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COMPARATIVE ANALYSIS OF THE VIBRATIONS OF A SPARK-IGNITION ENGINE WITH AND WITHOUT SUPERCHARGING, MOUNTED IN NEW MOTOR VEHICLES

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Abstract

The paper presents the results of tests carried out on two spark-ignition engines: 1.4BZ 90CV CD and 1.4BZ 120CV CD installed in new Fiat Bravo (model 198, version 54A) motor cars. The latter engine model (120CV) was equipped with a supercharging system. The investigations consisted in comparing engine vibrations measured in specific and representative points. In order to determine the vertical component vibrations, the measurements were performed via a mirror. A PSV-400 laser Doppler vibrometer made by Polytec was used to measure vibration velocities. The vibrometric system directly measures two quantities: displacement and velocity. In the investigated case, vibration velocity is the variable which supplies 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 using parametric windowing and filtering. Interesting conclusions emerge from the obtained results and on their basis 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, engine vibration, 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 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.

The aim of this research was to determine the effect of supercharging on combustion engine vibrations. It is obvious that the vibrations are transmitted to the rest of the vehicle and so affect the health and travel comfort of the driver and the passengers.

2. Description of investigated object

Two new Fiat Bravo Model 198 54A cars with respectively engine 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.

Tab. 1. Comparison of tested engines specifications

No.	Specification	Type of engine	
		1.4BZ 90CV CD	1.4BZ 120CV CD
1.	Engine cubic capacity	1368 cm3	1368 cm3
2.	Engine horsepower rating	90 hpm	120 hpm
3.	Engine mounting	front crosswise	front crosswise
4.	Type of camshaft	OHC	OHC
5.	Cylinders	bank	bank
6.	Number of cylinders	4	4
7.	Number of valves per cylinder	4	4
8.	Weight	1205 kg	1260 kg

In both cases the engine is mounted crosswise. The drive unit supports perform the function of a structural connection between the drive unit and the car body. The supports are suitably dimensioned to carry the drive unit weight and to withstand the loading with the torque transmitted from the engine. Each support has a rubber-metal shackle to dampen the vibrations generated by the engine. The shackle reduces most of the vibrations transmitted by the car body [5]. The drive unit support is of the centre of gravity type and consists of two shackles plus a reaction rod. The latter is a flexible connector in which the supports are aligned along the axis of gravity for the engine's centre of gravity in order to obtain a reactive force with a zero arm. The mounting is shown in fig. 1.

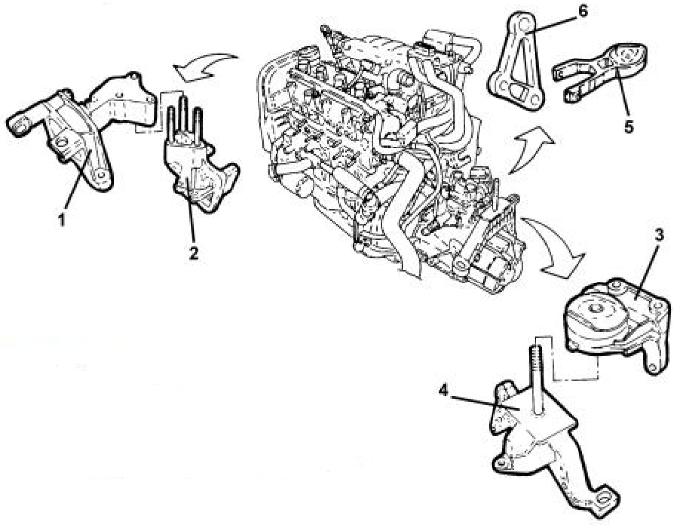

Fig. 1. Elements for mounting investigated object (1 - flexible connector on timing gear side, 2 - rigid support on timing gear side, 3 - flexible connector on gearbox side, 4 - rigid support on gearbox side, 5 - reaction rod on differential gear side, 6 - rod fixing support on differential mechanism side) [5]

3. Measuring system and method

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

A laser probe is the transmitting-receiving device. After its reflection and return to the scanning head the light beam hits the lens. Thanks to this measuring method one can directly measure velocity and relative displacement [4]. Any other parameter is a derivative the above quantities. Velocity is converted into voltage proportional to frequency shift. The measurement of displacement consists in 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. In order to measure vertical-vector vibrations a mirror (fig. 2) reflecting the laser beam was used.

Fig. 2. Test rig: 1- laser probe, 2- mirror, 3- place of laser beam reflection

4. Measurement results

The results are presented in the form of diagrams in which the measured vibration velocities generated by the cars 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 diagrams.

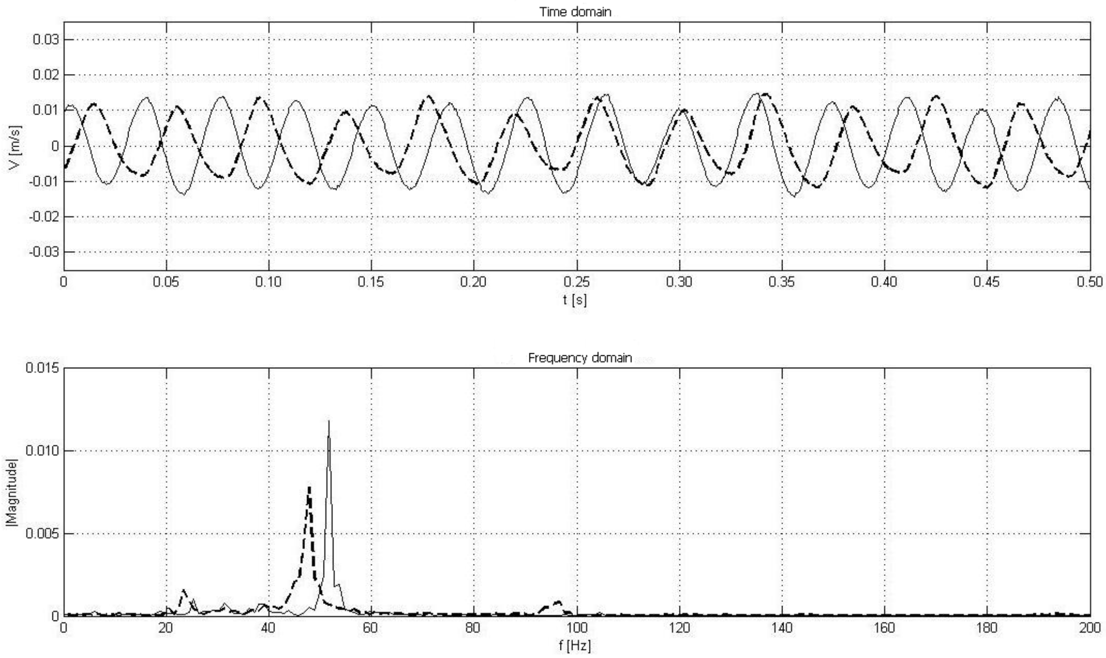

Fig. 3. Waveform and frequency spectrum of engine vibration velocity for not jacked up idle running car, solid line is for car with engine equipped with supercharger

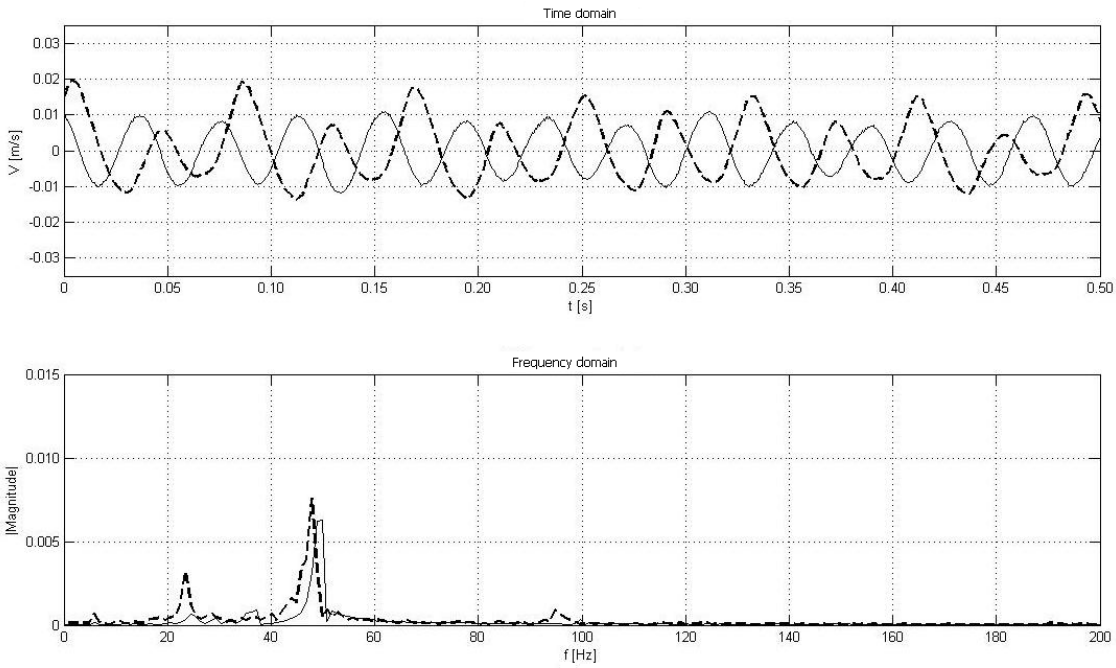

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Fig. 4. Waveform and frequency spectrum of engine vibration velocities for jacked up idle running car, solid line is for car with engine equipped with supercharger

The measurement of the vibrations of the engine with forced crankshaft rotational speed is poorly repeatable, particularly for the engine without supercharging. In order to obtain reliable results, the measurements were performed several times. The average and maximum vibration velocities are compiled in tab. 2.

Tab. 2. 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.	Idle running engine without forcing, car not jacked up	15.5	0.017	17.2	0.017
2.	Idle running car with forced 2000 min.$^{-1}$, car not jacked up	26.6	-0.041	27.6	-0.017
3.	Idle running engine without forcing, car jacked up	19.6	0.011	12.9	-0.018
4.	Idle running engine with forced 2000 min.$^{-1}$, car jacked up	23.5	-0.024	28.3	-0.010

5. Conclusions

The following conclusions can be drawn from the obtained characteristics and the vibration velocities measured by the laser vibrometer:

- the vibrations generated by the engine have a stationary character;
- the maximum vibration velocities are higher in the case of the engine equipped with a supercharger. Exactly the opposite was found for the average velocities;
- it is very difficult to maintain crankshaft rotational speed forcing and in order to obtain reliable results several measurements need to be performed, particularly in the case of the engine without a supercharger;
- the engine mounting system is highly effective in damping the vibrations transmitted to the rest of the car;
- the jacking up of the car does not affect the vibration frequency distribution, but it affects the amplitude of the individual harmonics. This means that it is not necessary to jack up vehicles for comparative analyses, provided the above measuring method is used.

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