THE IDENTIFICATION OF PISTON-CYLINDER CLEARANCE USING TIME-FREQUENCY METHODS

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Abstract

A fault recognition technique for the internal combustion engines using time-frequency representations of vibration signal has been presented in this paper. Engine block vibration results as a sum of many excitations mainly connected with engine speed and their intensity increases with the appearance of a fault or in case of higher engine elements wearing. In this paper an application of acceleration signals for the estimation of the influence of piston skirt clearance on diesel engine block vibrations has been described. Engine body accelerations registered for three simulated cases representing piston skirt clearance variations were an object of preliminary analysis. The presented procedures were applied to vibration and pressure signals acquired for a 0.5 dm3 Ruggerini, air cooled diesel engine. Reciprocating machines are difficult to diagnose using traditional frequency domain techniques due to the fact they generate transient vibrations. In the experiments that were conducted Gabor Analysis and Adaptive Spectrogram has been chosen The Gabor spectrogram is a powerful tool for on-line monitoring and diagnosis of combustion process. There are important features of the vibration signal that are sensitive to the change of IC engine condition. For that reason the DWT transform was applied. Based on the results, authors propose detection and piston skirt clearance monitoring algorithm.

Keywords: *fault diagnosis, engine vibration, Gabor Spectrogram, Adaptive Spectrogram*

1. Introduction

Piston slap is one of the most characteristic sources of engine body vibrations. Intensity of that excitation and its variations for different engine cycles depends mainly on in-cylinder pressure alterations. Changes of piston slap force value, influencing the piston horizontal movements result also from the following factors:

- piston and piston pin mass, connecting rod mass,
- dimensions and the geometry of crank-connecting rod mechanism,
- engine crankshaft angle,
- engine speed and its load,
- piston skirt clearance.

Engine block vibrations result as a sum of many excitations mainly connected with engine speed, and their intensity increases with the appearance of a fault or in case of higher engine elements wearing. There are several fault recognition methods currently in use, they are based on spectrum density analysis both in time and frequency domains, FFT, as well as on wavelet transform and Wigner-Ville transform [3-10].

In this paper, acceleration signals were used to estimate the influence of piston skirt clearance on engine block vibrations. Values of piston slap force, responsible for piston movement, were estimated on the basis of dynamic models of piston-connecting rod mechanism and the in-cylinder pressure variations in the function of engine crank angle.

Engine body vibration signal, registered for three simulated cases representing piston skirt clearance variations, was an object of preliminary analysis.

2. Experimental setup

All the described tests were conducted on a 0.5 dm^3 Ruggerini, air cooled diesel engine. Technical description of the test object has been listed in the table 1.

Test program provided sampling of the following data:

- in-cylinder pressure,
- vibration signal of engine head and wall, in two directions: x and y,
- crankshaft speed, together with TDC recognition,
- engine torque,
- manifold pressure.

In-cylinder pressure was measured with the use of piezoelectric pressure transducer type 6121 by KISTLER, coupled with charge amplifier model 5011.

Crankshaft position and TDC recognition has been completed with the use of KISTLER 2613B transducer. Engine body vibrations were measured with ICP sensors by PCB interfacing with PA3000 signal conditioner manufactured by Roga Instruments.

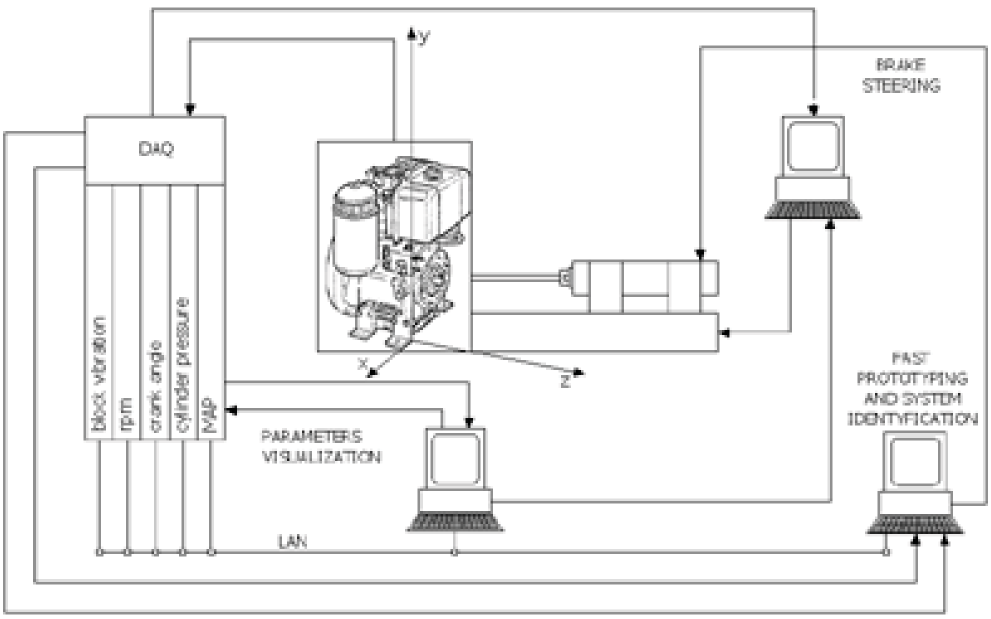

Fig. 1. Schematic diagram of experimental setup

3. Results discuss and analysis

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- piston skirt clearance.

Many publications connected with that problem provide a lot of useful information regarding the sources of vibration signal, as well as about methods concerning their application for IC engine technical state analysis [1-5]. Engine block vibrations result as a sum of many excitations mainly connected with engine speed, and their intensity increases with the appearance of a fault or in case of higher engine elements wearing.

In this paper, acceleration signals were applied for the purposes of estimation of piston skirt clearance influence on engine block vibrations. Values of piston slap force, responsible for its movement, were estimated on the basis of dynamic models of piston-connecting rod mechanism and the in-cylinder pressure variations in the function of engine crank angle.

The analysis has been completed in a way allowing the identification of two characteristic ranges of vibration signal close to TDC (Fig. 2, 3 and 4):
- first range – from 300 o to 372o crank angle,
- second range - from 372 o to 420 o crank angle.

First range includes information about the combustion initiation and its development. In the second range, temporarily increasing vibration acceleration may be noticed, which describes the piston slap phenomena.

Crank angle range for which temporary amplitude vibration acceleration increase occurs, caused by piston slap phenomena varies with the simulated clearance.

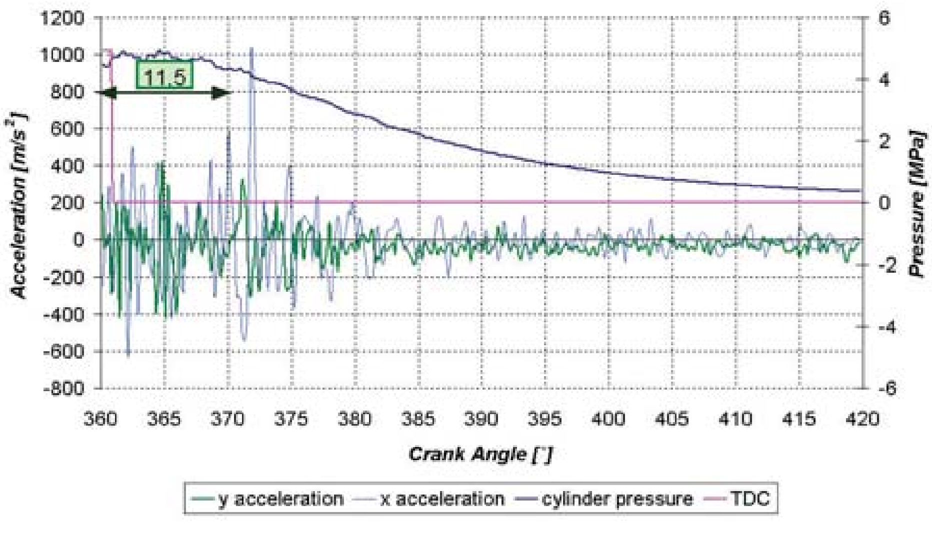


Fig. 2. Vibration acceleration amplitude angle shift for nominal clearance

With the increasing clearance the crank angle and a time delay raise.

The analysis of obtained results makes it possible to define that crank angle delays do fluctuate. It may be noticed for cases of 11.5° after TDC for nominal clearance, 13° after TDC for two times bigger clearance and 15.5° after TDC for four times bigger clearance then nominal.

For three simulated clearance values the engine vibration amplitude delay raises, as the effect of piston slap, that occurs however in the different points of a 372-420 CA deg range depending on actual clearance.

Preliminary time-frequency analysis involved Gabor’s and Adaptive spectrogram dispositions.

Due to vibration acceleration amplitudes drop that accompanies piston slap, registered phenomena has very high values. Those calculations were carried out independently for both crank angle ranges. Results of these calculations have been presented on the Fig. 5-10.

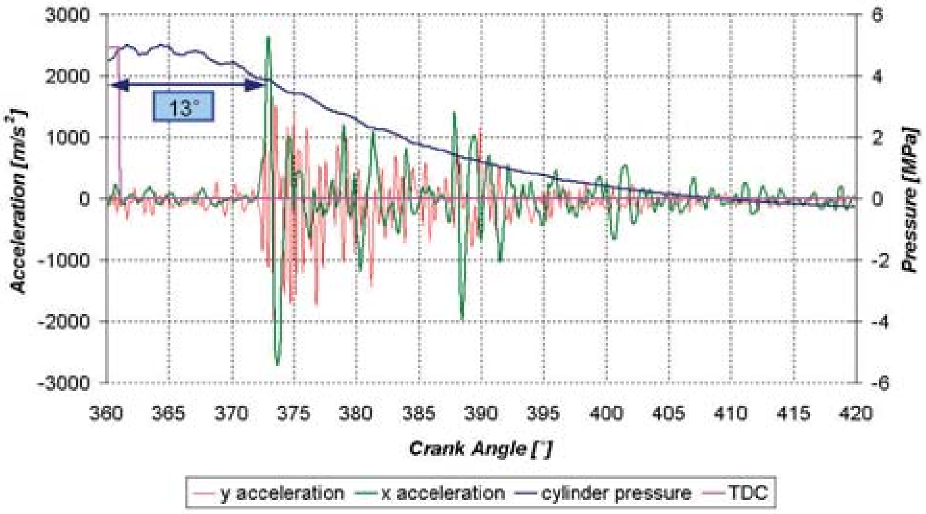


Fig. 3. Vibration acceleration amplitude angle shift for 2x nominal clearance

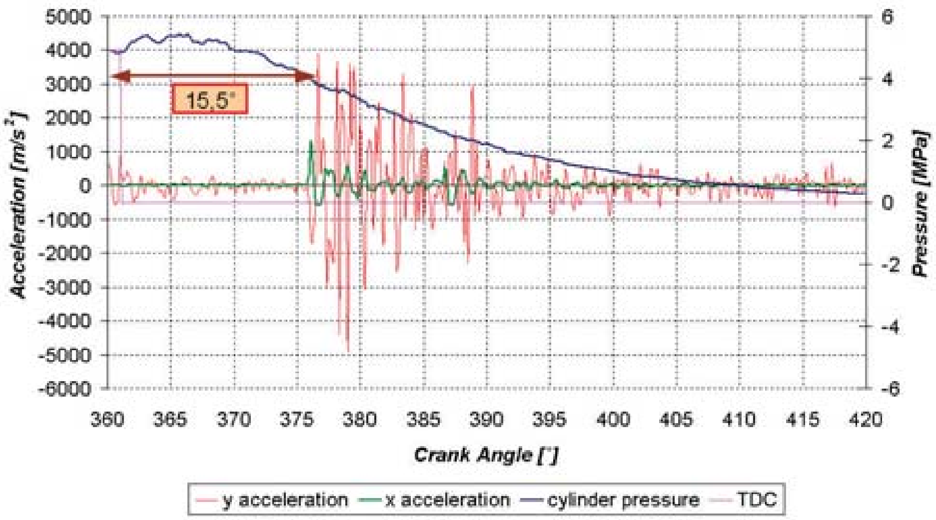


Fig. 4. Vibration acceleration amplitude angle shift for 4x nominal clearance

Figures present engine body acceleration traces and its time-frequency representation for three different simulated clearance values. Traces obtained for nominal clearance are presented on Fig. 5 and 8, meanwhile Fig. 6 and 9 presents results for 2 times bigger clearance while Fig. 7 and 10 for the 4 times bigger clearance. Changes in signal traces due to bigger clearance may also be noticed in time frequency plane.

Presented time-frequency analysis results do not allow simple piston-cylinder wall clearance identification. This happens mainly because of presence of hidden components describing the combustion process especially for four times bigger clearance. It is necessary therefore to find another way for identification of simulated piston-cylinder wall cylinder clearance.

Acceleration signals registered for three different clearance values were analyzed with the use of DWT (Discrete Wavelet Transform). In the first case, the decomposition level results to be properly chosen – therefore it was possible to separate components of mechanical phenomena from the ones regarding the combustion process and enable of it to identify simulated piston clearance value (Fig. 11).

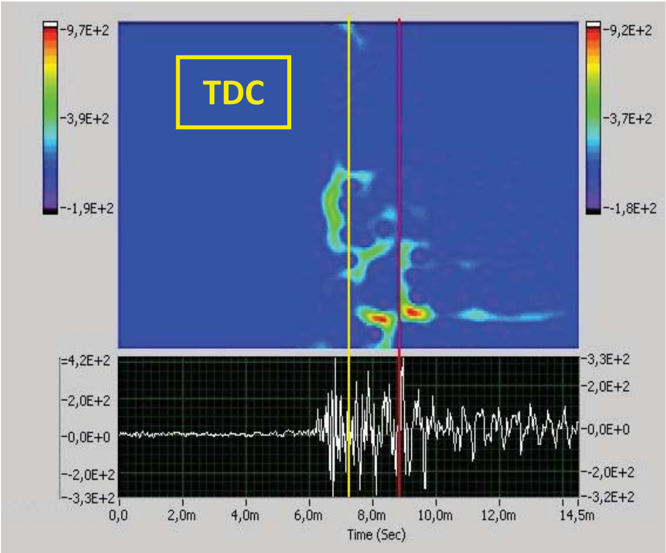


Fig. 5. Gabor analysis result, nominal clearance n = 1415 min^{-1}, x-axis

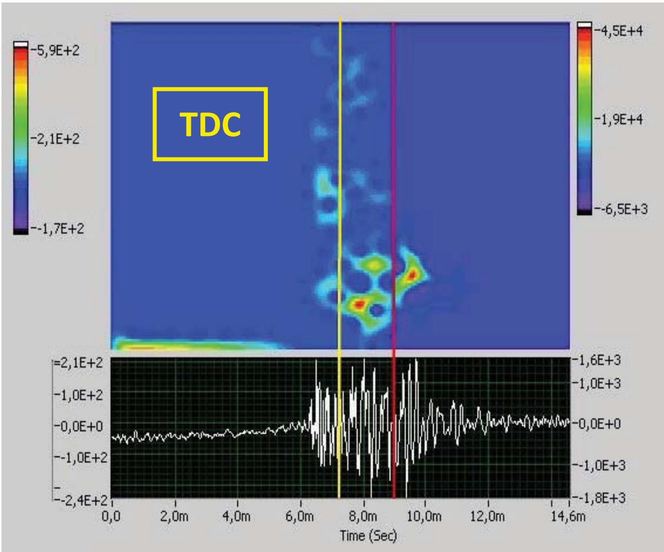


Fig. 6. Gabor analysis result, 2x nominal clearance n = 1437 min-1, x-axis

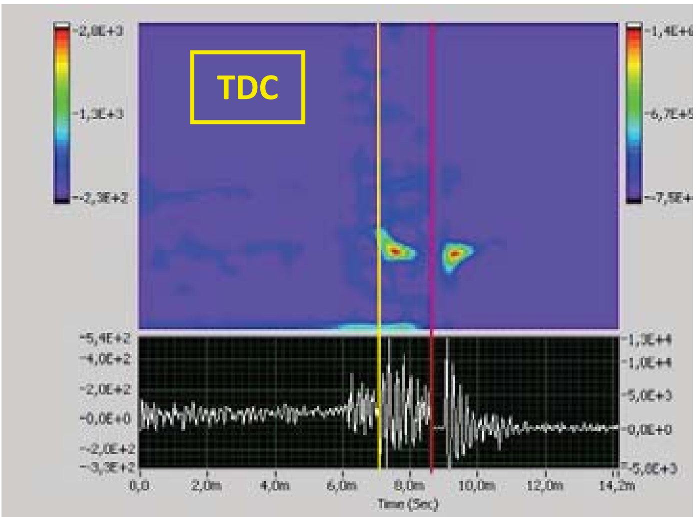


Fig. 7. Gabor analysis result, 4x nominal clearance n = 1415 min-1, x-axis

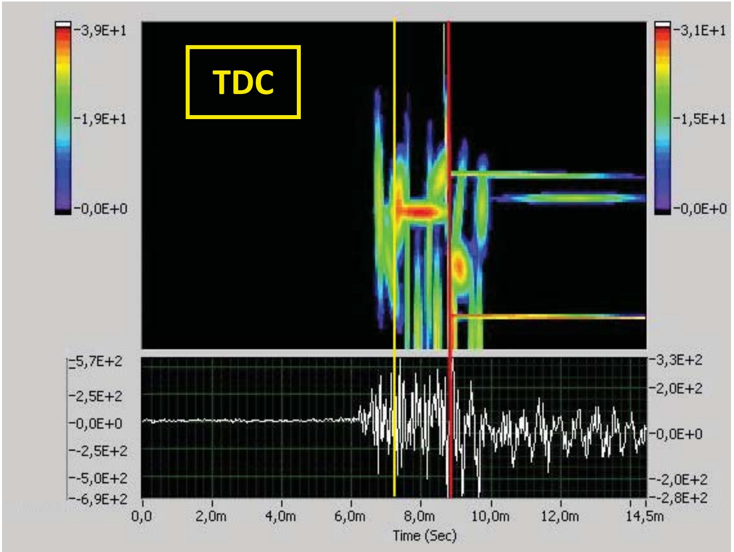


Fig. 8. Adaptive spectrogram analysis result, nominal clearance n = 1415 min-1, x-axis

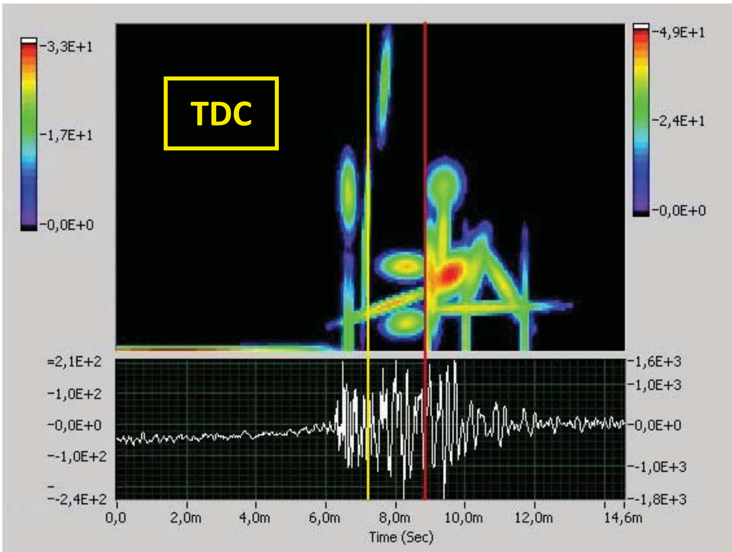


Fig. 9. Adaptive spectrogram analysis result, 2x nominal clearance n = 1437 min^{-1}, x-axis

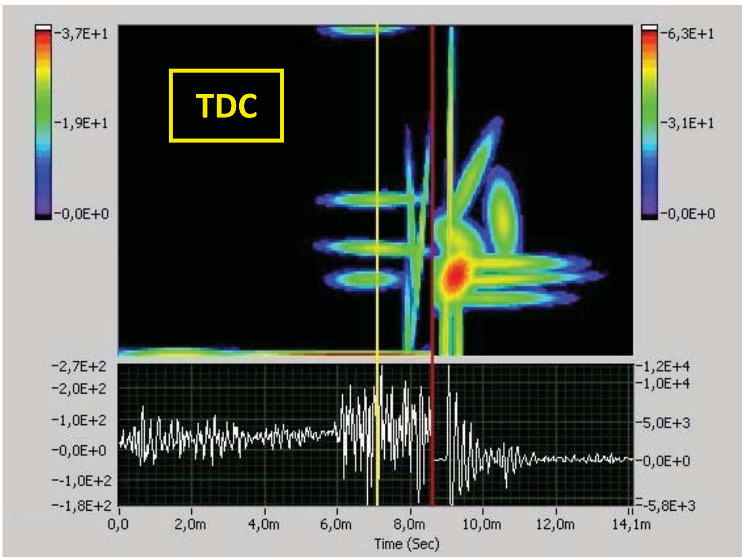


Fig. 10. Adaptive spectrogram analysis result, 4x nominal clearance n = 1415 min-1, x-axis

For signals after decomposition, calculation of factors and pointers has been carried out. Results have been shown on the Fig. 12 and 13.

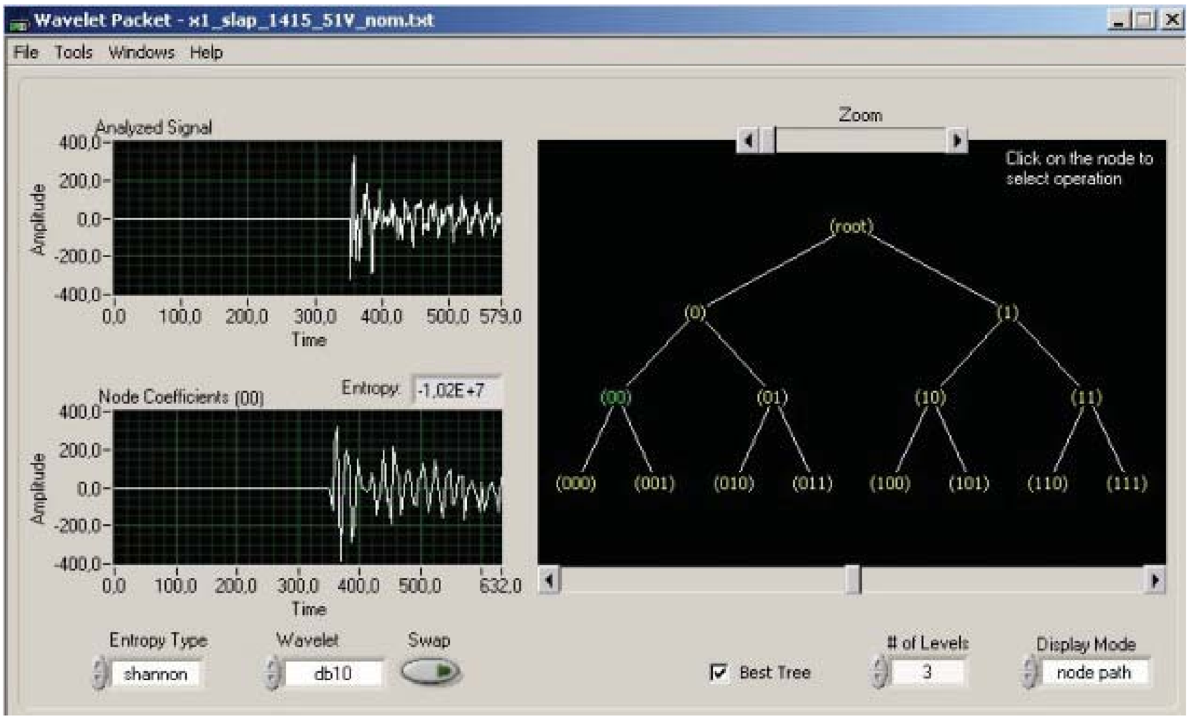


Fig. 11. DWT decomposition

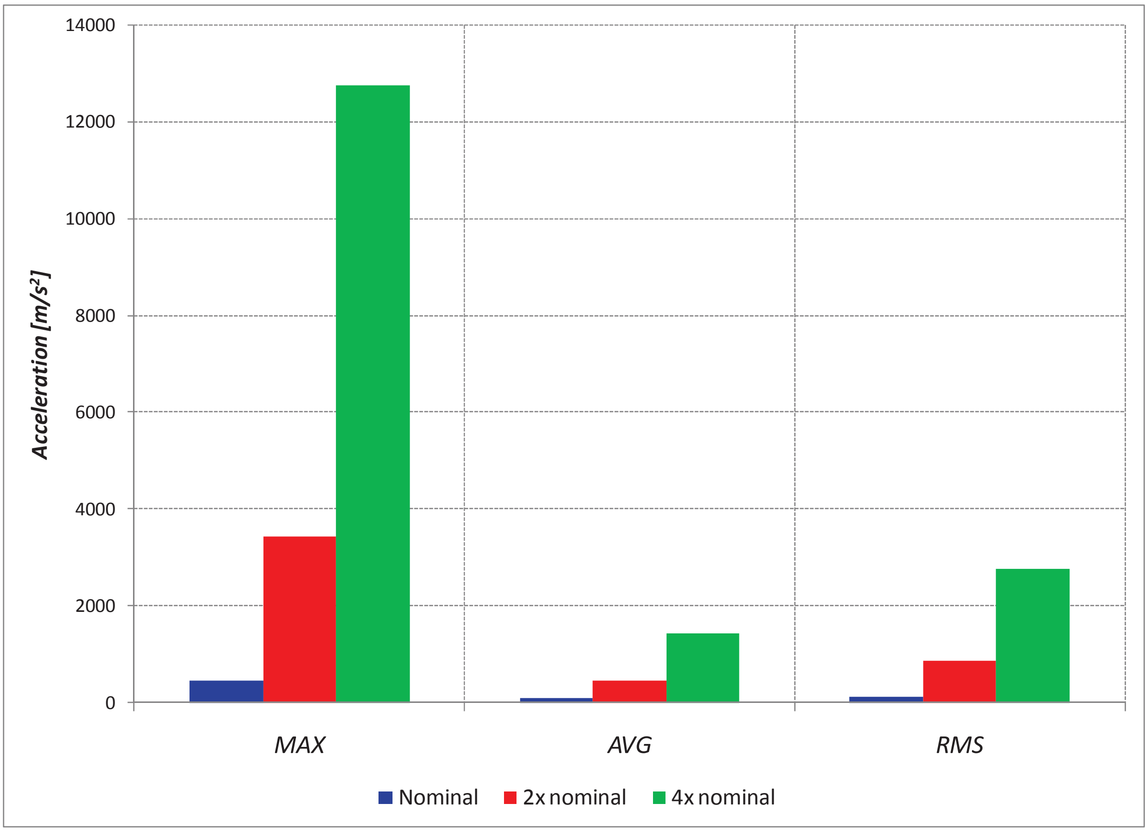


Fig. 12. Pointers calculated for acceleration signal after decomposition

The same signals analyzed with the use of Gabor's spectrogram in time-frequency plane have been shown on the Fig. 14.

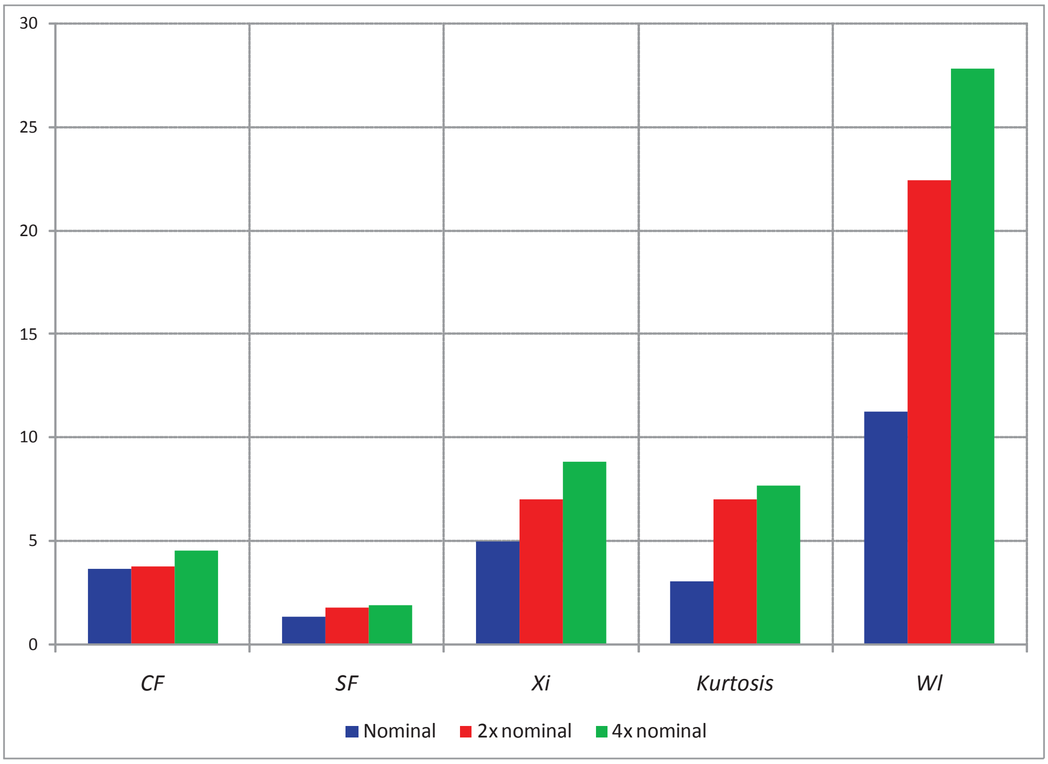
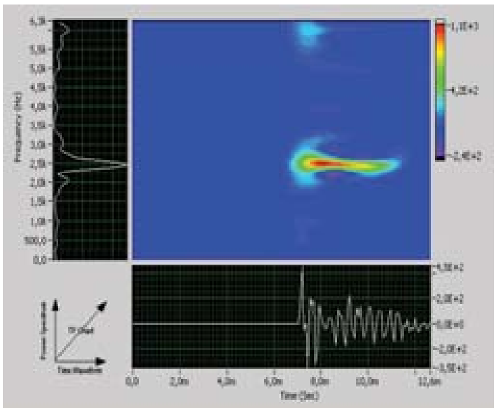
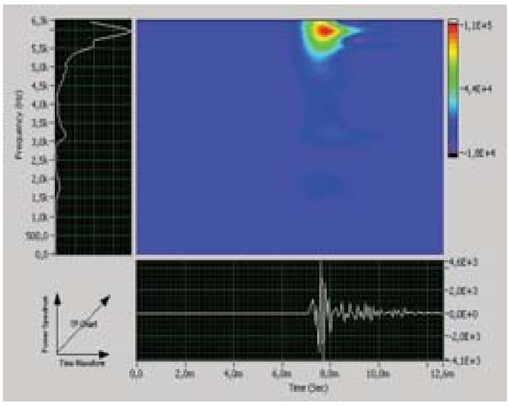


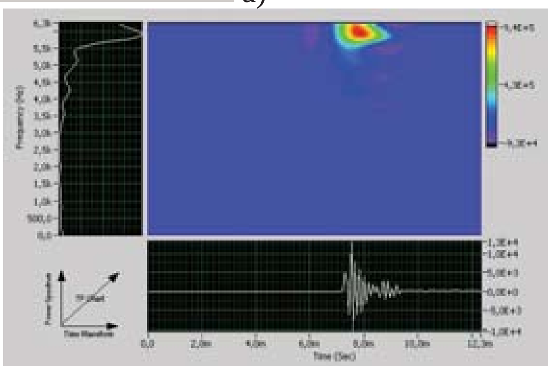
Fig. 13. Factors calculated for acceleration signal after decompsition



a)



b)



c)

Fig. 14. Results of Gabor's analysis for signal after decomposition, a) for nominal clearance, b) for two times bigger clearance, c) for four times bigger clearance

Results presented on time-frequency planes show that the maximal frequency values for different piston skirt clearances tend to move in the direction of higher frequencies. It can also be noticed that the vibration signals acceleration values increase together with the raising piston skirt clearance.

4. Conclusion

The Gabor spectrogram results a powerful tool for on-line monitoring and diagnosis of combustion process. Due to very high amplitude of mechanical phenomena it should be calculated separately for both crank angle ranges. It can recover important features of the vibration signal that are sensitive to the change of IC engine condition. That is the reason to apply the DWT transform.

Based on the results authors have proposed detection and piston skirt clearance monitoring algorithm, presented on the Fig. 15.

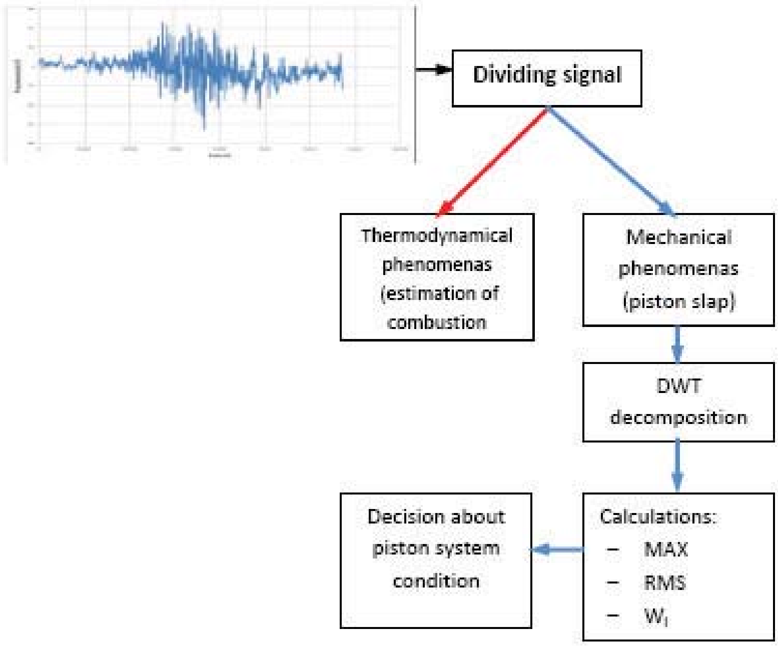


Fig. 15. Engine piston system condition algorithm

References

[1] Shibata, K., Takahashi, A., Shirai, T., *Fault diagnosis of rotating machinery through visualization sound signals*, Mech. Syst. Signal Process, 14, 229-241, 2000.

[2] Wang, W. Q., Ismail, F., Golnarghi, F., *Assessment of gear damage monitoring techniques using vibration measurements*, Mech. Sys. Signal Process, 15(5), 905-1022, 2003.

[3] Bai, M. R., Jeng, J., Chen, C., *Adaptative order tracking technique using recursive last-square algorithm*, Trans. ASME J. Sound Vibr., 124, 502-511, 2004.

[4] Tse, P. W., Yang, W. X., Tan, H. Y., *Machine fault diagnosis trough an effective exact wavelet analysis*, J. Sound Vib., 227, 1005-1024, 2004.

[5] Lin, J., Qu, L., *Feature extraction based on Morlet wavelet and its application for mechanical fault diagnosis*, J. Sound Vib. 234(1), 135-148, 2000.

[6] Jang, S., Cho, J., *Effect of skirt profiles on the piston secondary movements by the lubrication behaviors*, Int. Journal Aut. Technology, Vol. 5, 23-31, 2004.

[7] Antoni, J., Daniere, J., Guillet, F., *Effective vibration analysis of IC engines using cyclostationarity, Part I – A methodology for condition monitoring*, Journal of Sound and Vibration, 257(5), pp. 815-837, 2002.

[8] Badaoui, M. E., Daniére, J., Guillet, F., Serviére, C., *Separation of combustion noise and piston-slap in diesel engine – Part I: Separation of combustion noise and piston-slap in diesel engine by cyclic Wiener filtering*, Mechanical Systems and Signal Processing, 19, pp. 1209-1217, 2005.

[9] Geng, Z., Chen, J., *Investigation into piston-slap-induced vibration for engine condition simulation and monitoring*, Journal of Sound and Vibration, 282, pp. 731-751, 2004.

[10] Inagaki, M., Kawamoto, T., Yamamoto, K., *Prediction of structural and cinematic coupled vibration on Internal Combustion engine*, R&D Review of Toyota CRDL, Vol. 37, No. 2.
[11] Flekiewicz, M., Madej, H., *Influence of Combustion Noise on Engine Block Vibration in IC Engine Fueled by LPG*, VAFSEP 2006, DCU. pp. 67-75, 2006.
[12] Flekiewicz, M., Flekiewicz, B., Fabiś, P., Madej, H., Wojnar, G., *Influence of piston slap on engine block vibration*, SAE Paper 2007-01-2163.