in the table, given below [9].

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 *Place of beam reflection on vehicle body during investigation*

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 2 s long tests being part of the measurement lasting 4 s and involving 4096 samples in each case. Also frequency spectra (obtained through the Fourier transform) are shown in the figures.

4. Results

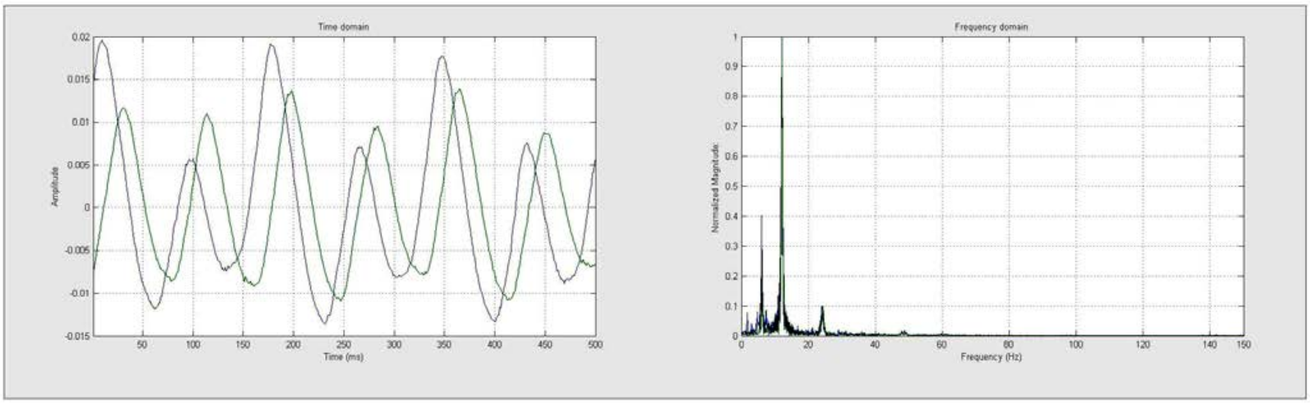

Fig. 4 *The investigation of ground bases influence, 1.4BZ 90CV CD, green – lifted on*

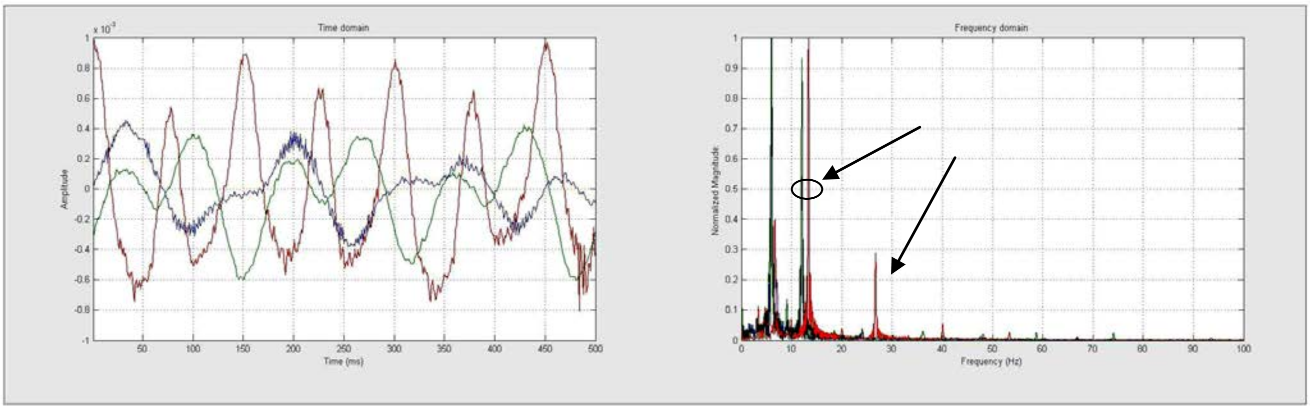

Fig. 5 *The comparison of vehicles bodies vibration: blue - 1.4BZ 90CV CD, green - 1.6 105CV CD, red - 1.6 105CV CD, idle (~900rpm)*

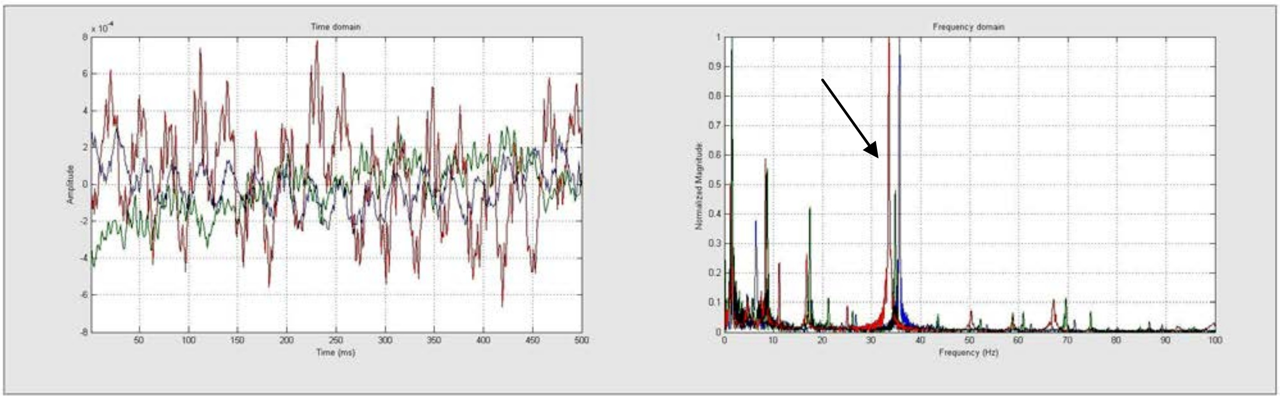

Fig. 6 *The comparison of vehicles bodies vibration: blue - 1.4BZ 90CV CD, green - 1.6 105CV CD, red - 1.6 105CV CD, idle (~2100rpm)*

Results is showed on three figures (4 – 6). First step, during researchers was based on checking of influence of floor base on vibration. In first step (fig. 4, blue) vehicle was standing on wheels, in second step car was lifted on. The character of vibrations in time domain (which is confirmed in frequency domain – harmonics were on this same values) is constant (in sense of phase) but magnitude of signal is bigger for standing car. This phenomenon was checked and it was repeated. So – in next step researchers was making for car standing (via wheels) on the floor.

Fig. 5 shows results of LDV vibration signals for three cars on an idle gear. Harmonics are on this same value of frequency. There is a small different between second, dominant harmonic (indicated in fig. 5b) for spark and diesel engine. Moreover diesel engine generate one extra harmonic (indicated in fig. 5b) on frequency 28Hz.

Fig. 6 shows this same kind of experiment but for bigger crankshaft speed. In this case widely spread of frequencies is showed. Harmonics for spark ignition engines are equal (in sense of frequency value) to approx. 15Hz. After that it spreads bigger value (indicated in fig. 6b). In this case considerable distortion of vibration (fig. 6a) is noticeable for all kinds of engines.

5. Conclusions

1. As it was shown, frequency may have an implications for the health and comfort of vehicle travelers.
2. The vibration signal, measured with force has non-stationary nature, as well as signal measured without force has also non-stationary nature.
3. Spark-ignition engines in all measurements generate smaller pattern of vibration compared with a diesel engine (it wasn't presented in figures). Moreover vibration of diesel engine generates bigger distortion.
4. Diesel engine might generate vibroacustic signal with major magnitude (in comparison to spark ignition) because of process and bigger pressure in combustion chamber.
5. Turbocharged engine generate vibrations with bigger stabilization then rest. Is it because the load in all cylinders is more defined.
6. Minimizing the potentially dangerous effects of vibration is possible not only by getting a better vehicle suspension and the separation of the driver, but also by the use of the compressor, which increases the frequency of the dominant harmonic outside the hazardous area. However, it is now rarely used method because it has negative impact on an electronic control of engine supply at low engine speeds (and it is more expensive).

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