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POSSIBILITY OF IDENTIFICATION OF TECHNICAL CONDITION OF BEARINGS FOR SELF-IGNITION ENGINES BY APPLICATION OF ACOUSTIC EMISSION AS A DIAGNOSTIC SIGNAL

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Abstract

This paper presents the results of empirical studies where the acoustic emission (AE) method was applied to identify the technical condition of sliding surfaces of main and crank bearings for main diesel engines. The test results indicate that the measurements of the AE parameters allow the technical condition identification for bearings of this type. The results refer to the measurements of the parameters for AE generated in the bearings whose sliding surfaces are in various conditions. The results illustrate the changes in AE parameters over time, like RMS (Root Mean Square), hits, counts, and also signal energy, amplitude, radial loads on bearing, friction torque, time of the mixed friction occurrence, rotational speed, temperature of bearing shell and oil film. It has been shown that AE can be an important diagnostic signal that allows disclosure of changes in technical condition of bearings in piston-crank mechanisms for the mentioned engines, in the early stages of the changes.

Keywords: *diagnostics, acoustic emission, slide bearing, diesel engine, damage*

1. INTRODUCTION

For operation of internal combustion engines, especially those of marine application, the information on occurrence of changes in technical condition of their components, especially bearings in the piston- crank mechanisms which are the most loaded systems, is of significant meaning [2, 4, 5]. To obtain such information, diagnostic methods and the associated diagnosing systems that allow early detection of changes in the engine components, which can be considered as microdamages, are useful in particular. Such methods may include the methods of analysis of vibroacoustic signals *(SWA)* and acoustic emission signals *(SAE)*. When comparing to the other diagnostic parameters, the characteristic feature of the vibroacoustic parameters and acoustic emission parameters, as the carriers of the information on the internal combustion engine condition, is a much greater information volume and transfer speed of the information on bad condition. Preliminary studies have shown that the acoustic emission, however, is more useful because it discloses changes in the structure condition of engine components in the early stage of their formation. This is due to the fact that acoustic emission *(AE)* is a low-energy elastic wave generated by a sudden release of energy stored in the material of the engine components, in the result, for instance, of:

- microslides occurring at the grain boundaries in the micro-regions subject to high stress up to the material plasticity limit,
- movement of vacancies and dislocations, particularly combined dislocations and movement of dislocation groups,
- microgaps and their propagation in the materials of engine components.

The last mentioned reason in particular, is a strong source that generates *AE*. That is why the application of the acoustic emission as a diagnostic signal for diagnosing diesel engines, is necessary. The article raises this issue in relation to the main and crank bearings for this kind of engines.

2. DESCRIPTION OF THE METHOD OF ANALYSIS OF DIAGNOSTIC USEFULNESS OF THE ACOUSTIC EMISSION PARAMETERS FOR IDENTIFICATION OF THE TECHNICAL CONDITION OF SLIDE BEARINGS FOR COMBUSTION ENGINES

For diagnosing the sliding surfaces of the shells of main and crank bearings for diesel engines, the acoustic emission *(AE)* method is useful to analyze and evaluate their technical condition. Such usefulness results from the fact that emergence of the low-energy elastic wave inside the elements of a slide bearing shell, in consequence of release of the energy accumulated therein, may be registered by a relevant measuring apparatus, whose diagram is shown in Fig. 1 [5, 7, 10].

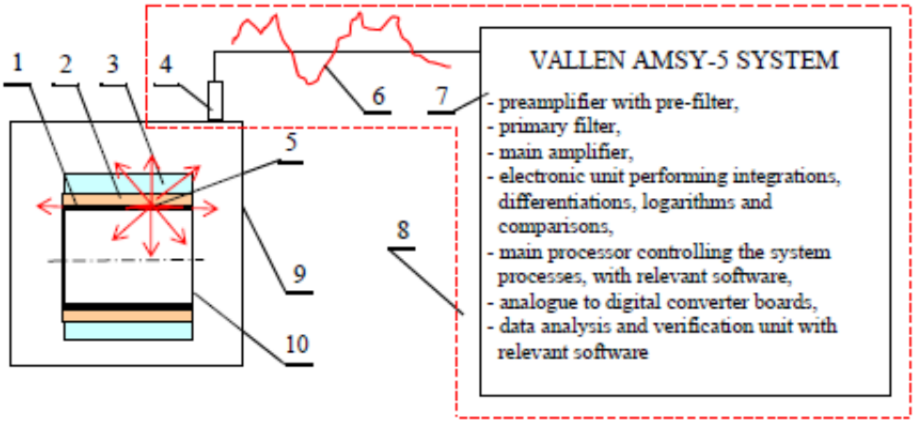


Fig. 1. Block diagram of the system for testing the elastic waves propagation in shells of three-layer slide bearings: 1 – sliding surface, 2 – bearing layer, 3 – support material, 4 – digital converter, 5 – damage (e.g. a microcrack) in the sliding surface, 6 – signal, 7 – measuring system with software, 8 – measurement unit, 9 – engine block, 10 – bearing shell

Thus, the acoustic emission method for testing a slide bearing shell 9 consists in (Fig. 1) registration of the elastic waves as signals 6, by the measurement unit 8. The elastic waves are the result of release of the internal elastic energy accumulated in the material of the shell sliding surface. Further on, the waves are subject to relevant statistical processing in the result of measuring the acoustic emission parameters [1, 2, 3, 7, 9].

Acoustic emission *(AE)* occurs in the bearings of internal combustion engines, as a result of both: microprocesses (microcracks, slides at boundaries, movement of vacancies and dislocations), and macrophenomenon e.g. macrocracks due to shell volume wear and considerable clearances due to wear in bearing shell and journal surfaces [6].

The use of acoustic emission *(AE)* for diagnostics of bearing shells for the combustion engines allows registration of the low-energy signals occurring in the shell, with the converter 4 (Fig. 1). This allows to detect a damage in the structure of the shell sliding layers [1, 2, 4, 7].

3. DETERMINATION OF USEFULNESS OF ACOUSTIC EMISSION PARAMETERS FOR IDENTIFICATION OF THE TECHNICAL CONDITION OF SLIDE BEARINGS FOR COMBUSTION ENGINES

Determination of the diagnostic usefulness of the acoustic emission parameters requires making a comparison of the registered *AE* signals corresponding to the particular technical conditions for the bearing metal alloy, to the signals characteristic for the undamaged alloys (which are in full ability). The usefulness should be determined through measurement of the *AE* parameters of and their analysis including [2, 3]:

- specification of time when the fluid friction in the bearing becomes a mixed friction,
- disclosure (signal) of first microdamages occurred in the material of bearing elements, in the form of micro-deformations or microcracks in the shell sliding surface.

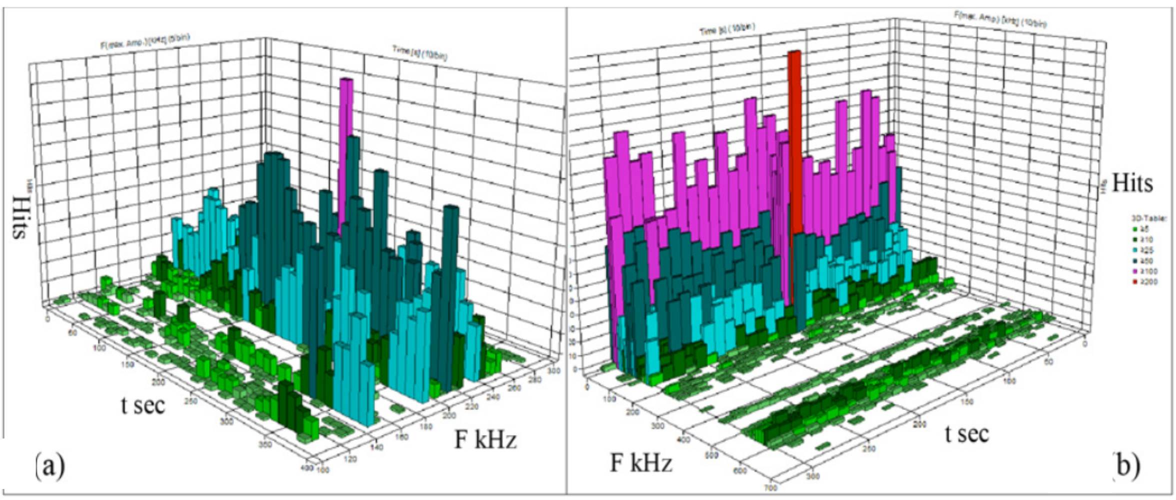
The mentioned usefulness was determined through laboratory tests of slide bearing shells at the test bench, and they included [7]:

- changing the rotational speed value, measuring and registration of the values,
- measuring and registration of the time when the mixed friction occurred in the bearing,
- measuring and registration of the temperature of the tested bearing and oil film,
- changing the radial load on the bearing, measuring and registration of the values.

The studies on the diagnostic usefulness of the acoustic emission *(AE)* parameters through determination of the dependence of the changes in the *AE* parameters on the shell technical condition, were carried by using the Vallen AMSY-5 System (Vallen - Systeme GmbH). The system is equipped with various types of AE sensors providing registration of signals in a wide frequency band [7]. The studies involved such sensors as WD-PAC, WD-PAC with waveguide, VS 30-V, VS 75-V, VS 150-RIC, VS 150-RIC with waveguide, VS 375-RIC, SE 45-H. The sensors were mounted on the measurement head at the test bench and the side surfaces of the tested bearings [7].

The measurements of the acoustic background and noise generated by operation of the test bench systems were carried in the first phase of the tests. The distribution of the frequency bands of the signals registered during the tests is shown in Fig. 2.

a) b)



Fig, 2. Distribution of the frequency bands of the signals registered for wide-band sensors: a) for the range of 100-300kHz, b) for the range of 20-850kHz

The frequency analysis of the recorded *AE* signals allowed identification of the main ranges of noise and selection of the frequencies for high-pass and low- pass filters, for further measurements to eliminate the noise generated by the test bench and other noise sources inside and outside the laboratory [7].

In order to determine the diagnostic usefulness of the *AE* signal parameters, the values of the signal parameters, registered during the tests of a new bearing shell, were compared to the parameters of *AE* signals generated by the shells of bearings with simulated damages. The studies covered three shells as follows:

- a new bearing shell with two holes (Fig. 3a),
- a shell with additional four holes simulating damages from excessive wear (Fig.3b),
- a bearing shell (Fig. 3c) with fatigue damage in the bearing alloy (sliding surface and bearing layer) presenting surface cracks and detachments of bearing alloy particles, which result in interrupted flow of the oil film,
- a bearing shell having longitudinal and circumferential grooves which simulate damages in the shell surface due to rolling some foreign bodies between the shell and the journal (Fig. 4).

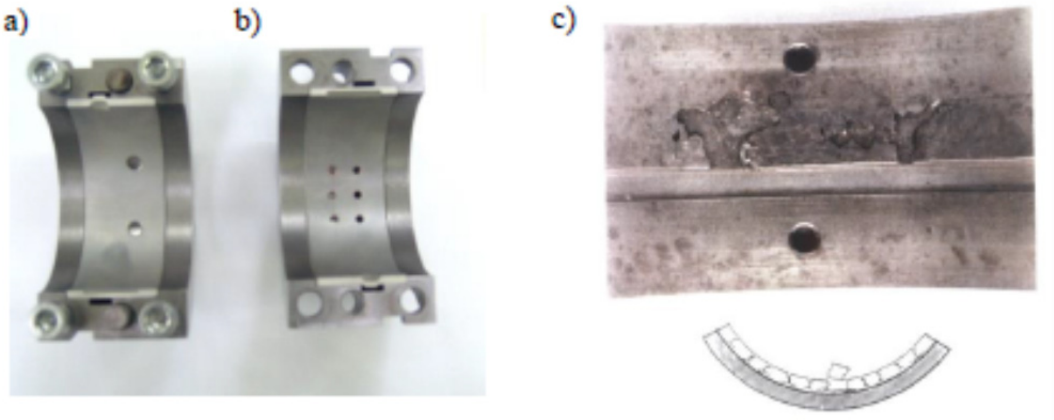


Fig. 3. A new shell (a) and a shell with fatigue damage in the bearing alloy: b) simulated damage in the form of holes with a diameter of 4 mm (Ø = 4 mm) every 15^{O}, c) cracks in hard substructure and detachments of the bearing alloy particles

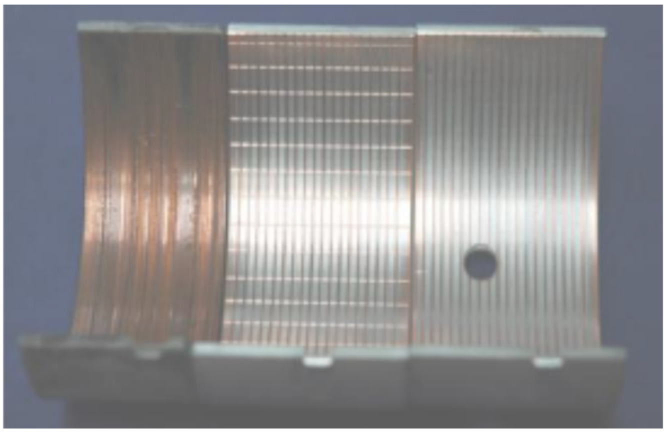


Fig. 4. Simulated damage in the form of grooves, which occurs as a result of rolling foreign bodies in the bearing

The relationships between the damages in slide bearing shells of diesel engines (Fig. 3 and Fig. 4) and the measured *AE* parameters were established during the studies.

During the tests the following values were registered: hits - the basic parameter of AE source activity, counts, signal energy, amplitude, RMS (root mean square) that contains information about the energy of the tested signal, radial load on the bearing, time of the mixed friction occurrence, rotational speed, temperatures of the bearing and the oil film. The mentioned *AE* parameters were used for monitoring the technical condition of slide bearings [1, 5, 6].

The outputs of registration of *RMS* values for a new bearing and the bearings with damages shown in Fig. 3 and Fig. 4, are presented in Fig. 5, 6 and 7 [7].

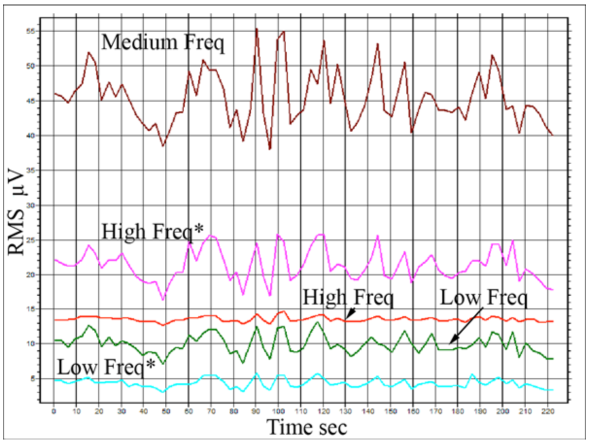


Fig. 5. RMS for filters of different frequency ranges - a new sliding bearing

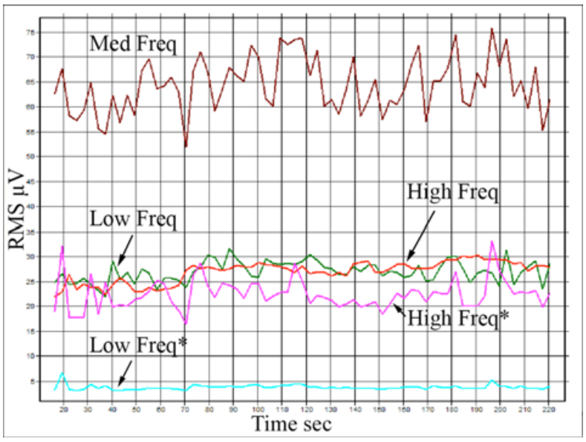


Fig. 6. RMS for filters of different frequency ranges - fatigue damage in the bearing alloy

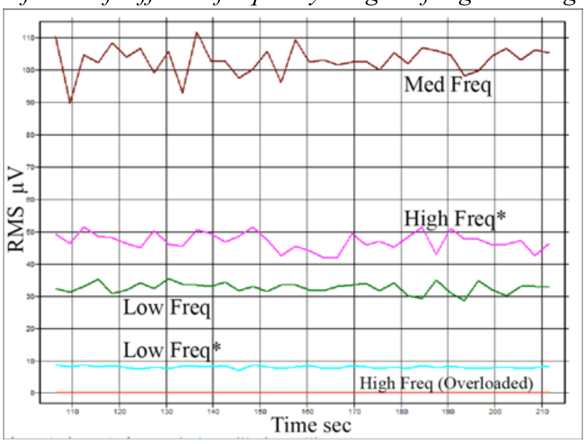


Fig. 7. RMS for filters of different frequency ranges - damage in the form of grooves in the bearing alloy

Stability in values is found for *RMS* with high frequency (red line) (Fig. 7 and, to a lesser extent, in Fig. 5 and 6). A general increase in the values of ***AE RMS*** can be stated in all channels, except for *Low Freq**.

The Figures 5, 6 and 7 show the values of measurements obtained in the channels with low, medium and high frequency for a new bearing (Fig. 5), and for damaged bearings (Fig. 6 and 7). However, the Fig. 8 presents the emission process in a new bearing and a bearing with simulated detachments of alloy particles, for the same acquisition parameters, by using VS75-V and VS150-RIC resonant sensors and the frequency filters installed on the measurement channels [7].

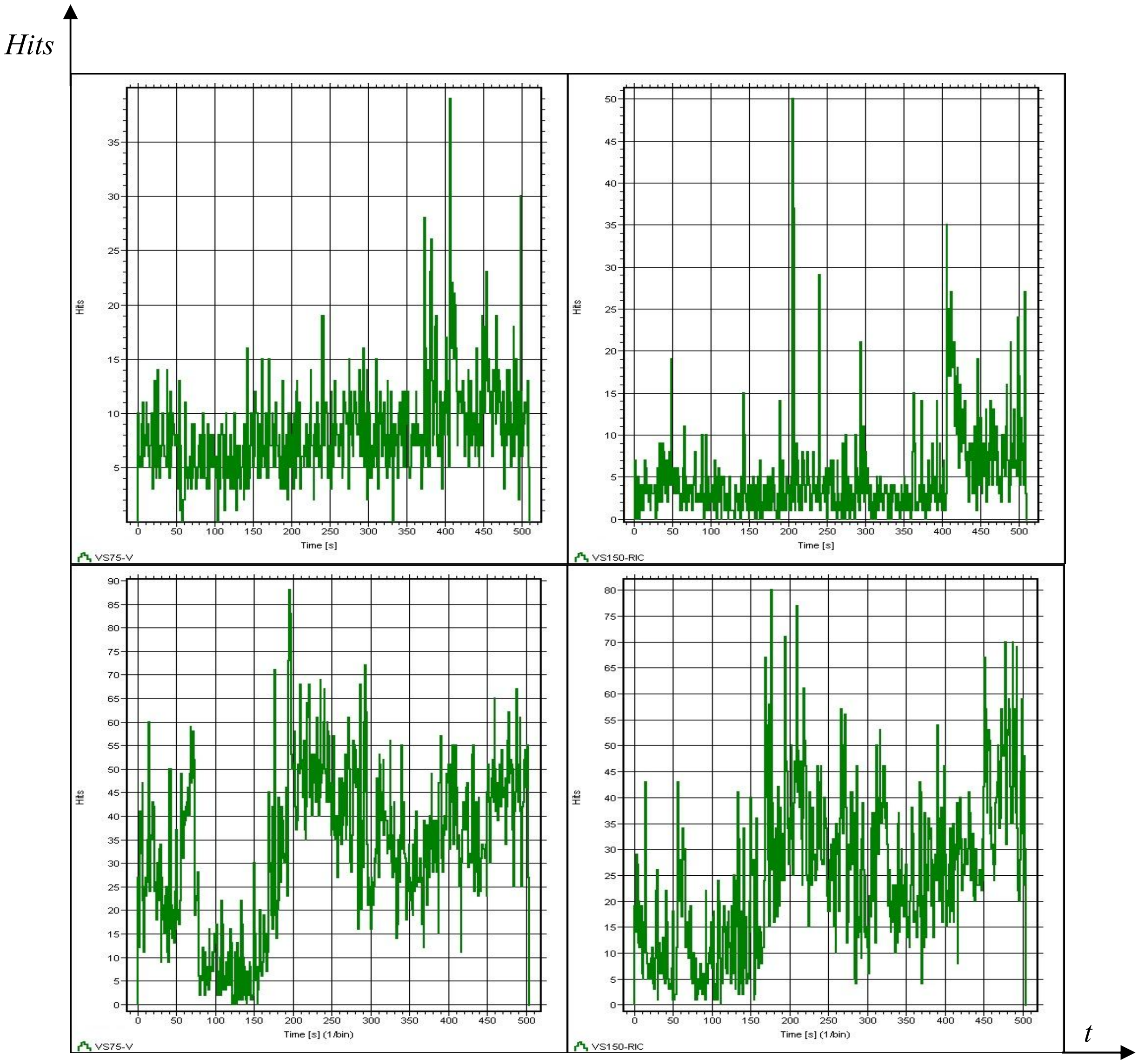


Fig. 8. Process of acoustic emission depending on time for: a) a new bearing b) a bearing with a hole that simulates detachments of alloy particles, when the axles are denoted as follows: Hits - ordinate, Time [s] – abscissa

Fig. 9 illustrates the sum of the signals registered during the determined operation of a bearing. It demonstrates a change in activity of the signals registered with the VS150-RIC sensor, which indicates a change in the bearing condition. The early signs of significant wear in the shell sliding surface were the reason for the sudden increase in AE (Hits) activity.

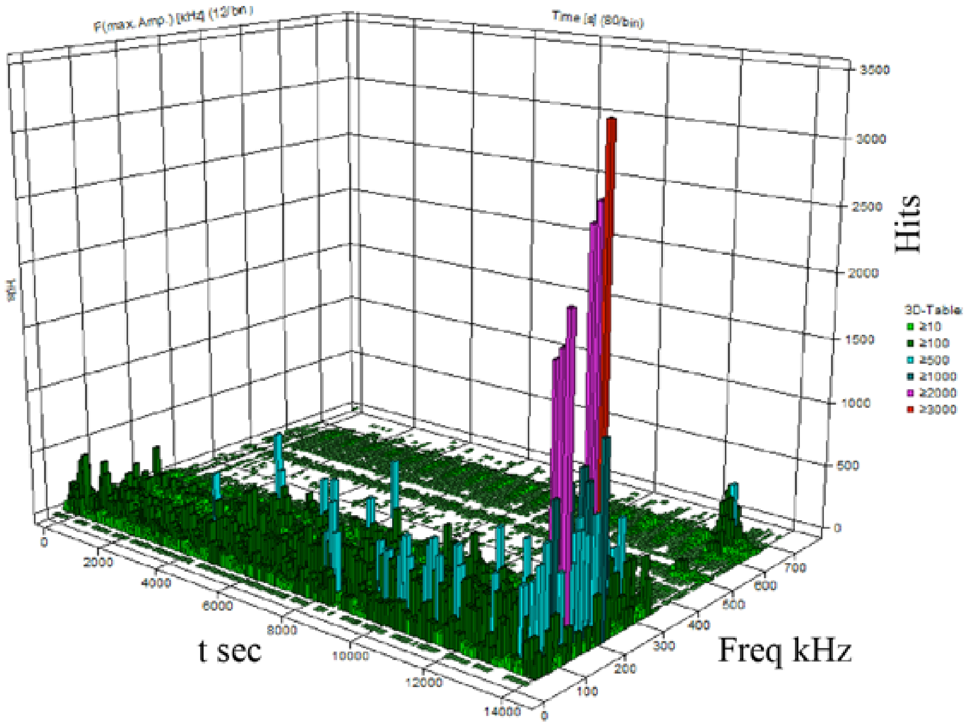


Fig. 9. The sum of Hits distribution for the frequency bands

In turn, the Fig. 10 presents the condition of the sliding layer surfaces of bearing half-shells type MB10 and MB35, after the tests.

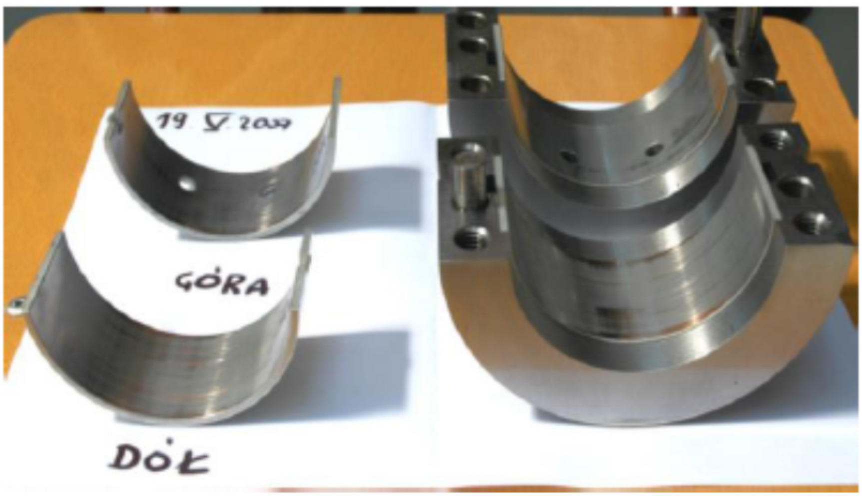


Fig. 10. Bearing half-shells type MB10 and MB35 after the tests - early signs of wear in sliding surface are visible

One of the important targets of the studies was measurement of the *AE* parameters during disappearance of the fluid friction and emergence of the mixed friction, at the time of the first contact of the journal micro-roughness with the bearing shell micro-roughness. During the tests the rotational speed was gradually reduced at the constant stress maintained. Reduction in the rotational speed resulted in reduction in oil film thickness, which in consequence led to a drop in the friction torque generated in the bearing (Fig. 11) and emergence of the contact of the journal micro-roughness with the shell micro-roughness. The mixed friction which then occurs, causes an increase in friction torque in the bearing. Therefore, the minimum value of the friction torque measured in the tested bearing corresponds exactly to the time of the first surface contact between the rotating journal and the stationary shell, which, in the first place, polishes the roughness tops. From this moment the value of torque increases.

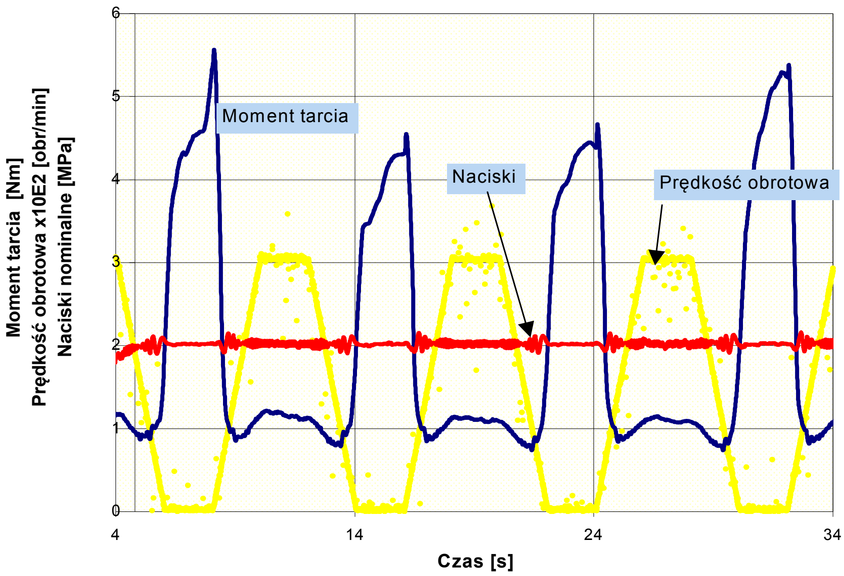


Fig. 11. Diagram of changes in the friction torque and the rotational speed, that proceed in the conditions of interrupted fluid friction, at constant nominal stresses

After stopping the journal in the bearing, the friction torque is proportional to the static friction coefficient. With the increase in peripheral speed the hydrodynamic pressure starts emerging, which causes gradual lifting of the journal in the bearing and reducing the amount of micro-roughness being polished off. This makes a decrease of the friction coefficient to the minimum value, which is achieved at the time of occurrence of the fluid friction. Further increase in the rotational speed results in the increase in the speed of the oil flow in the gap and increase of the friction coefficient [7]. The friction coefficient increase is the result of deteriorating lubrication conditions due to reducing the rotational speed till the journal is stopped in the bearing. However, while starting-up and gradually increasing the rotational speed of the journal, the friction coefficient decreases due to improving lubrication conditions. After reaching the minimum value by the friction coefficient, its value begins to increase with the increase in rotational speed of the journal. The activity of *AE* which was registered at that time, shown in Fig.13, indicated a decrease of the friction coefficient because of loss of activity of the *AE* signals. However, an increase of the friction coefficient between the surfaces of the journal and shells, indicates a sudden increase in the value of the parameters of *AE* signals. The activity of *AE*, registered at that time (Fig. 13), indicated a decrease of the friction coefficient, due to the loss of the activity of the *AE* parameters (Fig. 12). However, the increase of the friction coefficient between the surfaces of the journal and shells, was accompanied by a sudden increase in values of the *AE* parameters (Fig. 13). Fig. 13 shows the changes in the *AE* activity in the form of hits for different frequency bands. The value of the shaft rotational speed is equal to zero when the friction is the greatest. In these studies, no *AE* activity was recorded while reducing the rotational speed of the bearing journal until its rotational speed reached the value of 700 rpm (Fig. 13b).

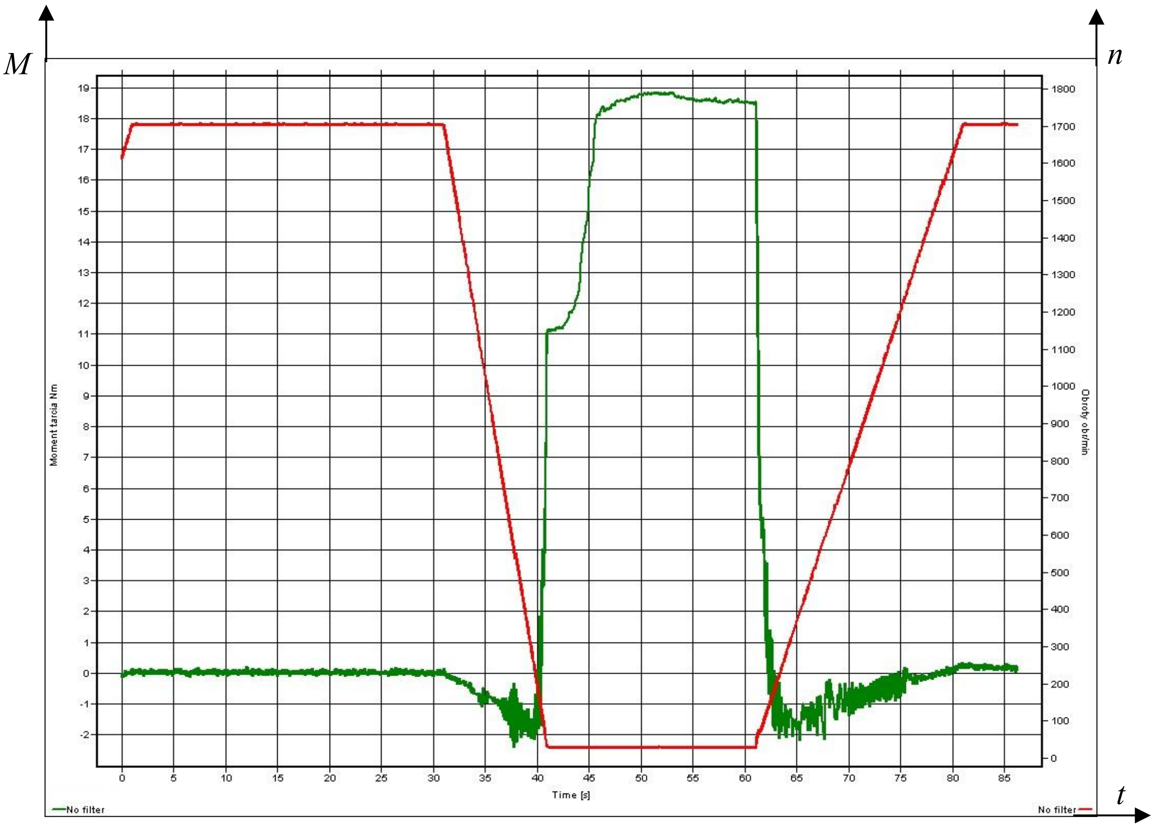


Fig. 12. Behavior of the parameters like: rotational speed (n) [rpm] - the red line, friction torque (M) [Nm] - green line, and loss of activity of the AE signals when the type of friction in the bearing undergoes changing, t - registration time of the changes

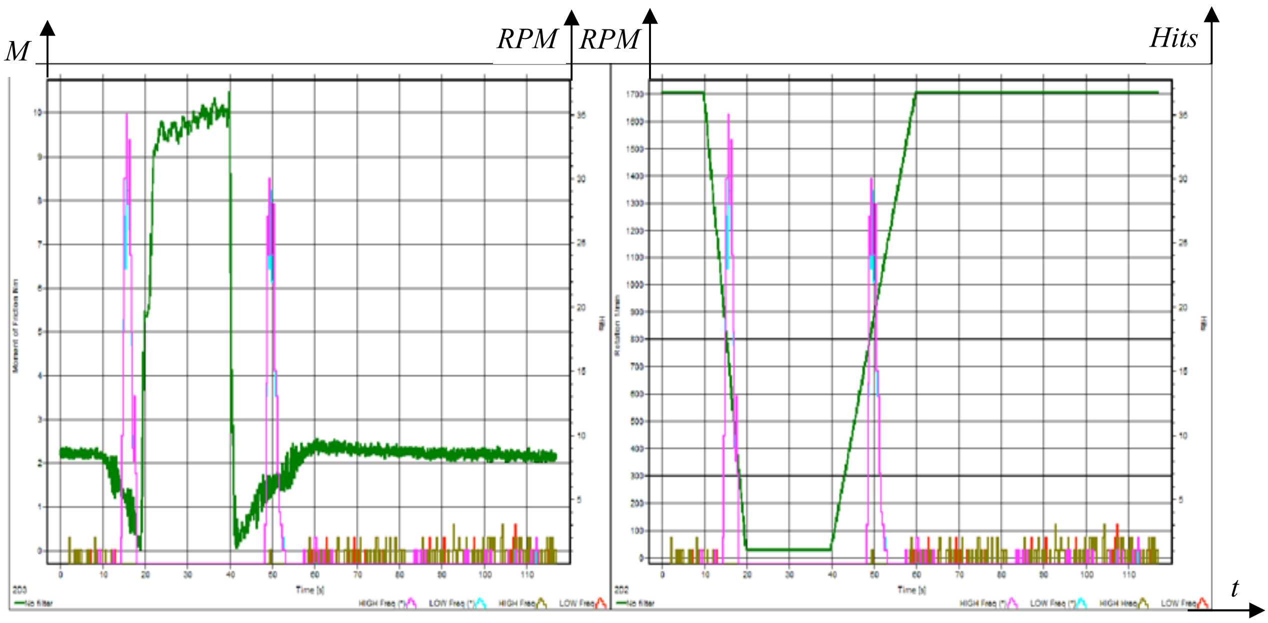


Fig. 13. Changes in AE parameters and activity: a) - friction torque (left) and RPM (right), b) - RPM (left) and number of hits (right), when the type of friction in the bearings undergoes changing, t - registration time of the changes

4. REMARKS AND CONCLUSIONS

The conducted tests show that application of the frequency filters allowed to eliminate most of the operation noise of the test bench. For this type of studies it is necessary to define the noise when the tested diesel engine is operated.

From the presented results it can be concluded that application of the acoustic emission *(AE)* for identification of the technical condition of slide bearings for combustion engines is possible. The sensitivity of the *AE* method allows registration of the *AE* signals when testing the bearings in laboratory conditions, which show the disappearance of the fluid friction in the bearings and occurrence of the mixed friction.

For such studies, it is important to have the classifiers with the Visual Class application and a large library of measurement data obtained from the tests carried at a laboratory stand.

Such classifiers allow identification of the *AE* signals generated by damage, when analyzing the *AE* signals spectrum, obtained during tests of diesel engine bearings in laboratory conditions.

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