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The comparative analysis of the disel and spark-ignition (with supercharger) engines vibrations

The paper presents the results of tests carried out on two engines: 1,6 105CV CD (diesel engine) and 1.4BZ 120CV CD (spark-ignition engine) 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 kind affects the vibrations of the car.
Key words: *Laser Doppler Vibrometry, engine's vibrations, vibration velocity, spark-ignition engine, diesel engine*

Analiza porównawcza drgań silnika o zapłonie samoczynnym z sailnikiem o zapłonie iskrowym (doładowanym)

Artykuł przedstawia wynika badań przeprowadzonych na dwóch silnikach:1,6 105CV CD (silnik o zapłonie samoczynnym) oraz 1.4BZ 120CV CD (silnik o zapłonie iskrowym), zainstalowanych w nowych pojazdach samochodowych Fiat Bravo (Model 198, wersja 54A). Drugi z wymienionych silników zaopatrzony był w układ doładowania. Badania polegały na porównaniu drgań generowanych przez silnik w specyficznych, reprezentacyjnych punktach. Dla uzyskania zmiennej pionowej drgań, tor diagnostyczny zaopatrzono w lustro. Do pomiaru prędkości względnej drgań wykorzystano dopplerowską głowicę laserową firmy Polytec, model PSV-400. System ten pozwala na bezpośredni pomiar dwóch zmiennych: prędkości i przemieszczeń. W wypadku prezentowanych metod diagnostycznych prędkość względna niesie lepszą informację pomiarową. Wibracje były mierzone gdy pojazdy stały na kołach oraz gdy zostały podniesione, aby zredukować wpływ drgań podłoża na wyniki badań. Wyniki badań zostały przedstawione wspólnych diagramów, pozwalających na komparację wyników. Ponadto użyto FFT, aby otrzymać widmo częstotliwościowe drgań. Dodatkowo, wykonano dodatkowe operacje cyfrowego kondycjonowania, takie jak okienkowanie parametryczne i filtracja. Na podstawie badań autorzy prezentują ciekawe wnioski, dotyczące wpływu drgań karoserię pojazdu przy różnych wartościach prędkości obrotowej wału korbowego. Wnioski te wskazują, jaki wpływ ma rodzaj silnika na drgania pojazdu samochodowego.
Słowa kluczowe: *Dopplerowska wibrometria laserowa, drgania silnika, prędkość drgań, silnik o zapłonie iskrowym, silnik o zapłonie samoczynnym*

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 DOF.

Vibrations, particularly the ones which may affect human health (and indicates on engine's state) 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 [4, 7] or the strictly vibration ones [1] and no attempt is made to explore the phenomenon from the mechanical or mechatronic point of view.

The main aim of presented research was to determine the effect of supercharging on spark ignition and diesel 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 (fig. 1) car vehicles with respectively diesel engine 1.6 105CV CD (model 54W, released 11th February 2010) and 1.4BZ 120CV CD (model 54G, released 10th December 2009) were tested.

Fig. 1. Fiat Bravo Model 198

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. 1.

Tab. 1. Comparison of tested engines specifications

No.	Specification	Type of engine	
		1.6 105CV CD	1.4BZ 120CV CD
1.	Engine cubic capacity	1598 cm3	1368 cm3
2.	Engine horsepower rating	105 hpm	120 hpm
3.	Engine mounting	front transverse	front transverse
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	1320 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. 2.

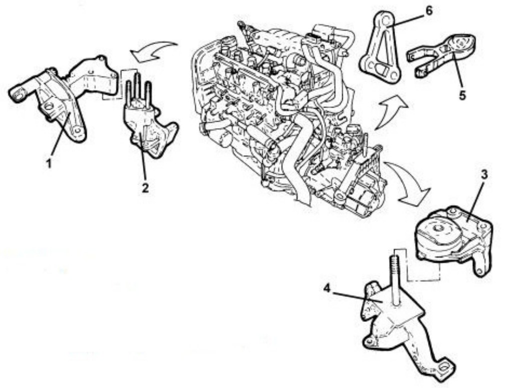

Fig. 2. Elements for mounting investigated object (1 - flexible connector on timing gear side, 2 - rigid support on timing gear side, 3 - flexible connector on gearbox side, 4 - rigid support on gearbox side, 5 - reaction rod on differential gear side, 6 - rod fixing support on differential mechanism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

3. Measured methodology

Laser Doppler Vibrometry 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 [6]. 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 engines (cars' vehicles) were investigated in the same conditions. In order to measure vertical-vector vibrations a mirror (fig. 3) reflecting the laser beam was used.

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

4. 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 1024 samples in each case. Also frequency spectra (obtained through the Fourier transform) are shown in the diagrams.

At the first compared signals obtained from a jacked up car and a car standing on its wheels (fig. 4).

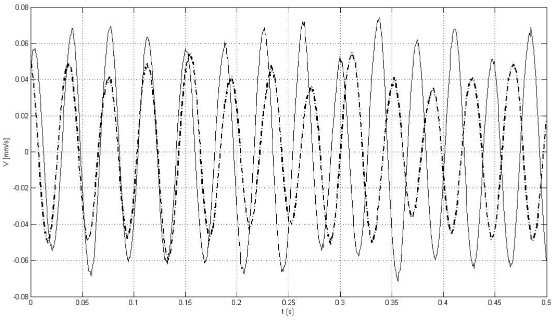

Fig. 4. The comparison of engines' signals of jacked up car up and a car standing on its wheels (solid line; idle running)

As it can be seen on fig. 4 vibrations of jacked car up vehicle (engine) characterize smaller difference of peak value. It seems that this kind of measurement is unconfused.

Fig. 5 and 6 show the comparison of vibration's velocity (jacked up vehicles) for idle running engine and forced crankshaft speed (2000 rpm).

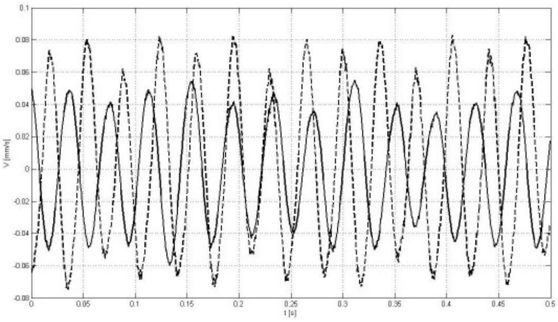

Fig. 5. Waveform spectrum of engine vibration velocity for jacked up, idle running car (solid line is for engine model 1,4BZ 120CV)

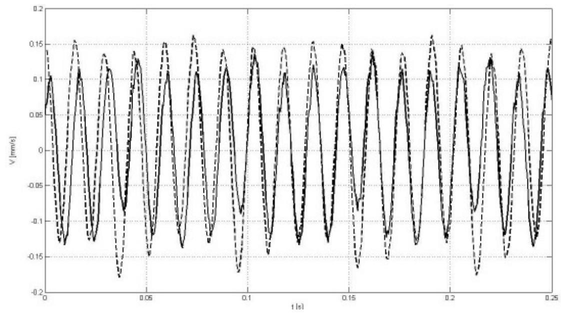

Fig. 6. Waveform spectrum of engine vibration velocity for jacked up, forced crankshaft speed (solid line is for engine model 1,4BZ 120CV)

Tab. 2 shows results of comparison maximum velocity of vibrations, presented in figures.

Tab. 2. Comparison of maximum velocity of engine vibrations for researched models

Next figures (fig. 7, 8) present this same results but in frequency domain (Fast Fourier Transform was used).

No.	Description	1,4BZ 120CV	1,6 105CV
		Vmax [mm/s]	
1.	Idle running	0.055	0.083
2.	Forced 2000 rpm	0.14	0.16

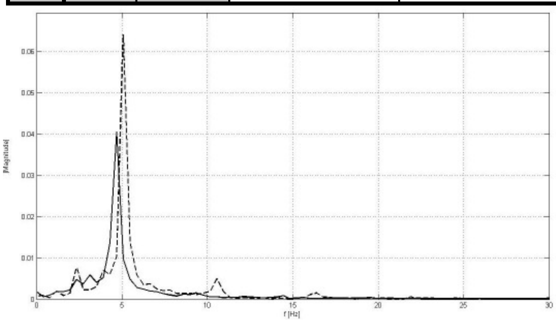

Fig. 7. Frequency spectrum of engine vibration velocity for jacked up, idle running car (solid line is for engine model 1,4BZ 120CV)

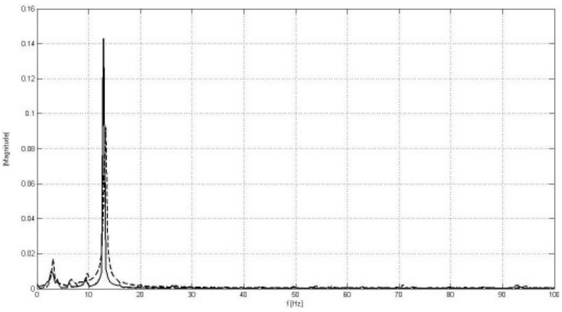

Fig. 8. Frequency spectrum of engine vibration velocity for jacked up, forced crankshaft speed (solid line is for engine model 1,4BZ 120CV)

4. 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 diesel engine than spark – ignition engine equipped with a supercharger,
- it is very difficult to maintain crankshaft rotational speed forcing and in order to obtain reliable results several measurements need to be performed,
- the engine mounting system is highly effective in damping the vibrations transmitted to the rest of the car (but extra correction is possible),
- 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 (but it is recommended).

Nomenclature/*Skróty i oznaczenia*

DOF Degrees of freedom
LDV Laser Doppler Vibrometry
FFT Fast Fourier Transform

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