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Vibration Diagnostics as an effective Tool for Testing Engines of Internal Combustion

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Abstract
There are several methods of automotive diagnostics used in services to detect a large variety of faults and damages of various parts of engines of internal combustion. Undoubtedly, they are effective, but they are simply unable to find all types of mechanical faults occurring during the operation. This is the reason why authors of this paper tried to use a special tool~~,~~ which has been proven for years for detecting faults of rolling element bearing in rotating machinery. During their research, the authors tried to find valuable results by measuring vibration of various parts of engines. Three items were tested, a Diesel engine and two Otto motors. A large number of measurements have been taken at various speed, at different points, in different directions, with different parameter setup, etc. However, there was one setup which has been applied to all three engines. It is the measurement setup of vibration velocity~~,~~ in the frequency range of 2 Hz-300 Hz. Valuable consequences have been found regarding the clogging of the air filters and the exhaust systems. As a conclusion the authors expressed their opinion~~,~~ that, apart from the traditional diagnostic methods used in services, vibration measurements can also be useful, especially for detecting faults of rolling element bearings.

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1. Introduction

Damaging processes of engines of internal combustion can be analyzed by means of various methods. Some of them are widely used, while others are less popular. Various signs of damages can be checked by measurements of geometry, and simulation of sensitivity (POKORÁDI L. 2008). Unfortunately, the regularities of diagnostic systems cannot be always described with mathematical algorithms which may sometimes cause a problem (LAKATOS I. 2013). In the following paper, the attempt to find a relationship between the reason of the vibration and the changes of vibration spectra is presented. Vibrations of engines depend – among others – on the damping characteristics of the body (SZŐKE D. 1989). Moreover, the dynamic behavior of engines is strongly influenced by manufacturing errors of geared wheels (MÁRIALIGETI J. 1995). Despite all the difficulties, observations confirmed that vibration and noise analysis is an effective method to qualify internal combustion engines as one of the measurement processes during the so called cold test (BÁNLAKI P., MAGOSI Z. 2010). If the methods of measuring and analyzing the vibrations of bearing systems are used properly, then the vibration signal (general vibration level, SPM method, etc.) contains important information about the machine condition monitoring (KRYNKE M. 2015). In this paper the goal was set to analyze the results of the tests, which was carried out at the laboratory of the Óbuda University, and started some years ago (PALÁNKAI M. 2013).

2. Goals of the vibration test

One of the goals of the following paper was to determine details in the vibration spectrum resulting from the change of the rotational speed. Another goal was to compare the vibration spectra of a 4 cylinder Otto engine, and a 4 cylinders Diesel engine. Moreover, vibration spectra of a 3 cylinder, and a 4 cylinder engines were compared. Also, the research aimed to clarify whether various artificial faults could be identified in the vibration spectra of an engine of internal combustion. Finally, there was a question to be answered if there are any significant differences in the vibration spectra taken at various locations of an engine of internal combustion.

3. Engines involved in the testing procedure

Initially, a Diesel engine of a Ford Mondeo TDCi vehicle was tested (Fig. 1). It has been installed and operated on a block-testing stand of Schönebeck type, i.e. it was not measured while working in a vehicle. Technical data of the engine are shown in Table 1.

Fig. 1. Layout of the Ford Mondeo Diesel engine

In the second part of the project two different Suzuki engines were tested. One of them was a Suzuki Swift 1.3 installed on a block-testing stand (Fig.2). Technical data of the engine and the main parameters of the vibration measurements are shown in the first column of Table 2.

The next Suzuki engine was a Swift 1.0, located and operated in the body of the car (Fig. 3). Technical data of the engine and the main parameters of the vibration measurements are shown in the second column of Table 2.

Fig. 2. General layout of the Suzuki Swift 1.3 engine

Fig. 3. General layout of the Suzuki Swift 1.0 engine

Table 1. Main data of the tested Diesel engine

	Ford Mondeo TDCi
Type of engine	Turbo Diesel
Number of cylinders	4
Cylinder capacity	1998 cm^3
Idle speed, rpm	750 ± 50
Number of measurement points	4 locations, 3 directions Acc, Vel, Env, SEE
Test speed, rpm	750, 1250, 1800, 2000
Test condition	When cool (temperature) At normal operating temperature Before cleaning of injection After cleaning of injection
Location of the testing procedure	Test bench in the Laboratory of the Óbuda University (Engine not built in the car body)

Table 2. Main data of the tested Otto engines

	Suzuki Swift 1.3	**Suzuki Swift 1.0**
Type of engine	Otto	Otto
Number of cylinders	4	3
Cylinder capacity	1300 cm^3	1000 cm^3
Idle speed, rpm	850 ± 50	850 ± 50
Number of measurement points	2 locations 3 directions	2 locations 3 directions
Test speed, rpm	850, 1500, 2400	850, 1500, 2400
Test condition	At normal operating temperature only Artificial faults - loose V belt - non-proper ignition - clogged air filter - clogged exhaustion system	At operating temperature only No artificial faults
Location of the testing procedure	Test bench in the Laboratory of the Fáy András College (Engine not built in the car body)	In normal, assembled state, i.e. engine built in the car body (at the Lab of Óbuda University)

4. Some typical faults of engines of internal combustion to be detected and identified

Maintenance has a special importance also in the case of vehicle engines of internal combustion which is the reason of their regular check-ups by the service staff of garages. Various diagnostic methods are there available to help them. Some of these methods are considered traditional automotive diagnostic methods. However, these “traditional” methods are certainly not likely to reveal all types of faults. Consequently, the method of vibration diagnostics has been tested whether it is capable to identify some of the faults. For this purpose – among others - artificial faults have been created in order to shorten the identification procedure. In this project the following fault conditions have been tested:

a, Tension of timing belt

Timing belt can become loose due to careless usage, improper adjustment during repair or even postponing regular maintenance. If the timing belt is loose, then it can badly affect the operation of the engines. On the other hand, if the timing belt is too tight, then it can cause other problems, as well: tension of the timing belt can overload the bearing, increase the wear, etc.

b, Clogging of the air filter

The air filter can be clogged due to postponed maintenance or often driving in dusty areas. The consequence is the reduction of power. What is more, dirt might enter the cylinder and damage the internal parts of the engine (piston, rings, wall of the cylinder, bearings, etc.)

c, Improper lubrication

The oil level can be too low due to the overconsumption (improper sealing) or not proper filling amount of the oil. The consequence might be the serious damage of the engine. On the other hand, if the oil level is too high (due to overfilling) then the sealing/gaskets might be damaged.

d, clogging of the exhaustion system

The reason of clogging of the exhaustion might be, among others, the damage of the catalyzer. It may result in the reduction of the power, and the overheating of the engine.

5. Methods and tools of vibration measurements

For the vibration measurements a portable data collector and analyzer of type CMVA-60 with a CMMS2200 accelerometer were used. The collected data were processed by the Prism4 for Windows software. As a measurement parameter usually the acceleration, velocity and Enveloped Acceleration were used. For the interpretation of the signals apart from the spectra the so called waterfall diagrams were used.

The purpose of the vibration measurements was to find out the followings:

- Does the change of rotational speed have any impact on the vibration severity?

- Are there any significant differences between the vibration spectra of four cylinder engines with different operation principles (Diesel and Otto engines)?

- Are there any significant differences between the vibration spectra of two Suzuki engines (having three and four cylinders respectively)?

- How the vibration spectra caused by artificial faults (created by the staff) will change over time?

Regarding the measurement setup, it has to be emphasized, that several versions were tested. However, it has to be underlined, that a vibration velocity in the frequency range of 2-300 Hz was measured in the case of all the three engines.

6. Typical vibration signature of a Diesel engine

The highest peak is at 1228 CPM (=20.25 Hz) which refers to the rotational speed of the main shaft. Moreover, the harmonics are also strong.

The picture below shows the vibration velocity spectra at four different rotational speeds. It seems interesting, that the vibration severity is not growing proportionally with the rotational speed. It is the strongest at the basic (750 rpm) rotational speed.

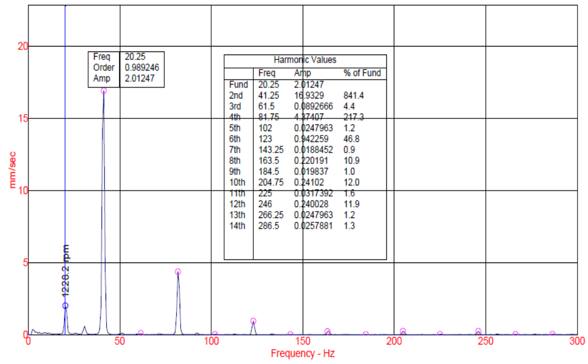

Fig. 4. Typical vibration spectrum of a four stroke Diesel engine

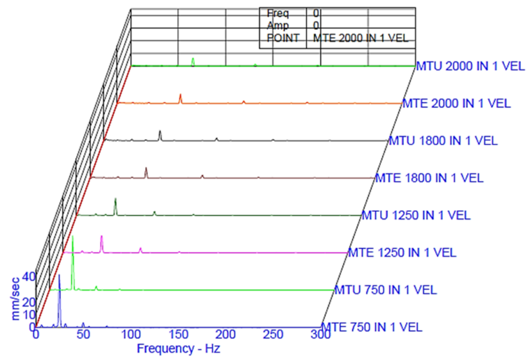

Fig. 5. Vibration velocity spectrum at 4 different rotational speeds of a four stroke Diesel engine

7. Typical features of a 4 cylinder Otto engine (Suzuki Swift) vibration

Typical vibration velocity spectra of a four cylinder Otto engine (Suzuki Swift 1.3), running at 2400 rpm is shown in Fig. 6. It can be seen that the highest peak is at the 2X of the rotational speed of the main shaft. The spectrum contains further harmonics, but in spite of the spectrum of the Diesel engine, here not only the even harmonics are strong. Moreover, there is a strong component at 0.5X, which might be the reason of the loose support (foundation). In the spectrum of a three cylinder Otto engine (Suzuki Swift 1.3), contrary of the four cylinder engines, apart from basic vibration component (1X), the 1.5X harmonic also appears. There are harmonics of 2X and 3X too, but no more.

Taking into account the effect of the clogging of an exhaust system (see Fig. 7), there are considerable changes. A strong increase in the amplitudes of the 1X and 2X in the horizontal directions can be seen. The reason for this might be the clogging of the catalytic converter. As a consequence, the engine becomes less powerful because the exhaustion gas cannot leave the engine. The engine itself and the exhaustion system can be overheated.

The air filter might be clogged due to improper maintenance. One of the consequences might be that the air supply of the engine is insufficient. The replacement of air filters is based on regular time intervals (or distance, e.g. after each 15000 km). The used air filter may cause damage to the valves, the piston, or to the bearings as well. Looking at the spectra, there are minor changes. Increase in the amplitudes of the 1X and 2X in the horizontal directions can be identified.

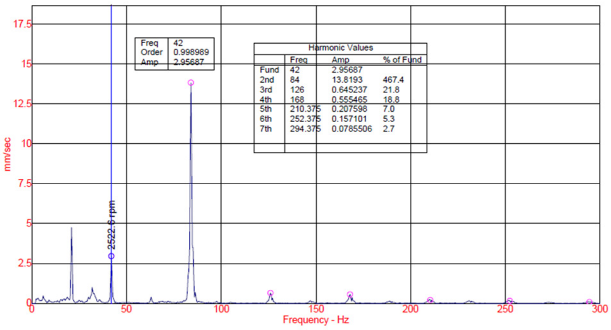

Fig. 6. Typical vibration spectrum of a four stroke Otto engine

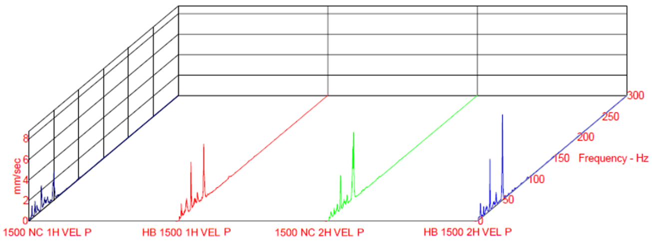

Fig. 7. Effect of exhaust clogging on vibration spectrum

Some artificial faults made on the engine structure were arranged, and their effects were determined. One of them was the improperly stressed V-belt, and the timing belt. These ones might have serious consequences, but they did not have a considerable influence on the vibration spectra. The same is the case of the lubrication of the engine, and the use of different types of sparking plugs. Undoubtedly, these are important, but, as it has been proven, the methods of traditional vibration diagnostics did not have valuable results.

8. Summary and conclusion

Any changes of the rotational speed can be successfully traced on the engines of internal combustion. Vibration severity is proportional to the rotational speed in the case of Otto engines. However, this was not observed in the case of Diesel engines. The number of cylinders has a significant effect on the vibration spectrum. In the case of 4 cylinders the 2X, while in the case of 3 cylinders the 1.5X order appears on the spectrum.

The replacement of ignition spark plugs by wrong ones has no significant effect on the spectra. It might be unexpected, but the clogging of the air filter has no considerable effect on the spectra. On the other hand, clogging of the exhaustion system has a considerable effect both on the vibration severity and on the spectra.

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振动诊断作为内燃机测试的有效工具

關鍵詞
引擎
振动
诊断
光谱
滚动轴承

摘要
在服务中使用几种汽车诊断方法来检测内燃机发动机的各种故障和损坏。毫无疑问，它们是有效的，但是它们根本无法找到在运行期间发生的所有类型的机械故障。这就是为什么本文作者试图使用一种特殊的工具，这种工具已经被证明多年来用于检测旋转机械中滚动体轴承的故障。在研究期间，作者通过测量发动机各部分的振动来尝试找到有价值的结果。三项测试，柴油发动机和两台奥托电机。已经以不同的速度，不同的方向，不同的方向，不同的参数设置等进行了大量的测量。然而，已经有一个应用于所有三个发动机的设置。在2 Hz-300 Hz 的频率范围内，是振动速度的测量设置。已经发现有关空气过滤器和排气系统堵塞的宝贵后果。作为结论，作者表达了他们的观点，除了在服务中使用的传统诊断方法之外，振动测量也可能是有的，特别是用于检测滚动体轴承的故障。