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VIBRATION DIAGNOSIS OF CAR MOTOR ENGINES

Abstract:

In the article the results of the tests are presented, which were to detect the mechanical damages of an internal combustion engine with the use of vibration methods. One of the main sources of inputs in an internal combustion engine is an impact of the piston on the cylinder wall. The results of the vibration signals analysis registered for an engine before and after repair are presented here. The engine repair consisted of the exchange of the used pistons and due to it a decrease of the clearance in piston-cylinder system was achieved.

Keywords:

fault diagnosis, engine vibration, internal combustion engines

INTRODUCTION

Growing expectations concerning the durability and the dependability of the internal combustion engines as well as the cost minimising and the bad influence on the surrounding cause that the necessity arises to get information about the engine condition during exploitation. The introduction of an obligation to produce car vehicles according to the OBDII norm caused that there are possibilities of access to data stored in controllers of separate systems [15]. In case of an engine the highest efficiency of the board diagnostic system is provided in the field of toxic substances emission control. However, some damages such as, for example: growing consumption of the valve seats and the faying faces of the valves, shift of timing gear phase, consumption of cylinder bearing surface even over the sizes allowed for a given engine, in many cases confirmed in practice do not serve as a basis for the diagnostic system to react. The most common cause of such a condition are the used algorithms of the adaptation steering of the internal combustion engine.

Adaptation steering of the engine may lead to the stage, when the appearing errors will be hidden or adapted [1,2,8,9]. The mechanical defects and the exploitation consumption, particularly in the early stages of development, are compensated by the adaptive regulation systems due to the approved ranges of regulation. The changes of the technical state of the engine caused by the early stages of its consumption are difficult to detect with the use of presently used diagnostic methods.

Diagnosis Of The Internal Combustion Engines With The Use Of Vibroacoustic Methods

One of the methods of gaining diagnostic information is monitoring of the vibrations level generated by the sub-assemblies of the engine. In a description of the vibroacoustic symptoms of the mechanical damages of an internal combustion engine one should take into account the fact, that a high level of nominal vibrations is generated, resulting from the target function realisation. Internal combustion engine is an object under the influence of internal and external inputs [7]. Among them there are mainly: burning pressure, the movement of the piston-crank mechanism, inputs from the timing gear system, inputs resulting from the work of the fittings of the engine (that is alternator, compressor, etc.), inputs transmitted from the motor-car body and the drive transmission system. One of the most important inputs during the work of the piston-crank mechanism are the impacts of the piston by the change of its work direction. The value of input is significantly dependent on the clearance between the piston and the cylinder wall, caused by the exploitation consumption of the engine [3-6,11-14]. The power value is a burning pressure function and the rotational speed of the engine function. The most important aspect is to identify the frequency bands in which the maximums of power generated by the defect are to be found. Because of the construction the most commonly chosen vibrations measurement point is the piston or the engine body.

The received signal is strongly interfered by various vibration sources and that is why there is a necessity to use advanced methods of signal selection. Due to the impulsive character of the inputs, the spectral diagnostic bands are in the area of high frequencies. That is why there is a need to use the acceleration sensors with high transfer range and their proper fastening on the body or the piston of the engine. The engine body is characterised by the low coefficient of dumping and that is why the vibrations of low and medium frequencies up to a few kHz are only slightly dumped on the propagation way. Stronger dumping effects appear only for frequencies of 10 kHz or more [10]. Dissipated energy in time of one vibration cycle for a given material is approximately stable.

For higher frequencies in the same period of time a bigger number of cycles appear and that results in higher dissipated energy. The fact, that the amplitude of elastic waves decreases with moving away from the input source, should also be taken into account. By high vibration frequencies in engine block there is a possibility of formulation of sinusoidal elastic waves. Their amplitudes decrease inversely proportional to the distance from the point of reception from the source and that is why the choice of fastening the converter of the acceleration is the more important, the higher frequencies are generated by the defect. The diagnostic signal is received in any place of the engine construction is weighted sum of its answers to all elementary events $x_i(t,\theta)$*, where as a balance we have here a convolution with impulse transition function* $h(r_i,t,\theta)$ *from the point of its generation to the reception of the diagnostic signal [10].*

In an internal combustion engine single events occur in a cycle sequence, and their repetition in each next cycle is a symptom of the working engine. Elementary events occurring in kinematic pairs occur also in an order. That is why, according to the place of impact impulse in respect of reference signal one can define an engine kinematic pair which created the impulse. It is then possible to isolate a summary signal of a tested kinematic pair (tested cylinder of a multi-cylinder engine) with the use of time selection.

Spectral selection of signals, however, is an efficient diagnostic tool, particularly in case, when the defect development stimulates vibrations in a tested system on its own frequency. In vibroacoustic diagnostics of internal combustion engines, among other methods, the comb filtering, synchronic averaging and selection in the field of time and rotation angle of the crankshaft are the methods used. Due to the fact, that the acceleration converters are characterised by big direction selectivity, the proper sensor placement enables the spatial selection of the diagnostic signal.

Research Experiment

Data in the experiments carried out is derived from time runs of the vibration accelerations in the engine body. The subject of tests was a Fiat

Panda with SI engine 1.2 dm^3. The tests were carried out in the roller bench. The vibration acceleration signal of the engine body was measured perpendicularly to the cylinder axis with a sensor placed at the 4th cylinder. The vibration acceleration transducer type ICP and data acquisition card controlled by a program developed in LabView environment were used for the measurements. The signals were recorded at the velocity of 2500 rpm, at the sampling frequency of 40 kHz. During the tests, 23 runs of accelerations of the engine body vibration were recorded before the repair, and 27 runs of accelerations of the engine body vibration were recorded after the repair, including full operating cycles within the rotation angle of 0-720°. The engine repair involved the replacement of worn pistons which reduced the clearance in the piston-cylinder assembly.

Refer to figure 1 for examples of vibration signals recorded before and after the repair.

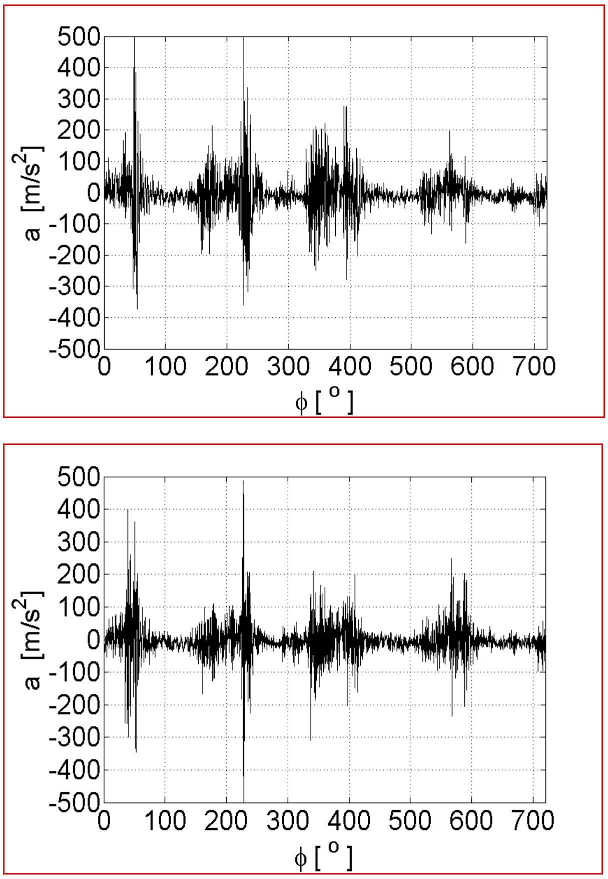

Fig. 1 Vibration acceleration runs recorded on the body before (a) and after (b) the engine repair.

The repair of the engine did not explicitly affect the character of changes in local measurements derived from the vibration signals (Table 1). Both, the measurements of average position, differentiation, the group of slope measure and the distribution kurtosis of measurable variants of vibration accelerations in time domain did not allow the clearance in the piston-cylinder assembly to be explicitly identified.

Tab. 1: Selected measures obtained from vibration accelerations

Parameter	Value of measure for engine	
	before repair	after repair
Root mean square	101,3	95,3
Mean value	50,3	48,4
Mean absolute deviation	49,9	48,2
Kurtosis	13,8	14,1
Crest factor	9,9	10,5
Clearance factor	1,4	1,4
Shape factor	2,0	1,9
Impulse factor	19,9	20,7

According to the studies carried out to date, wherever the vibro-accoustic signal can be presented as a series of elementary events, the cepstrum analysis can be useful:

$$C(\tau) = \sqrt{\left| FFT\left[\log\left(G_{uu}(f)\right)\right]^2 \right|} \qquad (1)$$

where $G_{uu}(f)$ – densities of spectral power.

Occurrence of noise, especially of periodic nature, is possible to be identified with that analysis [1]. It allows separating the series components respectively to the pulse response of the system and the initiation [11]. Series identity is used here in the time domain with the product of Fourier transforms in the frequency domain. For the diagnostics of technical facilities, the cepstrum analysis is used for all applications in which the change of state results in the appearance or disappearance of harmonics.

Cepstrum was determined from the recorded accelerations of engine body vibrations.

Refer to figure 2 for examples of cepstrum derived from the vibration signal for two different states of the engine.

According to the studies, signal analysis in two selected representative frequency ranges is required to evaluate the piston-assembly wear. Therefore, in the next stage of model construction, the cepstrum range achieved was divided into 5 sub-ranges:

- *sub-range I: 0 to 0.01 [s],*
- *sub-range II: 0.01 to 0.02 [s],*

- *sub-range III: 0.02 to 0.03 [s],*
- *sub-range IV: 0.03 to 0.04 [s],*
- *sub-range V: 0.04 to 0.05 [s].*

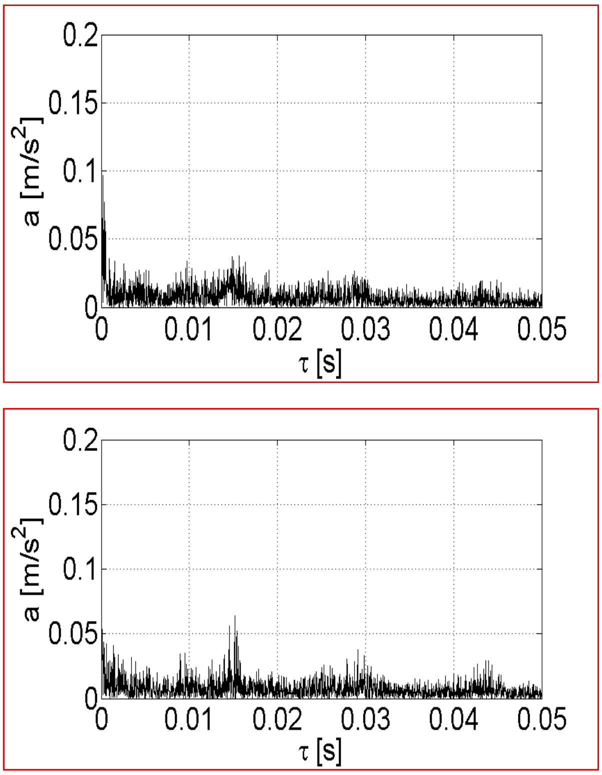

Fig. 2 Cepstrum of vibration accelerations recorded on the body before (a) and after (b)the engine repair.

A histogram was prepared to enable the description of the character of cepstrum changes for each sub-range. The limits of the histogram ranges were assumed by dividing the amplitude of cepstrum (determined for the maximum value of a given sub-range) into 5 equal parts. Based on the initial experiments, it was found that better results are obtained by assuming the value of the maximum cepstrum amplitude range, separately for signals recorded prior to and after the engine repair, than for the range determined based on all recorded signals, either before, or after the repair. The histogram ranges assumed for further experiments are as follows:

- *range 1: 0 to 20 % maximum cepstrum amplitude in a given sub-range,*
- *range 2: 20 to 40 % maximum cepstrum amplitude in a given sub-range,*
- *range 3: 40 to 60 % maximum cepstrum amplitude in a given sub-range,*
- *range 4: 60 to 80 % maximum cepstrum amplitude in a given sub-range,*
- *range 5: 80 to 100 % maximum cepstrum amplitude in a given sub-range.*

Refer to figure 3 for an example of cepstrum histogram for accelerations of engine body vibrations with various clearance values in the piston-cylinder assembly.

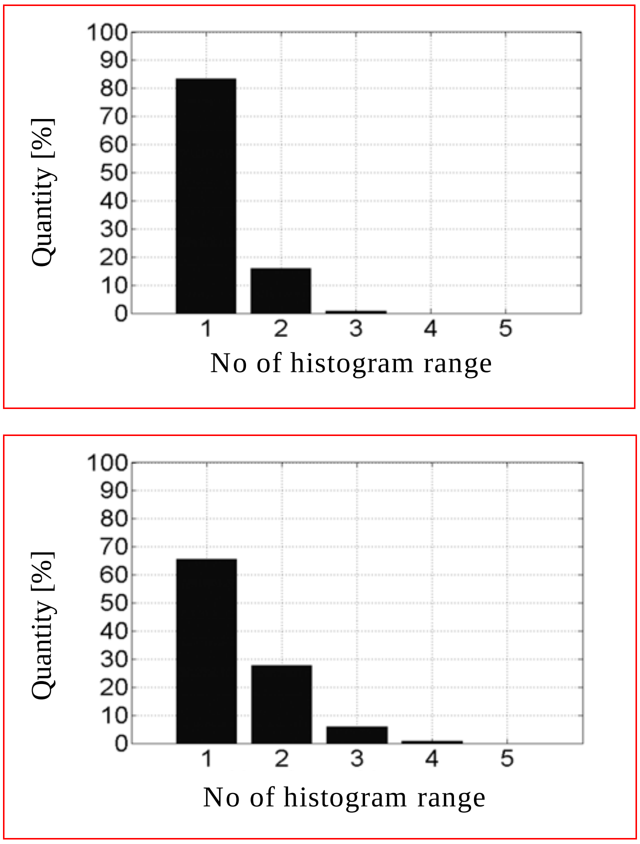

Fig. 3 Sample cepstrum histogram of vibration accelerations recorded o the body before (a) and after (b) the engine repair.

For all recorded time runs of the accelerations of vibration measured prior to and after the engine repair, cepstrum histograms were determined according to the procedure described.

Another stage of the modelling process was to select only those ranges of cepstrum amplitude (range 1 – 5) and only such cepstrum sub-ranges (sub-range I – V) for which the separation for classes referring to the worn and new pistons was visible.

As a result of selections which best separate the states prior to and after the engine repair, 15 comparisons between the cepstrum sub-range and histogram range were selected.

Refer to figure 4 for a sample comparison of cepstrum sub-range and histogram range for correct and incorrect classes separation.

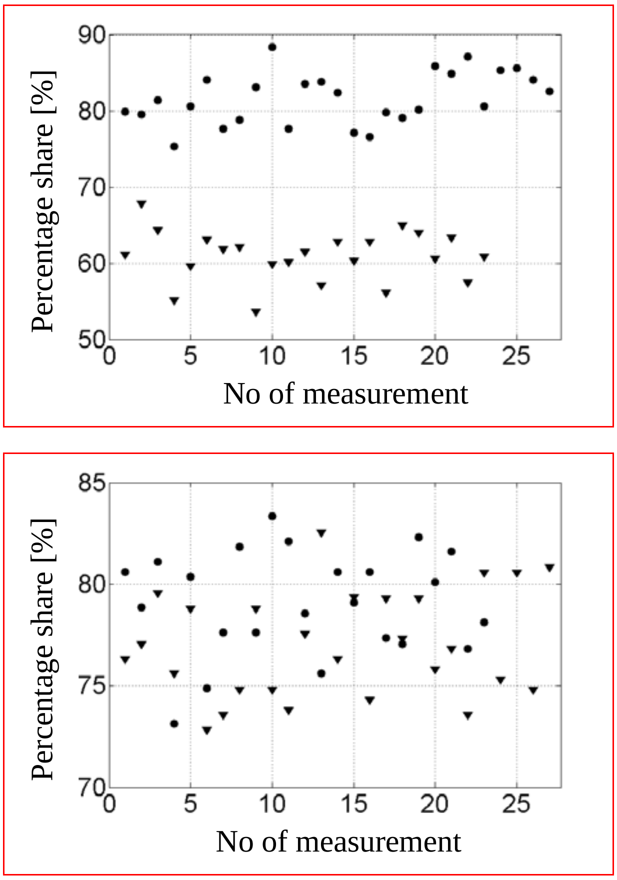

Fig. 4 Sample comparison between the cepstrum sub-range and histogram range for the correct (a) and incorrect (b) separation of wear classes of the piston-cylinder assembly (“triangle“ – engine prior to repair, “circle“ – engine after repair)

CONCLUSION

The block and head vibrations of a given engine are caused by many inputs connected with its rotational speed. Their intensity rises with the appearing mechanical defects, exploitation consumption and the occurring anomalies in the burning process.

From the tests conducted so far, one can gather that adaptive systems of engine steering can cause masking of some mechanical defects, particularly in the early development stages. That is why, in the diagnostic of internal combustion engines, one searches new processing methods of damage development sensitive signals.

In the conducted tests the signals of vibration acceleration were used to define the influence of the state of simulated clearance in the piston-cylinder combination. Due to the fact, that the internal combustion engines are complex diagnosis objects, the use of traditional analysis methods does not provide the precise identification of the characteristic inputs.

The tests show, that on the basis of cepstrum selection one can select the required measures of vibration signals, sensitive to the exploitation consumption of the piston-cylinder system. Such measures can be used to build a properly functioning diagnostic system based on artificial intelligence methods [12].

It is necessary to create the proper algorithms completing the OBD systems which would enable to detect the mechanical defects of an engine, which may be masked by the electronic steering devices of the presently used car vehicles

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