DIAGNOSTYKA 2016, Vol. 17, No. 4

ISSN 1641-6414
e-ISSN 2449-5220

DIFFERENCE SPECTRUM AS A MEASURE OF THE STATE OF WEAR OF THE EXHAUST VALVE

Dorota GÓRNICKA
Department of Fundamentals of Machine Design and Operation, Institute of Machine Design Fundamentals, Faculty of Automotive and Construction Machinery Engineering, Warsaw University of Technology, Poland
dorota.gornicka@simr.pw.edu.pl

Summary

The article presents an algorithm of diagnosing damages to the exhaust valve of the combustion engine. The process of obtaining a symptom as a difference spectrum takes into account time selection, which allows to reduce significantly the calculations necessary to obtain a measure of malfunction. As a result, we obtain a simple measure not requiring special conditions of object work and insensitive to simultaneously occurring valve clearance which is inappropriately set. Thus, we obtain a measure easy to use in diagnostics in real time.

Keywords: combustion engine, exhaust valve, damage, failure diagnosis, vibroacoustic symptom

WIDMO RÓŻNICOWE JAKO MIARA STANU ZUŻYCIA ZAWORU WYLOTOWEGO

Streszczenie

W artykule przedstawiono algorytm diagnozowania uszkodzeń zaworu wylotowego silnika spalinowego. Proces pozyskania symptomu w postaci widma różnicowego uwzględnia selekcję czasową, co pozwala znacznie ograniczyć obliczenia niezbędne do otrzymania miary niesprawności. W efekcie otrzymujemy miarę prostą, niewrażliwą na równolegle występujący nieprawidłowo ustawiony luz zaworowy i nie wymagającą specjalnych warunków pracy obiektu. Tym samym otrzymujemy miarę łatwą do wykorzystania w diagnostyce w czasie rzeczywistym.

Słowa kluczowe: silnik spalinowy, zawór wylotowy, uszkodzenie, diagnostyka, symptom wibroakustyczny

1. INTRODUCTION

Rapid development of technology, complicated machine designs and minimization of construction (downsizing) lead to the fact that machines are more susceptible to damages or malfunction. At the same time, from the point of view of the user, the demand of reliability of operating the object is growing. The development of rapid and long-term diagnostics in real time is natural in this situation. Identification of diagnostic symptoms for machines working at constant rotational speed is not a big problem. In the case of objects working at changing rotational speed, more advanced mathematical tool is needed, at the same time the diagnostic systems are often developed beyond rational needs. Complicated and expanded systems are achievable. However, the multitude of computing operations may negatively influence the reliability of diagnostic inference.

The vibroacoustic signal is closely associated with work of each machine, and its main advantage as an information carrier is time of its transfer and capacity [6]. Because of various generation sources, resultant vibroacoustic signal is complex in combustion engines. In the case of its use in a diagnostic process an appropriate signals selection is necessary. It seems to be a proper method of searching for symptoms of mechanical damages to the engine.

A lot of research centres have dealt for many years with the problem of diagnostics of drive units of vehicles with the use of vibroacoustic signal and with an attempt of selecting mathematical models which describe the reality in the best possible way [3, 4, 5, 7, 8, 11, 13, 14, 15, 17, 18, 19].

In most cases the proposed measures are qualitative or require advanced computing techniques. As a result, it may significantly complicate the use of symptoms in online diagnostics. The article presents a proposal for a simplified algorithm for diagnosing damage to the drive unit in condition of typical operation.

2. GENESIS OF THE PROBLEM

An active research carried out on the highly exploited object was the basis for inference. The damage measures of the exhaust valve (burnt valve) were sought. Vibrating signal generated by a drive unit was a source of information about the condition of the object. Tests were performed in real driving conditions, which despite the precision in maintaining constant rotational speed slightly influenced its fluctuations. Putting the condition of maintaining constant rotational speed as necessary to carry out the diagnostic procedure would be cumbersome for the user. It could also lead to inability of making an assessment of drive unit condition. Simple methods of signal processing in such a situation seem to be impossible to apply. Methods of analyses of nonstationary signals may appear to be helpful. However, it would lead to unwanted complication of the system of diagnostic inference. In order to simplify the inference, the classical Fourier method was used in the analyses. This assumption required a suitable preparation of vibration signals. Time synchronization method was used for that [1, 2, 9, 16]. The method proposed in the paper was used in the analysed case [10]. As a result, undesirable fluctuations of rotational speed were eliminated. A real signal was transformed so as to correspond to the signal for constant rotational speed. The use of procedure of equalization of rotations led to decrease in blurring the spectrum, which allowed to distinguish characteristic components (Fig. 1).

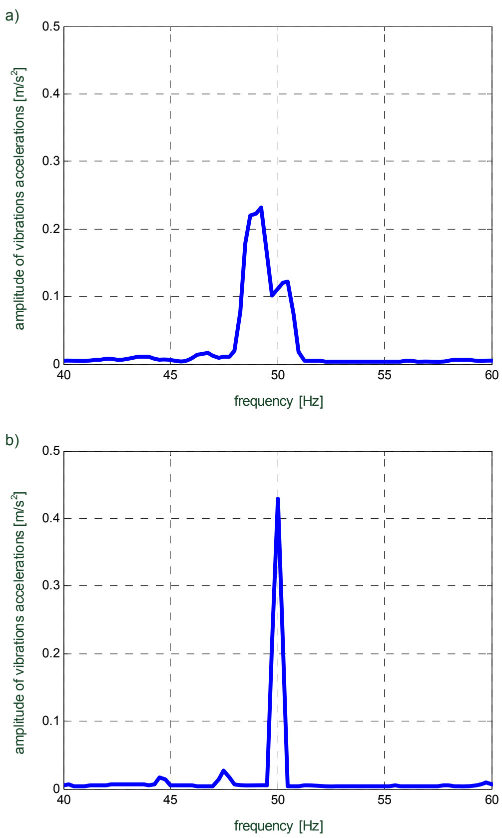

Fig. 1. The influence of resampling operation on the spectrum of vibrations accelerations, a) real signal, b) resampled signal

This operation made it possible to simulate the operation of the system at a constant rotational speed. At the same time the frequencies characteristic for the condition of the object were refined, and total energy was maintained. As a result, it was possible to use simple methods of analysis of stationary signals by increasing sensitivity to slight changes in the structure (more reliable and faster response of a diagnostic system).

3. THE PROPOSITION OF DIAGNOSTIC MEASURE OF DAMAGE TO THE EXHAUST VALVE

Now we can return to the main purpose of the experiment which is searching for measure of damage to the exhaust valve. The investigation object was the spark ignition engine, at an advanced wear (nearly 400 000 kilometer distance travelled by a vehicle without overhaul of engine) and of an unknown initial state. The mechanical defect, in a form of a cut of the exhaust valve face, was introduced into the engine to simulate a burned out valve. The experiment assumption was to reveal the defect at its initial stage. Finding the vibroacoustic response of the driving unit to the defect occurrence and increasing – was necessary. This would confirm that the symptom can allow to reveal explicitly the defect early stage. To this aim, the mechanical defect was increased and the system responses were recorded at each stage of changing the unit state. The acceleration amplitude of vibrations of the head, near the exhaust valve of the first cylinder, was the recorded signal. Measurements were performed under road conditions at – as constant as possible – driving conditions.

It is hard to imagine that the natural operational wear of the vehicle has no influence on vibrational signal recorded on the head. To separate the information coming strictly from damage, the difference of narrowband spectra was applied [12]. The subtracted signal (basic) was the signal recorded for the condition of unit after replacing the valve with a new one. It was treated as information about a general operational wear of the object with the exception of malfunction of tested exhaust valve. Such an assumption was supposed to lead to the fact that after subtraction of spectrum of the base state, the information about the malfunction is obtained. Schematic algorithm of working is presented in Fig. 2.

As a result of the applied subtraction procedure there was obtained the spectrum with components with positive and negative amplitudes. The positive part of differential spectrum was considered pure information about malfunction of the object, whereas a negative part was considered a response of the system connected with operational wear. In the case of signals recorded before the introduction of damages (initial state of tests hereinafter referred to as operating) positive difference of spectra was treated as information about the initial state of the valve without the impact of wear of other elements of the system (natural wear of tested element of timing system).

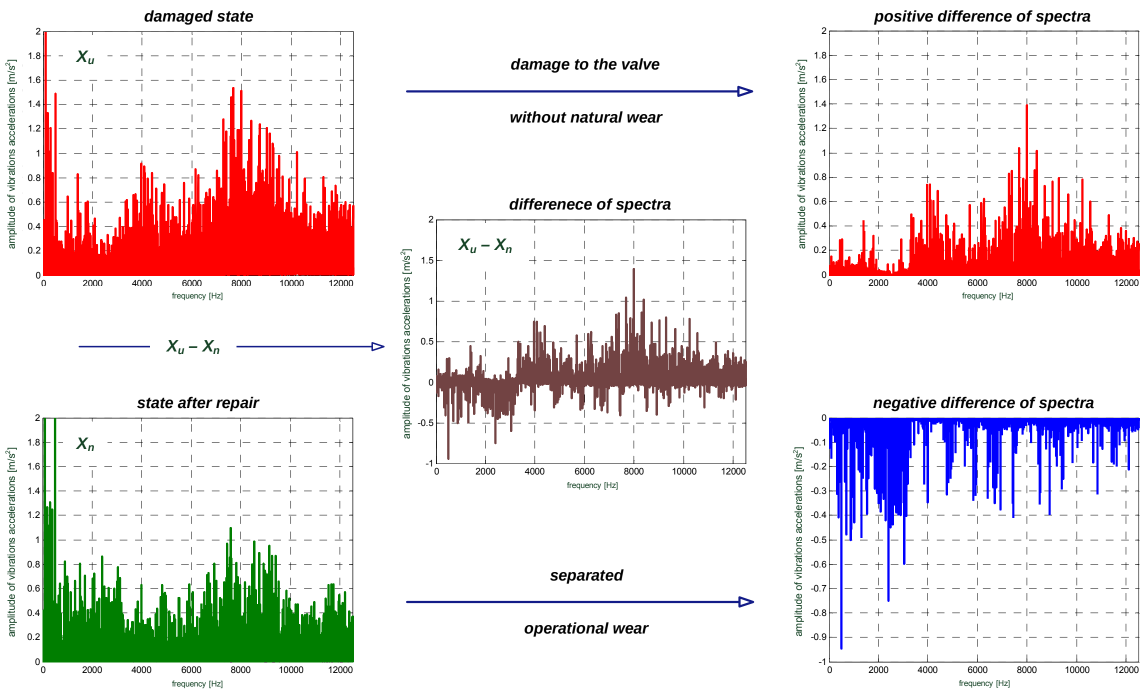

Fig. 2. The procedure for obtaining difference spectrum

Let's check how the operation of subtracting resampled spectra of vibrating signals influenced the change of spectra of vibrations accelerations of real signals (not subjected to any additional processing). Comparison of the spectra is shown in Fig. 3.

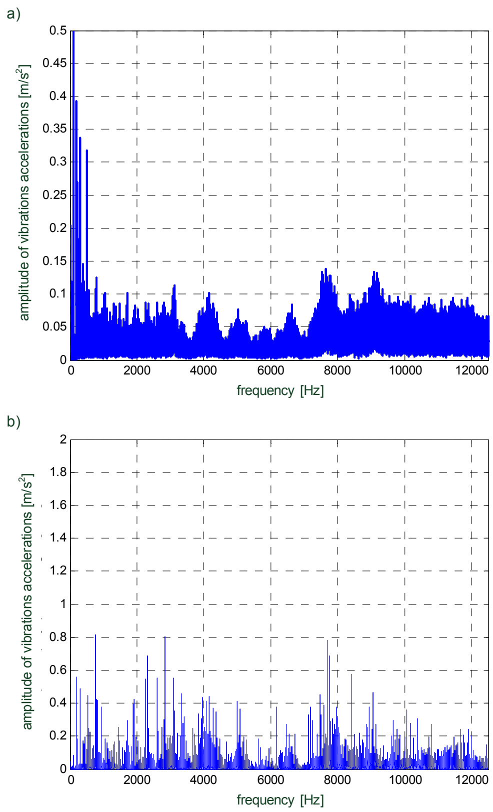

Fig. 3. Comparison of a) the spectrum of the vibration acceleration of the real signal, b) the spectrum of differential signal after resampling

The use of algorithm of subtracting spectra of signals after equalization of the rotational speed significantly improved the selectivity of spectrum. Resampling procedure of real vibrating signals led to increase in readability of frequency structure and allowed to subtract the spectra.

The positive part of differential spectrum of vibration accelerations of signals of three different states of tested object is presented in Fig. 4.

Comparison of spectra of three different states of tested object indicates clear differences in frequency structures. The positive part of the differential spectrum seems to be a good diagnostic symptom. Thus, next there was proposed the measure of malfunction of drive unit. The RMS value from the positive part of the spectra was calculated from the information about the damages to the element of timing system resulting from the difference of spectra. The obtained measure for three different states of exhaust valve and different conditions of operational is presented in Fig. 5.

Slight differences in RMS values for operational state and first phase of valve damage probably result from slight exploitation of vehicle and mileage without overhaul of analyzed engine. The operational state could be considered the beginning of the development of malfunction resulting from natural wear. The first and second valve damage is clearly distinguishable, however, the second phase of malfunction is represented by a decrease in the value of measure.

The use of a symptom so constructed in the diagnosing process of valve damage requires continuous tracking the symptom change and determining the limit threshold. After crossing this threshold, the system informs the user about the fault (Fig. 6).

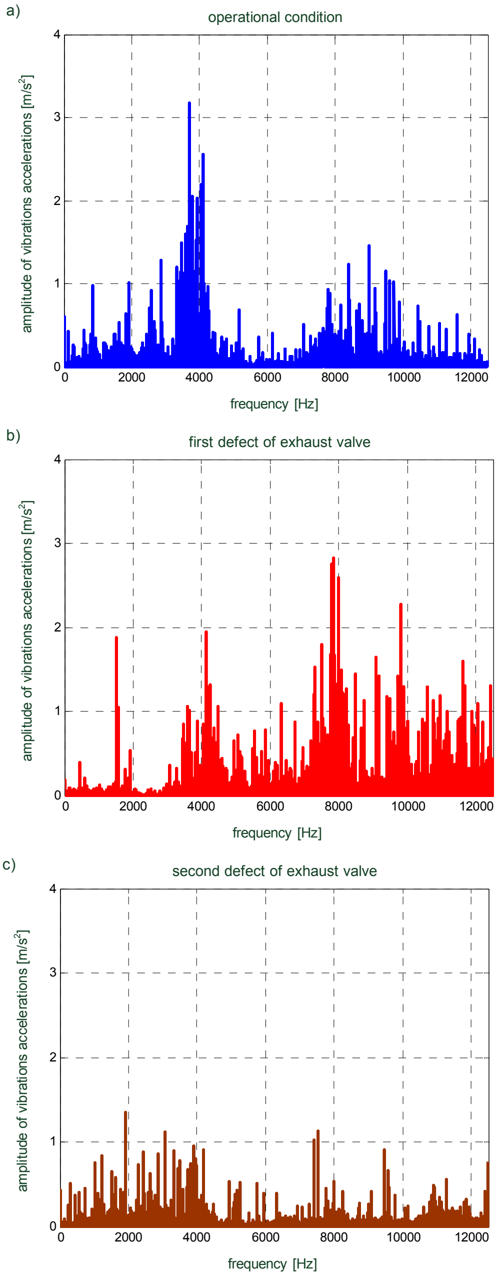

Fig. 4. The differential spectrum of acceleration of signal vibrations of, a) operational state, b) 1st damage to the exhaust valve, c) 2nd state of valve damage

Such constructed measure, with a fixed decisive threshold, seems to be also insensitive to other simultaneously occurring damages, especially their early phases. Figure 7 presents the measure for the exhaust valve damage and for the damage with concurrently increased valve clearance.

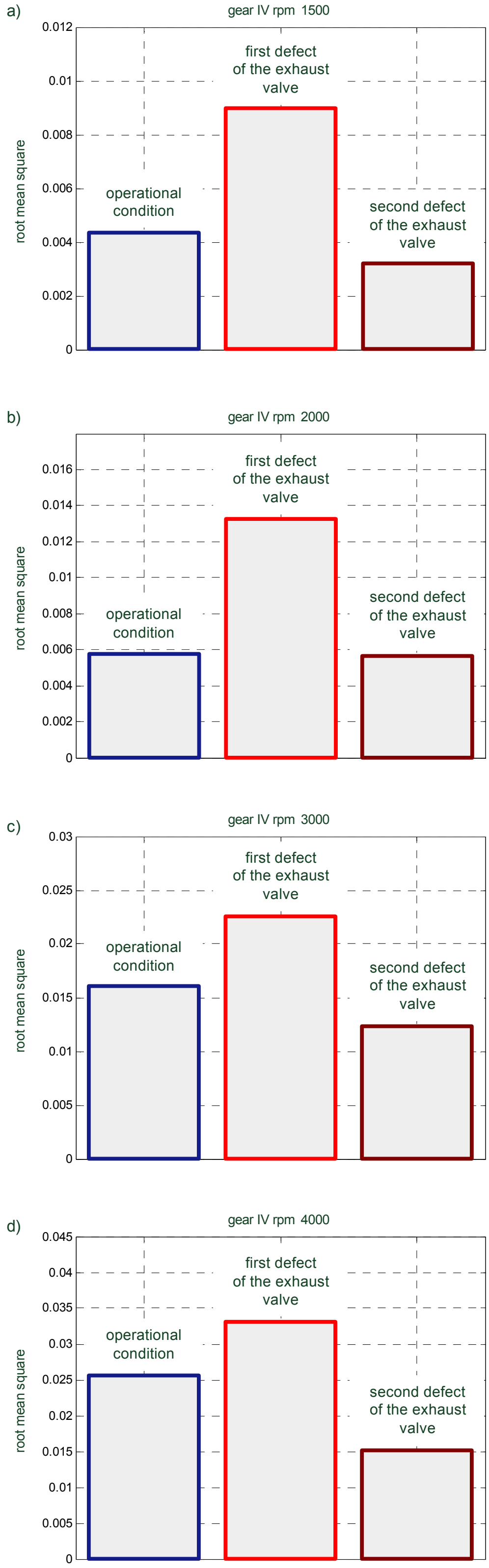

Fig. 5. The measure of damage obtained from the positive part of the differential spectrum, a) 4th gear 1500 RPM, b) 4th gear 2000 RPM, c) 4th gear 3000 RPM, d) 4th gear 4000 RPM

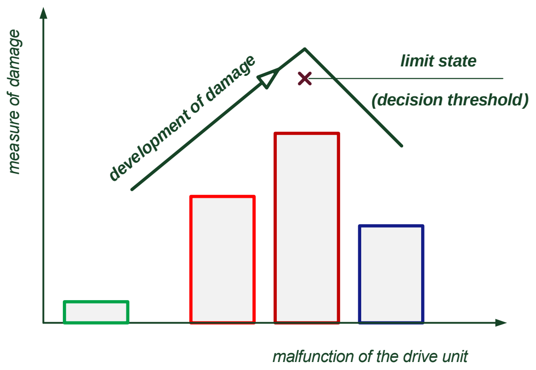

Fig. 6. Diagnostics with the use of decision threshold

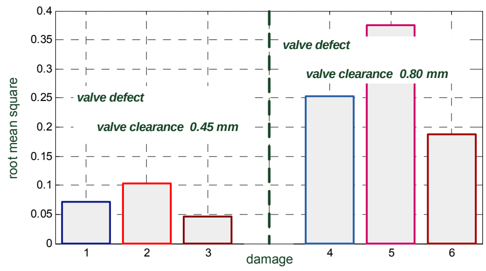

Fig. 7. The impact of concurrent damage on the proposed measure: 1 – operational state, nominal clearance 0.45 mm, 2 – 1st damage to the valve, nominal clearance 0.45 mm, 3 – 2nd damage to the valve, nominal clearance 0.45 mm, 4 – increased valve clearance 0.80 mm, 5 – 1st damage, valve clearance 0.80 mm, 6 - 2nd damage to the valve clearance 0.80 mm

Increased valve clearance resulted in a significant increase in the value of measure without changing the relationship between the states of damage to the exhaust valve. The change of valve clearance significantly increases the value of measure and it is dominant in signals with concurrently occurring damages to the valve and incorrectly set clearance. It is interesting that introducing an additional damage increases the dynamics of symptom changes, thus improves the recognition of damage.

4. CONCLUSION

The proposed measure in the form of RMS value of difference spectrum seems to meet all conditions imposed to a proper indicator of damage. It is a simple measure, which cannot be disturbed by simultaneously occurring malfunction in the form of increased valve clearance. Such a measure does not require special conditions of object work during the diagnosing process. Moreover, the use of procedure of subtracting the base state allowed to make the proposed system independent from natural operational wear of the vehicle. The threshold after which the decrease of value of indicator demonstrates further development of damage can be clearly defined. High repeatability of numerous experiments demonstrates the possibility of using such a method in online diagnostics with suitably selected frequency of observation. In addition, the use of such a measure is justified by great simplicity of inference. The necessity of determining the decision threshold and the necessity of continuous tracking the measure changes is compensated by the minimization of computing process.

BIBLIOGRAPHY

1. Adamczyk J, Krzyworzeka P, Łopacz H. Systems of synchronous processing of diagnostic signals. Collegium Columbinum. Kraków 1999. Polish.
2. Allier E, Sicard G, Fesquet L, Renaudin M. Asynchronous level crossing analog to digital converters. Measurement 2005; 37:296-309.
3. 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 2002; 257(5):815-837.
4. Antoni J, Daniere J, Guillet F, Randall RB. Effective vibration analysis of IC engines using cyclostationarity. Part II – New results on the reconstruction of the cylinder pressures, Journal of Sound and Vibration 2002; 257(5):839-856.
5. Barczewski R, Szymański G. Application of the time–frequency selection of the vibration to valve clearance assessment of a diesel engine. Diagnostyka 2004; 30:18-22.
6. Cempel C. Vibroacoustics condition monitoring, PWN, Warszawa 1989. Polish.
7. Delvecchio S, Dalpiaz G, Niculita O, Rivola A. Condition monitoring in diesel engines for cold test applications. Part I: Vibration analysis for pass/fail decision, Proceeding of the 20th International Congress & Exhibition on Condition Monitoring and Diagnostic Engineering Management. June 2007, Faro, Portugal.
8. Delvecchio S, Dalpiaz G, Niculita O, Rivola A. Condition monitoring in diesel engines for cold test applications. Part II: Comparison of vibration analysis techniques, Proceeding of the 20th International Congress & Exhibition on Condition Monitoring and Diagnostic Engineering Management, June 2007, Faro, Portugal.
9. Dziurdź J. Transformation of nonstationary signal into "pseudostationary" signals for the needs of vehicle diagnostics. Acta Physica Polonica A 2010; 118(1):3-12. doi: 10.4028/www.scientific.net/SSP.196.3
10. Dziurdź J. Analysis of nonlinear phenomena in diagnosing vehicle powertrain systems. ITE-PIB, Warszawa – Radom, 2013. Polish. doi:10.4028/www.scientific.net/SSP.196.3
11. Elamin F, Fan Y, Gu F, Ball A. Diesel engine valve clearance detection using acoustic emission. Advances in Mechanical Engineering 2010.
12. Górnicka D. Vibroacoustics symptom of the exhaust valve damage of the internal combustion engine. Journal of Vibroengineering 2014; 16(4): 1925-1933.
13. Wang H, Chen P. A feature extraction method based on information theory for fault diagnosis of reciprocating machinery. Sensors 2009; 9:2415-2436. doi:10.3390/s90402415.
14. Jedliński Ł, Caban J, Krzywonos L, Wierzbicki S, Brumerčík F. Application of vibration signal in the diagnosis of IC engine valve clearance. Journal of Vibroengineering 2015; 17(1):175-187.

15. Komorska I. Utilising the resonance frequency of the engine vibration sensor in diagnostics of the exhaust valve leakage. Journal of KONES 2010; 17(2):209-216.
16. Krzyworzeka P. Synchronous support in machine diagnosing. ITE–PIB, Radom 2004. Polish.
17. Liu S, Gu F, Ball A. Detection of engine valve faults by vibration signals measured on the cylinder head. Proceeding IMechE, Part D: Journal Automobile Engineering 2006; 220: 379-386.
18. Wen-Xian Y. Establishment of the mathematical model for diagnosing the engine valve faults by genetic programming. Journal of Sound and Vibration 2006; 293:213–226. doi:10.1016/j.jsv.2005.09.004
19. Wojnar G, Madej H. Averaged wavelet power spectrum as a method for piston – skirt clearance detection. Diagnostyka 2009; 2(50): 93-98.

Received 2016-06-24
Accepted 2016-10-28
Available online 2016-11-21

Dorota GÓRNICKA, M.Sc. is an assistant at the Department of Fundamentals of Machine Design and Operation, Institute of Machine Design Fundamentals of Warsaw University of Technology. Her scientific interests focus on vibroacoustic diagnostics of internal combustion engine.