THE ARCHIVES OF TRANSPORT

VOL. XXIV NO 1 2012

10.2478/v10174-012-0008-2

Frequency Analysis of Vibrations of the Internal Combustion Engine Components in the Diagnosis of Engine Processes

Franciszek Tomaszewski*
Grzegorz M. Szymański*

Received February 2011

Abstract

Many methods of diagnosing internal combustion engines have been already worked out. They can be divided into methods using working processes and methods using leftover processes. Working processes give information about general condition of internal combustion engine. Leftover processes give information about condition of particular subassemblies and kinematic couples; hence they are used as autonomous processes or as processes supporting other diagnostic methods. Methods based on analysis of vibrations and noise changes to determine technical condition of object are named as vibroacoustic diagnostics. In papers about vibroacoustic diagnostics of engine, problems connected with difficulty to select test point and to define diagnostic parameters containing essential information about engine's condition, are most often omitted. Selection of engine's working parameters and conditions of taking measurements or registering vibration signal are usually based on references, researcher's experience or intuition. General assumptions about taking measurements of signal closest to its source are most often used. Application of vibrations and noise generated by working combustion engine to assess correctness of its work and technical condition has many advantages. Vibroacoustic processes are a good carrier of diagnostic information for the following reasons:

– high information capacity,

– high speed of data transfer (signal's component describing change in object's condition is visible the moment the inefficiency occurs),

– vibration signal reflects all significant processes in combustion engine,

– measurement of vibrations and noise does not require special preparations of technical object for tests and can be carried out during regular operations.

This article presents a new approach to vibroacoustic diagnostics of internal combustion

* Poznań University of Technology Poznań, Poland

engine. Selection of test points of vibration on the basis of impact tests' results was suggested. Those results were applied to build dynamic models of systems of combustion engines. Such model was used to assess condition of the systems.

1. Introduction

Diesel combustion engines (ZS) of medium and high power are used as parts of drive units in railway vehicles. Diagnosing of their technical condition enables to carry out an overhaul policy conditioned by technical condition, to prevent most of unplanned outages and by detecting defects in early stage, to decrease significantly the scope and the cost of overhaul and service. Safety of transportation and their timelines constitute a separate issue.

To assess technical condition and working conditions (functional and operation parameters) of combustion engine, parameters and characteristics of vibration signal generated by combustion engine [3,4,5] are more and more often used. However, receiving from vibrations diagnostically usable information is not easy. Difficulty to identify and to deduct the technical or working condition of engine's part or subassembly on the basis of commonly used parameters and characteristics of vibroacoustic signal (WA), stems, among others, from complex nature of vibrations generated by engine, processes proceeding inside, coexistence of many sources of vibrations and complex kinetics. An important problem is the selection of the point of acquisition of vibration signals is described, among other things in the works [7,8,9]. This paper presents a conception of diagnosing combustion engines by using frequency analysis of proper vibrations of engine's structure.

2. Identification of Frequency of Propervibrations of Selected Engine's Parts

To assess technical conditions of combustion engine, parameters of accompanying processes, working processes and parameters of processes used in nondestructive tests (e.g. ultrasounds) are used as a vector signal. The following values describe working processes used in diagnostics of combustion engines: power, torque, reaction torque, instantaneous angular speed and turning angle of crankshaft etc. They are used as conceptualized parameters of technical condition of engine.

Parameters of accompanying processes (vibrations, noise, thermal processes, wear etc.) are used to diagnose detailed technical condition of engine and to localize failures. In diagnostics of combustion engine, vibroacoustic processes (vibrations, noise) are the most often used accompanying processes.

A working combustion engine generates vibrations, which are an accompanying process to processes proceeding in engine's units. To assess technical condition of combustion engines vibration components can be used, which are connected with excitation frequencies generated by units, kinematic couples and engine's parts or frequencies of proper vibrations of parts. This paper focuses on diagnostics using effects of proper vibrations of combustion engine's parts.

To work out a method of diagnosing combustion engine based on analysis of proper vibrations, impact tests of selected (main) engine's parts were carried with particular consideration of piston-crankshaft system and then values of frequencies of proper vibrations of those parts or units were compared to frequencies that can be observed during frequency analysis of signal generated by a working engine. On the basis of changes of amplitude in particular wavebands, change of technical condition of combustion engine's parts or units can be found out.

2.1. Analysis of test results

To assess frequencies of proper vibrations of selected parts and units of combustion engine type 2112 SSF, impact tests were carried out. Registered signals of vibration accelerations were made subject to analysis in frequency domain. Such analysis consists in defining series of characteristics, which present dependencies of various values (e.g. amplitude, power, phases) from frequency.

During analyses, normalization and averaging of amplitude spectrum were carried out. Normalization enabled comparing spectra defined for various excitation powers. The purpose of aver-aging was to minimize influence of hums on the results of signals' analyses.

Because of formal matters, this paper includes graphic presentation of results of a selected engine's unit – head and cylinders. Exemplary time flow of impact reply and power exciting head's vibrations is presented in Fig. 1.

It results from Fig. 1 that duration of impact of power exciting vibrations is multiply shorter than deadening time of vibrations in engine's parts.

Heads (one per a cylinder) are made of alloy cast iron with addition of silicon and manganese. Heads of engines 2112 SSF are equipped with four valves, injector, indicating valve. They are mounted to engine block with double-nutted bolts. A head of internal combustion engine is a complex unit. During engine work, a head is affected by powers exciting its vibrations. The powers stem form the following physical and chemical processes:

- combustion of combustible mixture in cylinder,
- flow of cooling factor, inlet and outlet gases, inlet and outlet of fuel through injector,
- inertia of cam unit's parts,
- impacts of head's parts.

Figure 2 presents normalized and averaged amplitude spectra of signals of vibration accelerations (in three reciprocally perpendicular directions) registered on a head of engine type 2112 SSF.

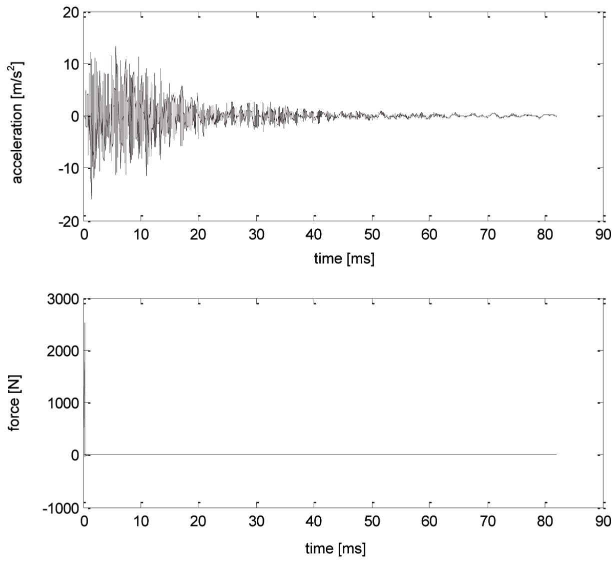

Fig. 1. Time history of impact reply and force exciting vibrations of a head of cylinders in combustion engine

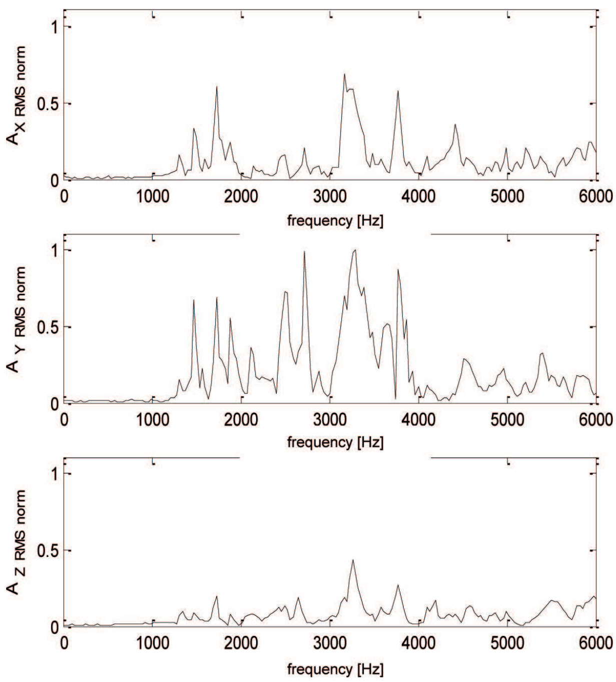

Fig. 2. Normalized and averaged spectra of signal of vibration accelerations for converter mounted on a head

Analysis of signals of vibration accelerations enabled assessing frequencies, which are supposed to be frequencies of proper vibrations of a head of engine 2112 SSF.

On the basis of carried out analyses, frequencies were assessed, which could be frequencies of proper vibrations of parts of combustion engine 2112 SSF and they were inserted in Table 1.

Table 1

Assessing values of frequencies of proper vibrations of combustion engine's parts or units

Part/unit	Frequency [kHz]						
Crankshaft	4,3	5,2	5,5	5,6			
Connecting rod	1,0	1,7	2,9	3,1	5,1	5,8	
Piston	2,4	4,4	5,2	5,5			
Piston with crankshaft	0,8	1,3	2,3	4,4			
Head	1,5	1,7	2,5	3,3	3,8	4,5	5,5

Searching for assessed values of frequencies of proper vibrations of signals registered on working engine type 2112 SSF was the next stage of the analysis. Two types of signals registered on engine's heads were analyzed. First analysis comprised signals registered in the cylinder in which combustion did not occur. This enabled assessing frequencies generated by impacts of parts (valve clearance canceling), which were affected by inertial powers. Second analysis comprised signals from the cylinder, in which combustion process proceeded properly. This enabled receiving information about frequencies generated by parts, which were affected by big impact forces resulting from combustion of load in the cylinder. Figure 3 presents averaged spectrum from signal of vibration accelerations for the case, in which in tested cylinder combustion process did not occur.

Figure 4 presents averaged spectrum from signal of vibration accelerations for the case, in which in tested cylinder combustion process occurred.

In spectrum presented in Fig. 3 the following frequencies were marked: 0.8; 1.3 and 3.3 kHz. Two first components (0.8 and 1.3 kHz) may be connected with work of piston and connecting rod system, whereas component 3.3 kHz may stem from work of head's parts.

Spectrum presented in Fig. 4 contains more frequencies, which can be frequencies of proper vibrations of engine's parts. Two first components (0.8 and 1.3 kHz) may be connected with work of piston and connecting rod system, component 1.6 and 2.9 kHz may be connected with work of connecting rod, whereas components 3.8 kHz may stem from work of head's parts.

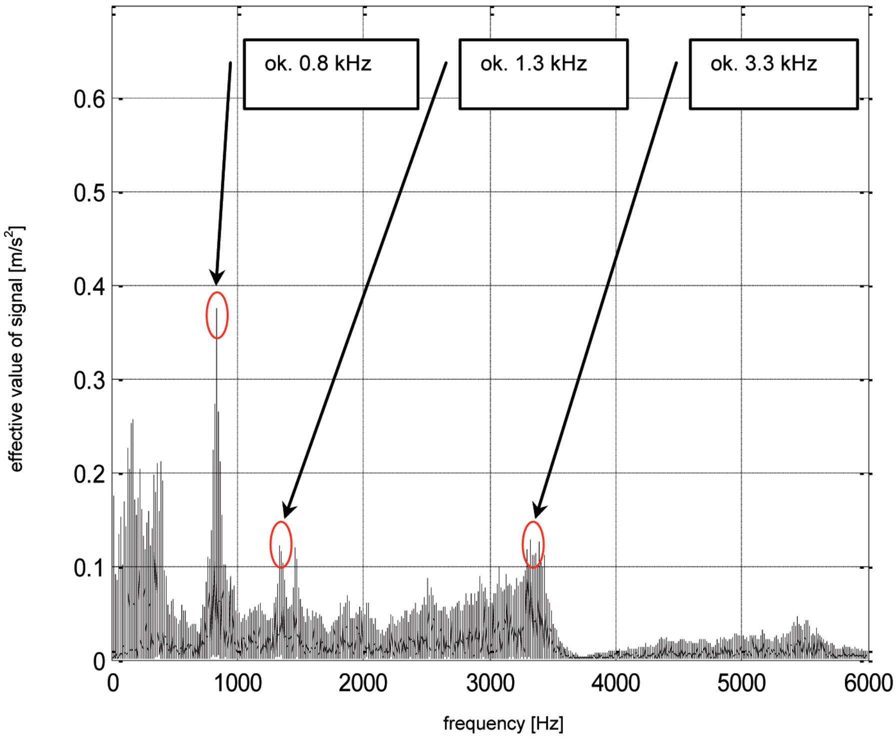

Fig. 3. Averaged spectra from signal of vibration accelerations (in tested cylinder combustion process did not occur)

3. Diagnostic Models in Assessment of Technical Condition of Combustion Engines

Complex description of effect proceeding in technical objects is difficult to realize (problems with receiving all data about a real object, problems with converting big amount of data), that is why models, which enable to describe reality with satisfactory accuracy, are used. Satisfactory accuracy means that model after considering assumptions meets comparative criteria, which were set by modeling person. General definition of model can be presented in the following way:

Model is a simplified presentation of a selected part of reality to understand it better [1].

Combustion engine is a device of a very complex structure. Various effects can be observed in it. To describe the effects, knowledge of at least a few science domains should be applied. The most important domains include: classical mechanics (study of movements and interactions of engine's parts), thermodynamics (study on heat generation and transmission), chemistry (description of combustion process) liquid mechanics (exchange of load, lubrication of engine).

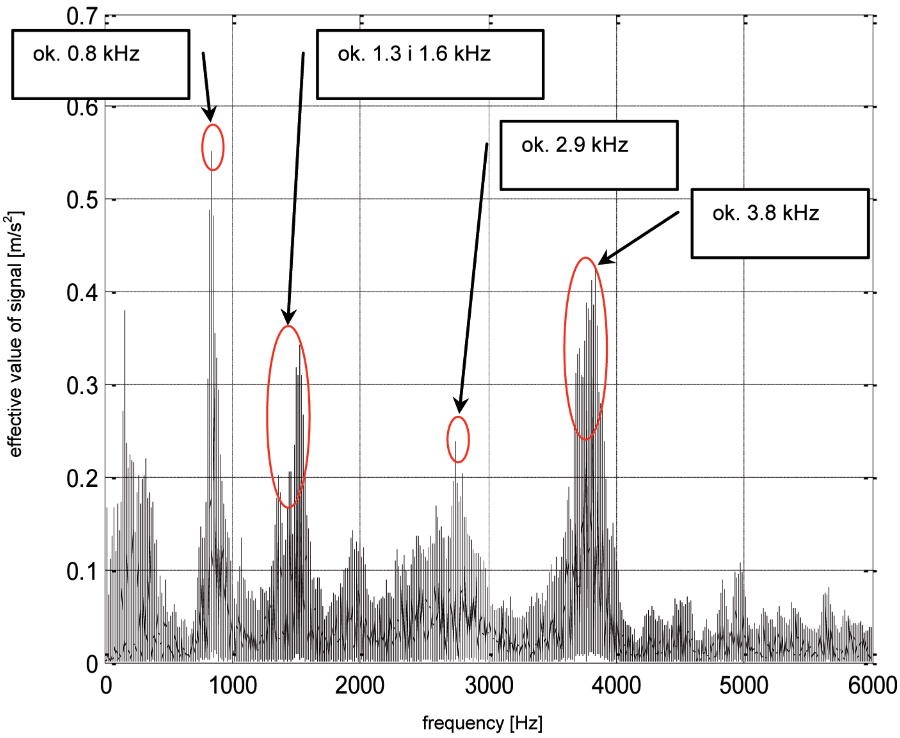

Fig. 4. Averaged spectra from signal of vibration accelerations (in tested cylinder combustion proceeded properly)

Broadly speaking – diagnostic model of an object is the relation between parameters of diagnostic signals and their conditions.

A good definition of diagnostic model of an object is presented in paper [6], it says: diagnostic model is a purpose-effect relation between characteristics of object's condition and diagnostic parameters, damage oriented, reflecting changing technical condition of the tested object.

In a more detailed definition of diagnostic model of an object, it can be said that it presents dependence relations between:

– signal parameters and condition parameters,
– signal parameters and operating parameters,
– signal parameters and conditions,
– diagnostic parameters, excitations and loads, springy and deadening parameters [3].

In this paper to assess technical condition of units of engine 2112 SSF a model presenting dependence between signal parameters and condition parameters was suggested. Amplitudes filtered in bands determined by frequencies of proper vibrations were suggested to be considered as signal parameters, whereas change of valve clearance in kinematic couples was suggested to be considered as parameters of change state of geometric values of combustion engine's part.

4. Algorithms in Diagnostics of Combustion Engine

The word algorithm comes for Arabic language and means a method of solving a problem. Each algorithm should have marked start and finish, names of objects (data), on which the actions are to be carried out, names of those activities and the order of performing them [2].

In this paper to assess technical condition of engine's units, an exemplary algorithm was suggested. This algorithm enables general assessment of technical condition of the unit in bivalent assessment of technical condition (suitable or unsuitable). Figure 5 presents algorithm of bivalent assessment of technical condition of combustion engine's unit.

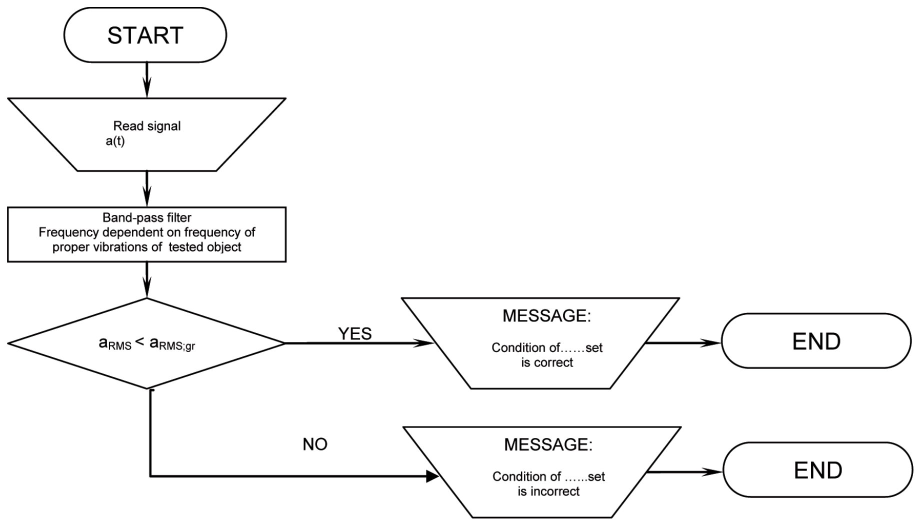

Fig. 5. Algorithm of bivalent assessment of technical condition of engine's units

In presented algorithms, the following marks were used:
a(t) – time history of vibration accelerations,
marker(t) – time history of angle marker of crankshaft torque,
$a_{rms} a_{rms\ gr}$ – effective value of vibration accelerations and their border value.

5. Conclusion

During research to assess technical condition of combustion engine, characteristics of vibration signals were used. Analysis of presented results showed that knowledge of frequencies of proper vibrations of engine's parts and units enables to increase accuracy of defining their technical conditions.

On the basis of carried out tests and analyses of results of experiment, algorithms enabling general assessment of general technical condition of engine's units and their detailed diagnostics on the basis of parameters describing vibration signal, were worked out.

Knowledge of frequencies of proper vibrations of combustion engine's parts and units enables to build model propagating vibrations in engine, which then enables application of a new trend in diagnostics i.e. diagnosing with a model.

Diagnosing with a model requires building diagnostic system, whose structure contains a model, thanks to which unsuitability of the system can be simulated and symptoms generated by a real object can be compared with symptoms defining conditions generated by model. Knowledge of the model enables working out algorithm of assessing technical condition of combustion engine's units. Construction of such diagnosing system may constitute a subject of further research.

References

1. Cempel C.: Nowoczesne zagadnienia metodologii i filozofii badań, Poznań, Instytut Technologii Eksploatacji Radom 2003.
2. Encyklopedia Powszechna. PWN Warszawa 1983.
3. Niziński S., Michalski R.: Diagnostyka obiektów technicznych, Biblioteka Problemów Eksploatacji Polskie Towarzystwo Diagnostyki Technicznej, Katedra Eksploatacji Pojazdów i Maszyn Wydziału Nauk Technicznych Uniwersytetu Warmińsko-Mazurskiego w Olsztynie, Instytut Technologii Eksploatacji w Radomiu, 2002.
4. Czechyra B., Szymański G.M., Tomaszewski F.: Assessment of camvalves clearance in internal combustion engine based on parameters of vibration – methodological assumption, Combustion engines No. 1/2004 (118).
5. Szymański G.M.: Analiza możliwości zastosowania wybranych charakterystyk sygnału drganiowego do diagnostyki silnika spalinowego. Rozprawa doktorska, Politechnika Poznańska, Poznań 2005.
6. Żółtowski B., Ćwik Z.: „Leksykon diagnostyki technicznej". ATR, Bydgoszcz 1996.
7. Łukasiewicz M.: Badania przydatności eksploatacyjnej analizy modalnej w diagnozowaniu silników spalinowych. Rozprawa doktorska, Uniwersytet Technologiczno – Przyrodniczy, Bydgoszcz 2008.
8. Randall R. B.: Vibration-based Condition Monitoring: Industrial, Aerospace and Automotive Applications, Chichester: Wiley 2011.
9. Tomaszewski F.: Zastosowanie procesów wibroakustycznych do oceny stanu technicznego silnika spalinowego lokomotywy. Praca doktorska. Politechnika Poznańska Poznań 1987.