Journal of POLISH CIMAC
Faculty of Ocean Engineering & Ship Technology
GDAŃSK UNIVERSITY OF TECHNOLOGY

POSSIBILITY OF ASSESSMENT OF OPERATION OF SLIDING BEARINGS IN PISTON-CRANK MECHANISMS OF DIESEL ENGINES WITH REGARD TO LOAD AND TIME OF CORRECT WORK OF THE BEARINGS BY APPLYING ACOUSTIC EMISSION AS A DIAGNOSTIC SIGNAL

Jerzy GIRTLER
Wojciech DARSKI

Gdańsk University of Technology,
Faculty of Ocean Engineering and Ship Technology
***Department** of Marine and Land Power Plants*
80-951 Gdańsk, ul. G. Narutowicza 11/12, fax/tel. (058) 347 1981,
e-mail: jgirtl@pg.gda.pl

Abstract

The paper presents a possibility of determining (assessing) operation of sliding bearings with multilayer bushings in crank-piston mechanisms of diesel engines. Properties of load and wear, particularly fatigue and abrasive, are characterized in general. Acoustic emission as a diagnostic signal was proved to be useful for detection of the wear of sliding and barrier layers. Results of measurements of acoustic emission parameters, made with AMSY-5, the 12-channel system, manufactured by Vallen GmbH are presented herein. The measurements include such parameters as: the number of discrete emissions determined by counts of EA events, the effective value (RMS), the number and also the rate per unit of time of oscillating above the threshold level (the number of exceeding the threshold level), amplitude of discrete emission signal, rise time, duration time and damping time of discrete emission, power (energy unit) of discrete emission signal. The usefulness of acoustic emission (AE) application as a diagnostic signal for detection of micro-damage in sliding and barrier layers of bearings in crank-piston mechanisms of diesel engines was confirmed.

Keywords: *acoustic emission, sliding bearing, load, diesel engine, wear*

1. Introduction

Operation of marine diesel engines, especially the main ones, requires determination (assessment) of work of their main and crank sliding bearings. This is because the sliding bearings in piston-crank mechanisms of diesel engines, just like of other internal combustion engines, are these tribological systems which are the most loaded [1, 9, 14, 16, 17]. The load on the bearings may be different, depending on the engine rotational speed (n) and the rate of pressure rise (φ_p). Bearings of high-speed engines receive higher dynamic load than the bearings of medium- and low-speed engines. Consequently, the life of these bearings till damage is shorter. Mechanical load in high-speed engines is characterized by a high rate of pressure rise ($\varphi_p = \frac{dp}{d\alpha}$), which in significant way affects adversely the wear of main and crank bearings. As a result, the bearings get damage faster. Sometimes, the damage occurs to the bearings during a ship's cruise. The empirical studies show that values of loads on engine piston-crank mechanisms at any time t (Q_t) cannot be predicted accurately, but with a certain probability only [3, 4, 5, 8, 17, 18, 21]. Thus, the following hypothesis $\boldsymbol{H_1}$ can be formulated: **"the load on bearings $\boldsymbol{Q_t}$ in engine piston-crank mechanisms, at any time *t*, is a random variable, because its values of the sequentially performed measurements, can be predicted only with a specified probability".** Thus, at any time t, different values of ratings (parameters) can be registered for the said load, which are random events [1, 3, 4, 5, 9, 12, 14, 16, 19, 20].

The so far studies also provide that a stochastic relation should be expected between mechanical load $Q_M(t)$ and thermal load $Q_C(t)$ of bearings in crank-piston mechanisms of marine diesel engines [2, 4, 5, 11, 20]. Hence the conclusion comes that the relationship between the processes of $Q_M(t)$ and $Q_C(t)$ loads cannot be described by applying a common method of algebraic equations [10, 14]. The relationship between the said loads on diesel engine bearings is affected by a large number of factors, including those which cannot be measured [4, 13, 18, 19, 21]. Thus, for any bearing the degree of association of its Q_{tM} with its Q_{tC}, at any arbitrary time t, may be very different. Explanations for this dependence can be included in the following hypothesis $\boldsymbol{H_2}$: " **for any bearing in crank-piston mechanisms of internal combustion engines, at any time *t*, there is a stochastic dependence between its thermal load $\boldsymbol{Q_{tC}}$ and mechanical load $\boldsymbol{Q_{tM}}$, because the specific variants of the thermal load $\boldsymbol{Q_{tC}}$ are accompanied by different variants of its mechanical load $\boldsymbol{Q_{tM}}$**" [2, 6, 8, 10, 19]. Therefore, it is clear why the up to now studies on diesel engines say that bearing failure cannot be predicted precisely (but only with a certain probability).

For that reason, an assumption needs to be made that wear of sliding layers of bushings, due to their loading, must also be considered at any time t as a random variable Z_t. The wear analyzed in any time interval $t_0 \leq t \leq t_n$,, should be considered as a random function $Z(t)$ which is a set of random variables Z_t for the said time interval $[t_0, t_n]$. It is essential that the wear is possible to be noticed at the earliest possible stage of its occurrence. This requires application of appropriate diagnosing systems (*SDG*) to control the operation $D(t)$ of bearings up to the distinguished time t. In this case, engine sliding bearings must be treated as diagnosed systems (*SDN*), which along with the *SDG* make diagnostic systems (*SD*) [4, 22]. Nowadays, the method which allows investigation of acoustic emission (*AE*) [11, 13, 23] and vibroacoustic processes [20] is more and more often used to identify technical condition of sliding bearings. The further considerations provide a proposal of applying acoustic emission (*AE*) as a diagnostic signal to identify technical condition of bushing layers for sliding bearings in diesel engines [6]. This proposal follows from the fact that acoustic emission as an effect of spreading the vanishing low-energy elastic wave formed in the consequence of micro-damage occurrence in sliding layers of bushings, detects the damage initiation earlier than other diagnostic signals [11, 13, 22, 23, 25-28]. Due to this, the time of correct work of main and crank bearings in diesel engines can be determined more precisely. This in turn makes that operation of bearings in any piston-crank mechanism of the engines can be determined more precisely. As for assessment of the operation it is necessary to determine the accurate time of correct work of the bearing (apart from work that the bearing is to perform), which results from the interpretation of operation of bearings in the crank-piston system

2. Interpretation of **operation** in terms of energy for **bearings in** crank-piston mechanisms of diesel engines

During operation of bearings in crank-piston systems of a diesel engine there is a need to prevent damage in sliding layers of their bushings. This requires control over the wear of sliding layers of the bushings. This is necessary because with increase in bushing wear, the operation ($D_Ł$) of bearings, so the engine as well. is reduced [7]. This operation consists in transferring the mechanical energy that induces exchange of piston motion to crankshaft movement so that the work L needed to complete the task $Z = \langle \Phi, W, t \rangle$ can be performed at a given time t. This task means such operation of Φ of bearings, to enable them transfer of the occurring loads $Q_t = \langle Q_{tC}, Q_{tM} \rangle$ under the given conditions W and at the demanded time t.

Such understood bearing operation can be analytically expressed as a relationship [24]:

$$D_Ł = \int_{t_0}^{t_z} L(t)dt \tag{1}$$

where: $D_Ł$ - bearing operation, L - work that allows performance of a specific task, t - time of task performance, t_0 - start time of operation, t_z - time needed to perform the task Z.

Operation $D_Ł$ defined by the formula (1) can be shown as a graph in a „L–t" coordinate system, which is called *the graph of bearing operation* [7]. An example of such an operation graph for a selected time t_z, $t_{\min}$ and $t_{\max}$ is depicted in Fig. 1.

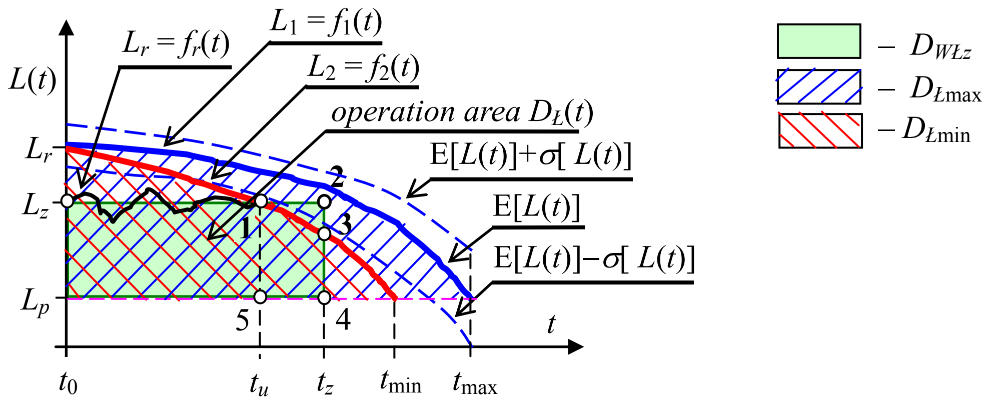

Fig 1. Exemplary graph of operation for an engine bearing: L(t) – work performed at any time $t \geq 0$, L_1 – work performed by bearing No. 1 (less worn), L_2 – work performed by bearing No. 2 (more worn), L_r – work at time t_0 of starting operation $D_Ł$, L_p – work at any time (t) needed for bearing operation without its useful load, L_r – real work during performance of the task Z, L_z - average work needed to perform the task Z, E[L(t)] – expected value of L_t, σ[L(t)] – standard deviation of L_t, $D_Ł(t)$ – operation at (any) time t, $D_{Łz}$ – operation until t_z, $D_{Ł\max}$ – operation at time t_{max}, $D_{Ł\min}$ – operation at time t_{max}, $D_{Ł\min}$ – bearing operation demanded to perform the task Z, t_u –time of correct work of the bearing, t_z –time needed to perform the task Z, t – time

The importance of accurate diagnosis on the technical state of bushings of engine main and crank bearings and thereby establishment of the value of the possible operation $D_{MŁ}$ for this kind of bearings can be explained on the example of the operation graph shown in Fig. 1. The operation graph shows the area of operation $D_{WŁz}$ for the required bearing, which is necessary to perform the task Z. The operation area L_z–1–2–4–L_p is colored with green. Possible operations $D_{MŁz}$ depend on the condition of bearings. The bearing, whose work possible to perform is denoted with the function $L_1 = f_1(t)$, is capable to perform the task Z. However, the bearing in the condition, that allows performance of work defined with the function $L_2 = f_2(t)$, is unable to perform the task.

The operation graph (Fig. 1) shows that the bearing which is capable to perform the work only following the equation $L_2 = f_2(t)$, cannot perform the task Z. This is due to the fact that the bearing's demanded operation $D_{WŁz}$ is defined by the area L_z–1–2–4–L_p. The bearing's possible operation $D_{MŁz}$ is determined by a smaller area L_z–1–3–4–L_p.

Therefore, using the formula (1) and Fig.(1) the following can be determined [24]:

1) demanded operation for a bearing to perform the task

$$D_{WŁ,z} = \int_0^{t_z} \left(L_z - L_p\right) \mathrm{d}t = \left(L_z - L_p\right) \cdot t_z \tag{2}$$

2) possible operation for a bearing during task performance, when $L_2 = f_2(t)$,

$$D_{MŁ,z} = \int_0^{t_z} \left(L_z - L_p\right) \mathrm{d}t - \int_{t_u}^{t_z} \left(L_z - L_2\right) \mathrm{d}t = D_{WŁ,z} - L_z \cdot \left(t_z - t_u\right) + \int_{t_u}^{t_z} f_2(t) \mathrm{d}t \tag{3}$$

Assuming that changes in bearing's work on the track 1 - 3 are linear, the considerations can include the bearing operation illustrated by the triangle with vertices 1 – 2 – 3. In this case, its cathetus 1-2 is equal to $(t_z - t_u)$, while the cathetus 2-3 is equal to $^1/_3(L_z - L_p)$. In this case, according to equation (3), the bearing's possible operation $D_{MŁz}$ can be determined with the formula

$$D_{MŁz} = D_{WŁz} - {}^1/_6(L_z - L_p) \cdot (t_z - t_u)$$

(4)

From equations (2) and (3) and the equation (4) as well, it follows that

$$D_{MŁz} < D_{WŁz}, \tag{5}$$

which means that bearing's possible operation ($D_{MŁz}$) is not sufficient to perform the task $Z = \langle \Phi, W, t \rangle$. The task can be performed by a bearing whose operation allows to carry out the work (i.e., convert energy into work) according to the equation $L_1 = f_1(t)$.

The considerations show that we should tend to determine the time of correct work for each bearing, i.e. the time of its operation until its damage. The time can be determined with diagnosing systems (*SDG*) capable to record and analyze parameters of acoustic emission (AE), which here is considered as a diagnostic signal, that enables assessment of bearing condition. This requires investigation of acoustic emission in order to determine the relationship between diagnostic EA parameters and the technical state of sliding layers of engine bearings.

3. Detection of micro-damage in sliding layers of bearings in crank-piston mechanisms of diesel engines

Bearings of marine engines generally comprise multilayer bushings, which consist of a sliding surface on the contact side with a journal (or main crankshaft) and, further in succession there are: barrier layer, supporting substrate (sliding layer), a steel shell (husk), and a protective coating [14, 16].

During operation of diesel engines, damage of bearings in the crank-piston mechanisms is usually the result of raising wear of their bushings [6].

Damages such as fatigue cracks in the bushings are the consequence of their dynamic loading which has roughly a pulsing character, and may cause a fatigue damage.

Tests of bearings with bushings type MB 58 were carried out at the rotational speed of 3000 rev / min, the values of load P = 20÷111 kN and the pressures p = 71 MPa, In consequence a flow of cyclic load was obtained for the tested bearing, which is shown in Fig. 2. The averaged course of this load, registered by an *EA* measuring system is depicted in Fig. 3 [6].

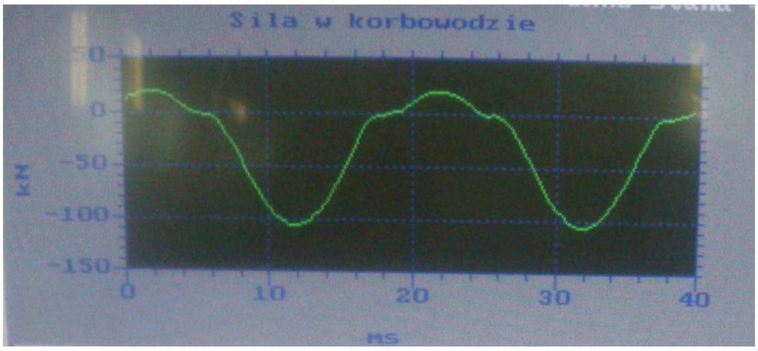

Fig. 2. Flow of the load on a sliding bearing with tested bushings type MB58 [6,22, 23]

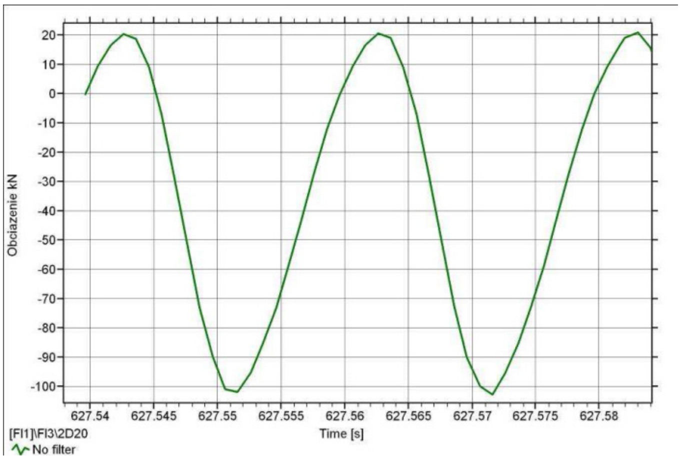

Fig. 3. Flow of the load on a sliding bearing with tested bushings type MB58, averaged by AE measuring system [6, 22, 23]

Permanent monitoring and recording of load and temperature of the tested bearing and the support, temperature of oil and shaft rotational speed were provided by the measuring system on the bench (Fig. 4). Prior to mechanical and thermal overload the bearings were protected by an automatic control system. If the temperature of any bearing rose above 403^{o}K, the bench would automatically switch itself off [6, 21].

Acoustic emission *AE* was recorded permanently in order to register the AE signals coming from the working bearing with the tested bushings for both: a bearing in good condition and a bearing with developing fatigue damage. The collected measurement data was subject to parametric and frequency analysis in order to select out the signals characterizing the states of bearing emergency operation for the tested bushings type MB58 [6].

For analysis of the recorded AE signals there were applied the methods of analysis, such as: wavelet transformation, neural networks, patterne recognition, finite element method (FEM). One of the applications is VisualClass from the Vallen's software, which uses the method of patterne recognition. It allows to obtain the full shape and form of *AE* wave and its frequency components (Fourier transforms), the peak amplitude, the amplitudes of the components, RMS and the pulse signal energy, and classifies them into individual groups of similar waveforms. VisualClass software enables to build classifiers that contain rules to associate the particular waves with relevant classes that are used by VisualAE to identify the AE sources.

The measurements of *AE* parameters were carried out by using the 12-channel AMSY-5 System and set of sensors: VS30-V, VS150-RIC, VS375-RIC, VS75-V, WD1, SAE45-A [6, 22, 23]. The test system type AMSY-5 consists of the following components: *EA* sensors, preamplifiers including pre-filter, primary filters, electronic unit performing integrations, differentiations, logarithms and comparisons, digital converter boards (modules), main processor controlling the system processes, with relevant software, data visualization and analysis software [6, 22, 23]. A detailed description of the test bench and particulars on the Vallen's AMSY-5 system as well as methodology of the carried tests on bushings for sliding bearings are presented in the publication [6].

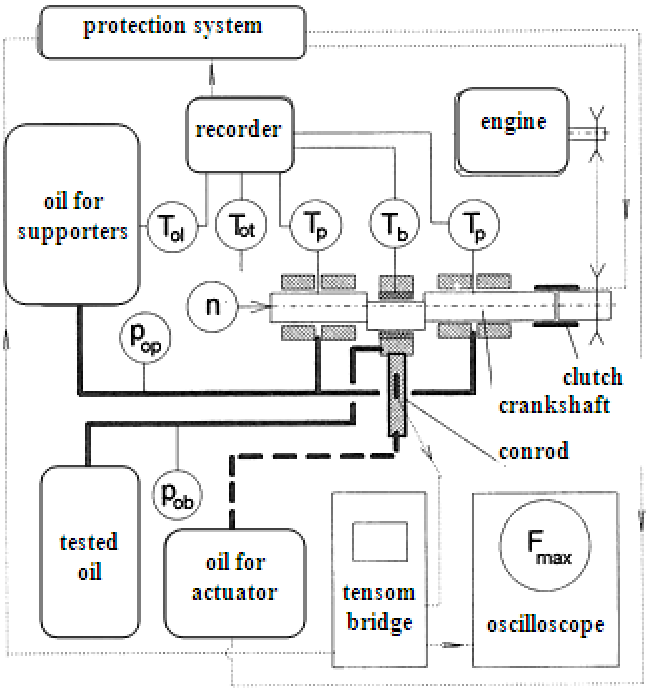

Fig. 4 Diagram of a measuring system displaying the quantities of: T_b – temperature of the tested bearing, T_p – temperature of the support bearing, T_{ot} – ambient temperature, T_{ol} – oil temperature, F_{max} – loading force on the tested bearing, p_{ob} – lubricating oil pressure in the tested bearing, p_{op} – lubricating oil pressure in support bearings, n – rotational speed of the tested shaft [6, 23]

Registration by the AMSY-5 system of the first signs of AE activity was a signal to interrupt the test. Then inspection took place to identify the technical condition of the bushing. It was found that the bushing had small grooves caused by micro-cuttings in its sliding surface with solid particles. No signs of seizure were found in the surface. A view of the tested bushing surface is shown in Fig. 5

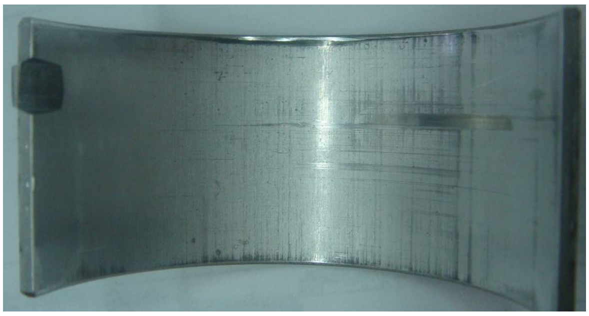

Fig. 5. View of bushing surface made of MB58 material, with visible grooves that occurred by micro-cuttings in the sliding surface with solid particles [6, 21].

After re-installing the bushing the tests were continued until a clear instability in values of bearing operation parameters, the temperature in particular, was recorded. After breaking the test (switching off the bench) and surveying the bushing, there were found visible changes in its sliding layer, indicating fatigue damage. A view of the layer is shown in Fig. 6.

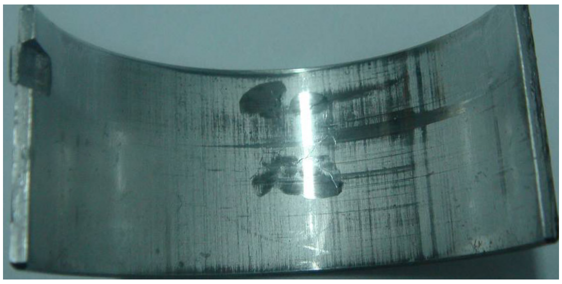

Fig. 6. A view of the bushing surface type MB58 with fatigue damage after test completion [6, 21]

Detection of the damage in the tested bushing made of the MB58 material, shown in Fig. 6 and 7, was possible due to *AE* signals registered during testing of the bearing. The signals were processed through the defined filters provided by the Vallen's "VisualAE" software to eliminate interference (electrical, electromagnetic). For the signals the following parameters were taken into account: rise time, counts, duration, amplitude and RMS. An analysis of the obtained results enabled production of graphs, for each measuring channel, which illustrate dependence of signal duration from amplitude (Fig. 7), counts as an amplitude function (Fig. 8) and RMS as a function of time (Fig. 9).

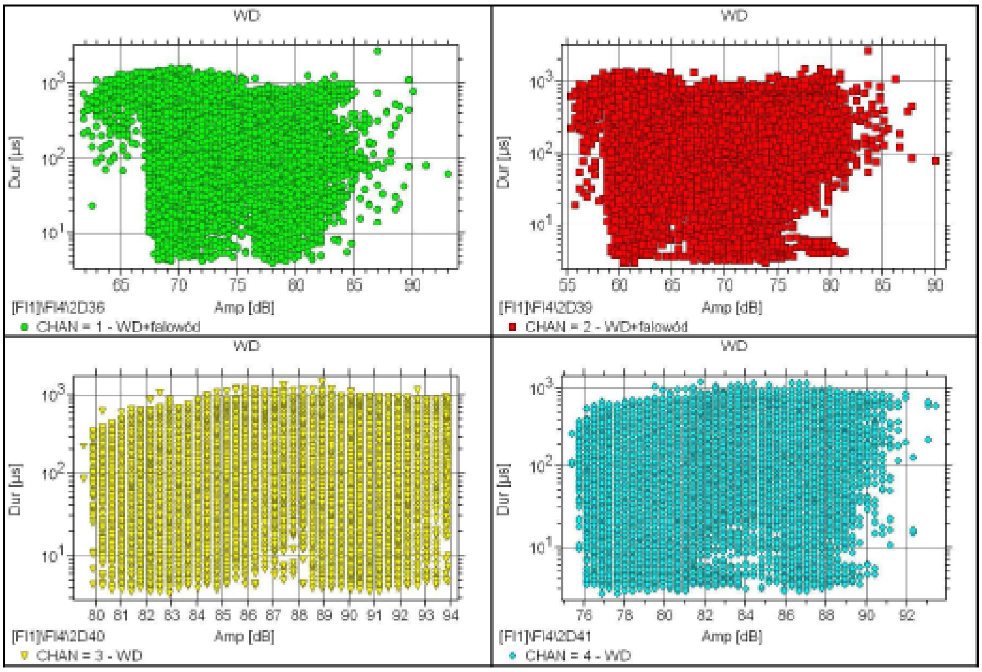

Fig. 7. Values of signal duration depending on the amplitude for individual channels throughout the entire period of testing of the bushing type MB58 [6, 22].

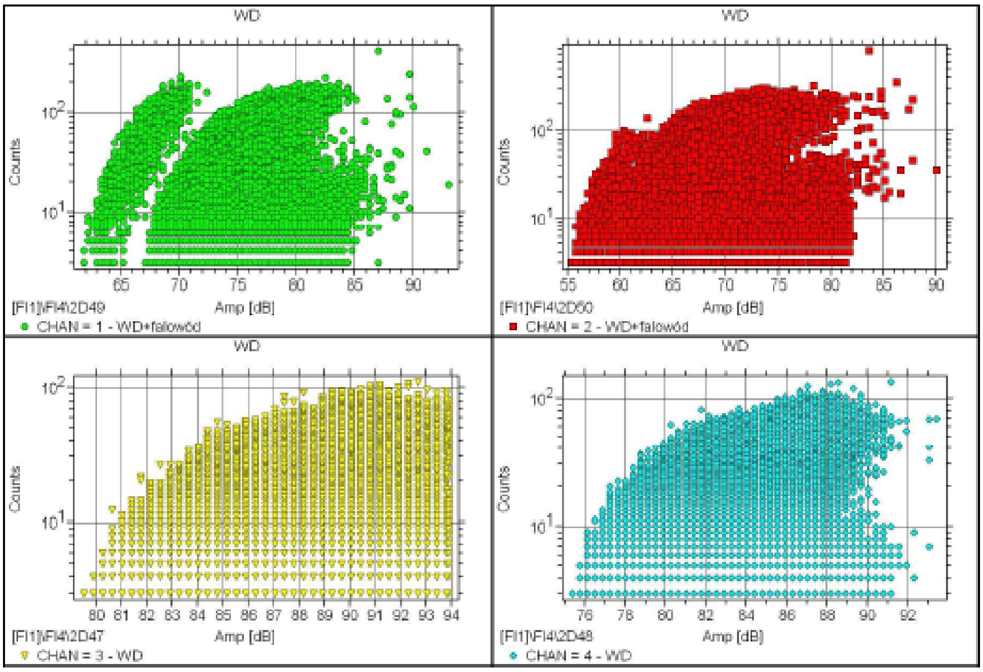

Fig. 8. Counts as an amplitude function for individual channels throughout the entire period of testing of the bushing type MB58 [6, 22]

Fig. 9 shows the graphs illustrating for each *AE* sensor, the dependences of RMS-Status values from duration, with a significantly higher activity of *AE*. At that time the fatigue cracks on the bushing surface were identified. The registered RMS values were from 50µV to 1900µV, depending on the used parameter and the type of sensor.

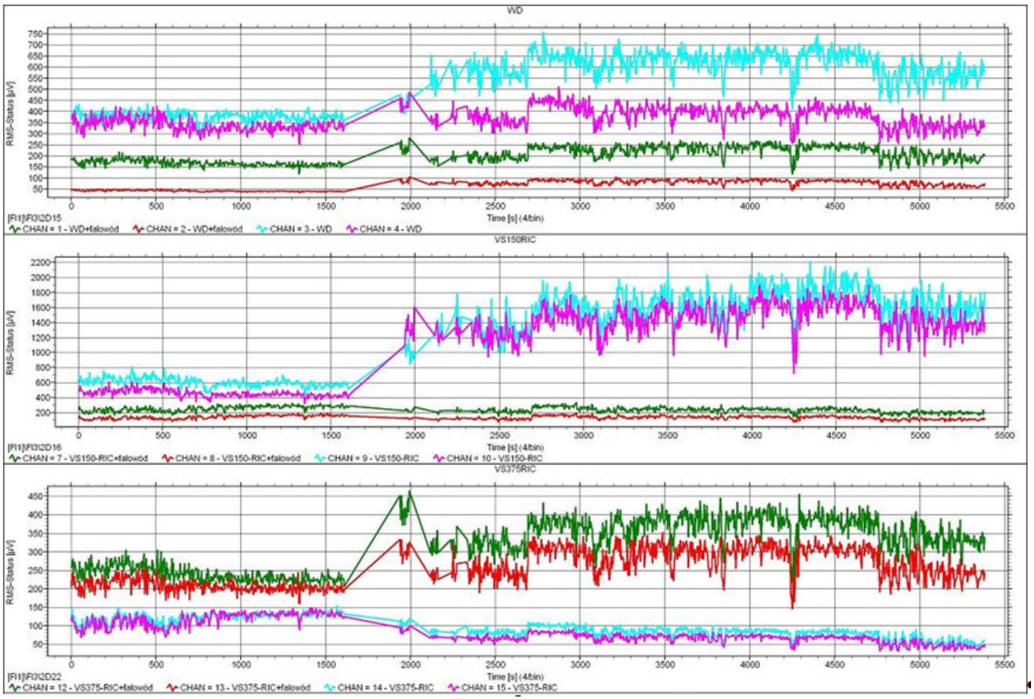

Fig. 9. Graphs of RMS-Status parameters for individual measuring channels, as functions of time which enabled identification of fatigue cracks in the bushing surface [6, 22]

Additionally, during the fatigue tests on the bushing, a frequency analysis of AE signals was carried out. The results of the analysis, developed in the form of graphs, are depicted in Fig. 10 and 11. The graphs demonstrate the frequency distribution for the maximum amplitudes of *AE* signals during measurements, for individual measuring channels and all the channels together.

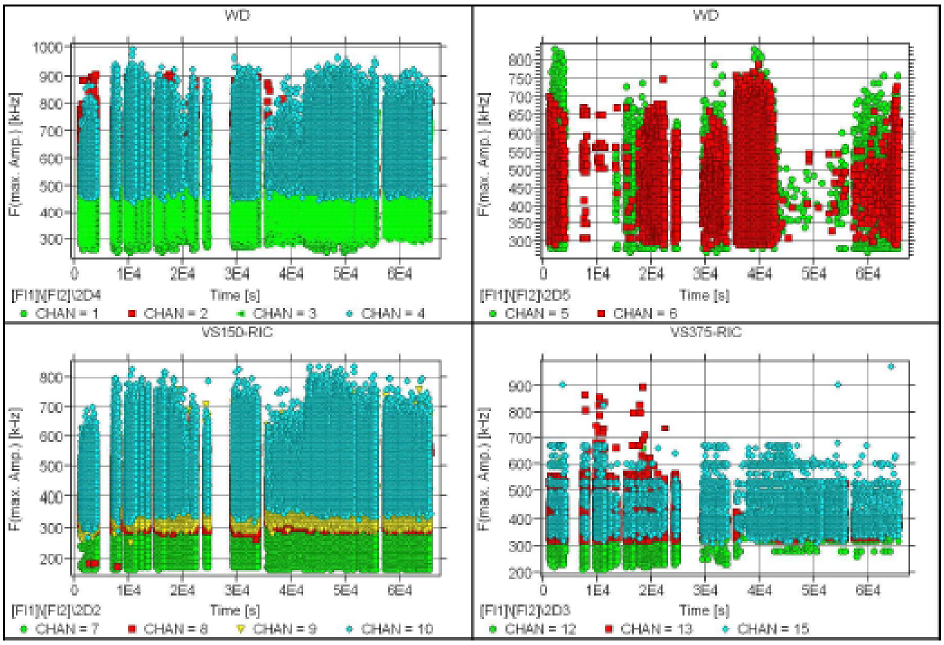

Fig. 10. Graphs of frequency values for the maximum amplitude of the signals (F(max.Amp.) [kHz]), as the functions of time, for the entire period of testing of the bushing type MB58 [6, 22]

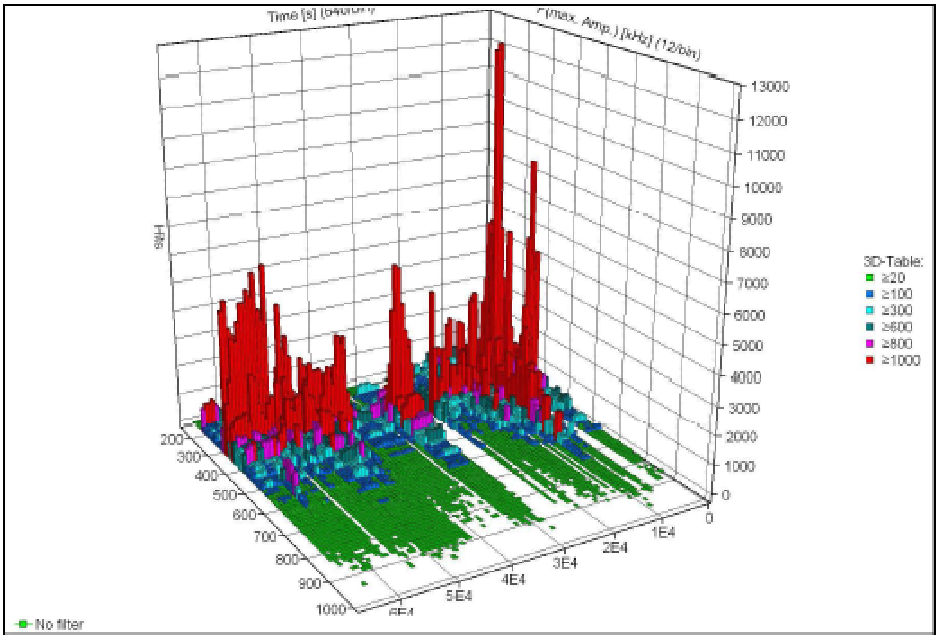

Fig. 11. Distribution of frequency values for the maximum amplitude of the signals in time, for all measuring channels throughout the entire period of testing of the bushing type MB58 [6, 22]

The above analysis allowed to carry out classification of the signals by using the VisualClass application, which bases on frequency characteristics of *AE* signals [6].

The graphs (Fig. 12 and 13) were developed as a result of the analyzes, which indicate that 2 (two) classes of *AE* signals can be distinguished. It has been found thereby that the selected class 2 encloses signals produced by the damaged sliding layer of a bushing and the class 1 encloses interference.

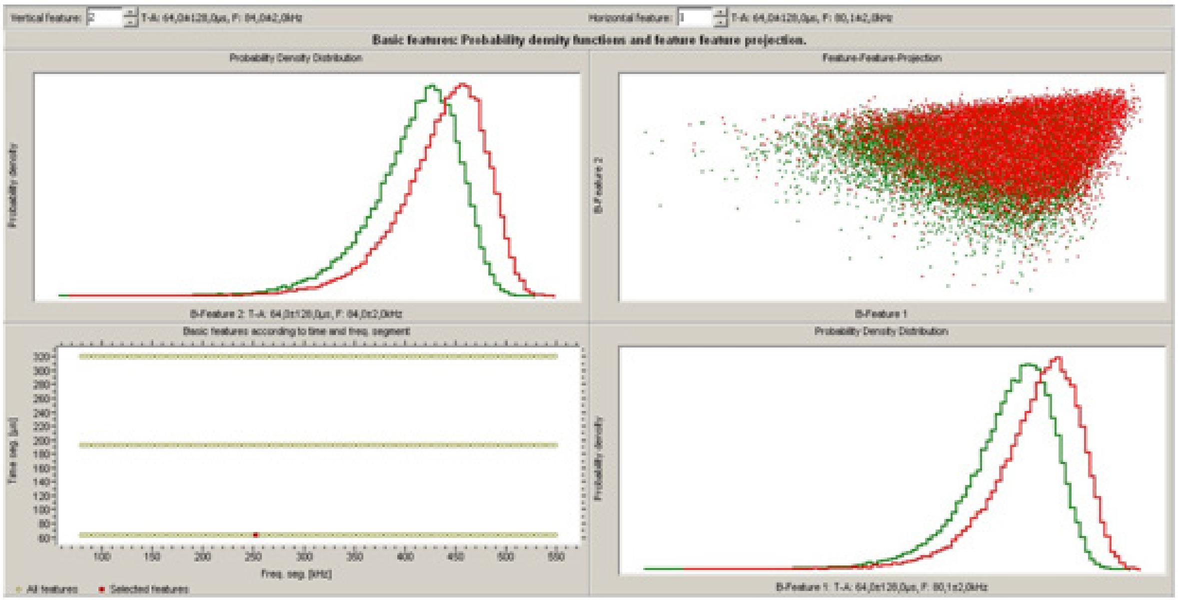

Fig. 12. Probability distribution for particular classes, for fundamental features [6, 22]

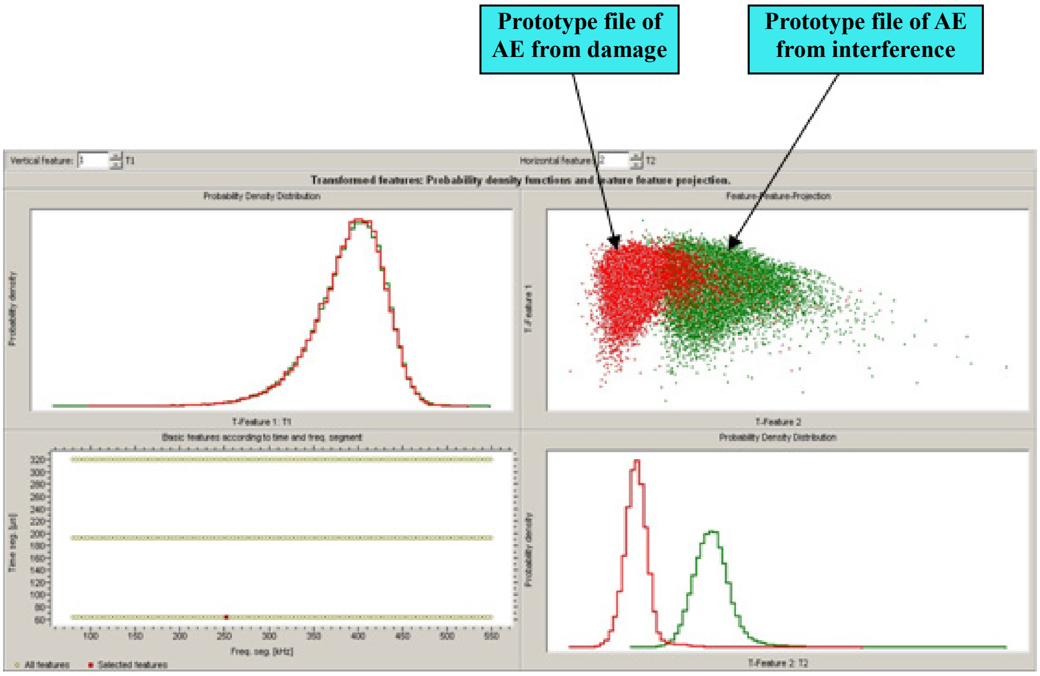

Fig. 13. Probability density function and features for classification of AE signals into 2 (two) classes after the transforms [6, 22]

In turn, Fig. 14 presents the intensity of the signals in the given class for relevant measurement sequences. It shows that the signals from the class 2 dominate only when the material damage in the sliding layer of the bushing occurs. In the early stage of testing, i.e. when the bearing break-in proceeds, although the total number of the registered *AE* signals is high, the signals from the class 2 are scarce. This reveals a possibility of selecting the signals, registered during work of a damaged bushing, which are oriented to damage.

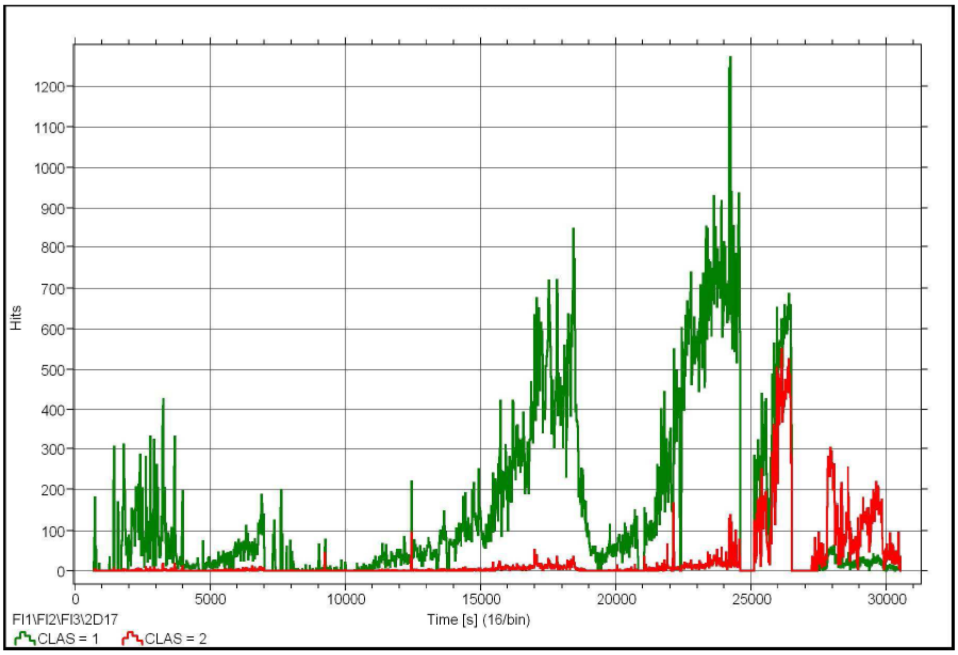

Fig. 14. Intensity of AE signals for the given class (1 - interference, 2 - damage) during crack initiation and development within the sliding surface of the bearing alloy type MB58 [6, 22]

4. Remarks and conclusions

For bearings of marine diesel engines, both their load $Q(t)$ and their wear $Z(t)$ investigated in their operation time t are stochastic processes. Hence, the conclusion that the dependence between the load processes $Q(t)$ and the wear $Z(t)$ cannot be described by applying a common algebraic equations method. This would make identification of bearings condition complicated, because for each time t, the values of the processes are random variables Q_t and Z_t. This is because it is impossible to predict the bearing technical state, only to estimate the probability of its occurrence.

Following the considerations, the theory of random processes, stochastic in particular, should be applied for investigating the process of changes in technical state of bearings for crank-piston mechanisms of diesel engines.

No possibility for unambiguous identification of technical condition of main and crank bearings for marine engines causes that operation of each of the bearings cannot be accurately determined. Nevertheless, it is necessary to assess the possible operation ($D_{MŁ}$) for each bearing as well as the demanded operation ($D_{WŁ}$), which is essential for operation of the bearings to perform the task (Z) taken by the engine operator. Hence, there is a need to continue the studies which should aim at building diagnosing systems (*SDG*) for bearings, capable to detect damage in bushings at the earliest possible stage of its initiation. Such a possibility exists in case of use of diagnosing apparatus (*UD*) belonging to the said *SDG*, which are designed to analyze acoustic emission (*AE*) as a diagnostic signal that contains information on the technical state of sliding layers of bearing bushings for crank-piston systems of marine diesel engines. The conducted empirical studies confirmed the usefulness of acoustic emission as a diagnostic signal for identification of technical condition of the bushings.

The analysis of the test results provide a conclusion that a dynamic load does not lead to a sudden catastrophic fatigue damage in the alloy of bushings in sliding bearings. Fatigue damage develops slowly, and its advance degree can be evaluated on the base of parametric (amplitude-frequency) analysis of the recorded *AE* signals.

The data collected during the measurements and the classifiers built on this basis by using the VisualClass application, are useful for identification of *AE* signals being produced by damage in bushing alloys, for further studies on diesel engines. This means that the possibility exists for application of the mentioned classifiers in diagnostic tests of bushings of main and crank bearings in marine diesel engines, under operation in real conditions.

When building classifiers it is important to develop them with regard to as many performed measurements as possible, because the classifier effectiveness grows with the increase in number of performed measurements.

5. References

1. Brun R.: Szybkobieżne silniki wysokoprężne. WKiŁ, Warszawa 1973. Dane o oryginale: Science et Technique du Moteur Diesel Industriel et de Transport. Copyright by Societe des Editions Technip et Institut Francais du Petrole, Paris 1967.
2. Firkowicz S.: Statystyczna ocena jakości i niezawodności lamp elektronowych. WNT, Warszawa 1963.
3. Girtler J.: A probabilistic concept of load assessment of self-ignition engines. Polish Maritime Research. No 2(56), Vol. 15, 2008.
4. Girtler J.: Diagnostyka jako warunek sterowania eksploatacją okrętowych silników

spalinowych. Studia Nr 28, WSM, Szczecin 1997.
5. Girtler J.: Physical aspects of application and usefulness of semi-Markov processes for modeling the processes occurring in operational phase of technical objects. Polish Maritime Research, Vol. 11, No 3, September 2004.
6. Girtler J., Darski W.: Możliwości identyfikacji stanu technicznego powłok ślizgowych łożysk silników spalinowych o zapłonie samoczynnym w przypadku wykorzystania emisji akustycznej jako sygnału diagnostycznego. Materiały VII Międzynarodowej Konferencji Naukowo-Technicznej EXPLO-DIESEL & GAS TURBINE'14 „Utrzymanie w ruchu silników tłokowych i turbinowych z uwzględnieniem ochrony środowiska naturalnego", Gdańsk-Gdynia-Karskrona, 23-27.05.2014. Płyta CD, 22 str.
7. Girtler J.: A method for evaluating the performance of a marine piston internal combustion engine used as the main engine on a ship during its voyage in different sailing conditions. Maritime Research 4(67) 2010 Vol 17, pp. 31-48.
8. Girtler J.: The semi-Markov model of energy state changes of the main marine internal combustion engine and method for evaluating its operation during ship voyage. Polish Maritime Research 4(71) 2011 Vol 18, pp. 36-42.
9. Kozłowiecki H.: Łożyska tłokowych silników spalinowych. Warszawa, WKiŁ 1982.
10. Krzysztofiak M., Urbanek D.: Metody statystyczne. PWN, Warszawa 1979.
11. Malecki I., Ranachowski J., Emisja akustyczna, źródła, metody, zastosowanie, KBN, Warszawa 1994.
12. Niewczas A.: Podstawy stochastycznego modelu zużywania poprzez tarcie w zagadnienia trwałości elementów maszyn. Zeszyty Naukowe, Mechanika nr 19, Politechnika Radomska 1989.
13. Ono K., Fundamentals of acoustic Emission, University of Kalifornia, Los Angeles 1976.
14. Piotrowski I., Witkowski K.: Eksploatacja okrętowych silników spalinowych. AM, Gdynia 2002.
15. Wajand J.A.: Silniki z zapłonem samoczynnym. WNT, Warszawa 1980.
16. Wajand J.A., Wajand J.T.: Tłokowe silniki spalinowe średnio- i szybkoobrotowe. WNT, Warszawa 2005.
17. Włodarski J.K.: Tłokowe silniki spalinowe. Procesy tribologiczne. WKiŁ, Warszawa 1982.
18. Włodarski J.K.: Stany eksploatacyjne okrętowych silników spalinowych. WSM, Gdynia 1998.
19. Identyfikacja warunków eksploatacji układów korbowo-tłokowych okrętowych silników głównych, Sprawozdanie z realizacji etapu projektu finansowanego przez MNiSW Nr N N509 494638. Projekt badawczy własny pt.: „Decyzyjne sterowanie procesem eksploatacji układów korbowo-tłokowych silników napędu głównego statków morskich z zastosowaniem diagnostyki technicznej oraz uwzględnieniem bezpieczeństwa i ochrony środowiska". Autor opracowania J. Girtler. Kierownik projektu J. Girtler. Prace badawcze nr 1/10 /PB. Wydział Oceanotechniki i Okrętownictwa Politechniki Gdańskiej.
20. Sprawozdanie z realizacji projektu badawczego Grant Nr N504 043 31/3480, pt.: *„Identyfikacja stanu technicznego układów korbowo – tłokowych silników o zapłonie samoczynnym ze szczególnym uwzględnieniem emisji akustycznej jako sygnału diagnostycznego"*.
21. Sprawozdanie z realizacji projektu badawczego Grant MNiSW Nr N N509 494638 pt.: *„Decyzyjne sterowanie procesem eksploatacji układów korbowo tłokowych silników napędu głównego statków morskich z zastosowaniem diagnostyki technicznej oraz uwzględnieniem bezpieczeństwa i ochrony środowiska"*.
22. Sprawozdanie z realizacji pracy naukowo-badawczej pt. „Opracowanie projektu wstępnego systemu diagnozującego przysposobionego do identyfikacji stanu technicznego panwi łożysk

ślizgowych silników spalinowych tłokowych z zastosowaniem emisji akustycznej jako sygnału diagnostycznego", wykonanej w ramach projektu finansowanego przez MNiSW Nr N N509 494638. Projekt badawczy własny pt.: „Decyzyjne sterowanie procesem eksploatacji układów korbowo-tłokowych silników napędu głównego statków morskich z zastosowaniem diagnostyki technicznej oraz uwzględnieniem bezpieczeństwa i ochrony środowiska." Autorzy: Jerzy Girtler, Wojciech Darski, Piotr Darski. Kierownik projektu prof. dr hab. inż. Jerzy Girtler. Prace badawcze nr 15/11/PB. WOiO Politechniki Gdańskiej, Gdańsk 2011.

23. Sprawozdanie z realizacji pracy naukowo-badawczej pt. „Analiza wyników badań w celu określenia przydatności systemu diagnostycznego w zakresie identyfikacji stanu technicznego łożysk układów korbowo-tłokowych okrętowych silników głównych", wykonanej w ramach projektu finansowanego przez MNiSW Nr N N509 494638. Projekt badawczy własny pt.: „Decyzyjne sterowanie procesem eksploatacji układów korbowo-tłokowych silników napędu głównego statków morskich z zastosowaniem diagnostyki technicznej oraz uwzględnieniem bezpieczeństwa i ochrony środowiska." Autorzy: Jerzy Girtler, Wojciech Darski,. Kierownik projektu prof. dr hab. inż. Jerzy Girtler. Prace badawcze nr 29/11/PB. WOiO Politechniki Gdańskiej, Gdańsk 2011.
24. Sprawozdanie z realizacji pracy naukowo-badawczej pt. „Analiza i synteza sytuacji decyzyjnej w procesie eksploatacji urządzeń i systemów energetycznych", wykonanej w ramach projektu finansowanego przez MNiSW Nr N N509 494638. Projekt badawczy pt.: „Kształtowanie bezpieczeństwa działania systemów energetycznych środków transportowych na przykładzie systemów okrętowych". Autor: Jerzy Girtler. Kierownik projektu prof. dr hab. inż. Jerzy Girtler. Prace badawcze nr 06/08/PB. WOiO Politechniki Gdańskiej, Gdańsk 2008.
25. ASTM – E 1316-96 Standard Terminology for Nondestructive Examination (orig.- 89).
26. ASTM – E 610 82 Standard Definitions of Terms Relating to Acoustic Emission (now incorporated into E 1316)
27. PN-EN 1330-9 Badania nieniszczące, Terminologia, Arkusz 9 Definicje terminów stosowanych w emisji akustycznej, July 1996.
28. PN-EN 13477-1-2001 Badania nieniszczące, Emisja akustyczna, Charakterystyka aparatury, Część 1: Opis aparatury.