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INTRODUCTION TO DIAGNOSTIC INVESTIGATION OF MARINE DIESEL ENGINES AT LIMITED MONITORING SUSCEPTIBILITY

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Abstract

There have been presented preliminary assumptions of the new diagnostic method concerning the marine diesel engine's workspace areas, which had been elaborated at the Polish Naval Academy. There is expected that the method will be very useful to diagnose technical shape of marine diesel engines at limited monitoring susceptibility, it means, which are not equipped with the indicator valves. The research problem and main purposes of the research have been formulated. The notion of the workspace areas has been defined, moreover the analysis of factors that have the most decided impact on destruction phenomenon has been carried out. There have been also considered operation strategies applied at present on marine diesel engines: according to the engine installation life, according to the technical shape as well as according to the level of reliability. The mutual interdependences between characteristic technical states of the research object (workspace areas) have been characterized. The conducted research is showed in the background of achievements of foreign and national scientific centres. By this way the research diagram of gasdynamical processes has been precised for diagnostic purposes of marine diesel engines.

Keywords: *Marine diesel engines, diagnostics, workspaces area*

1. Introduction

How to elaborate a diagnostic method that makes it possible to diagnose workspace areas of marine diesel engines, which are not provided with indicator valves, represents the most important research question for diagnostic teams from the Polish Naval Academy nowadays. Such the engines have been recently implemented into the Polish Navy. The main solved problem consists in determination of the relation between gasdynamical parameters of the working medium inside exhaust passages and the alterations within the structure of an engine's workspace areas. The authors estimate that the elaborating diagnostic method makes it possible to introduce the operation system according to technical shape for diagnosing workspace areas of marine diesel engines without indicator valves. It means that in practice all the worship's diesel engines in the Polish Navy will be operated according to their technical state.

2. The reasons of unserviceable states appearance within marine diesel engine's workspace areas

Marine diesel engines are in common usage on boards of the Polish Warships. There are usually high-speed and medium-speed engines equipped with turbochargers [8,17]. The largest number of the turbochargers works in the pulsatory configurations of supercharging systems. Such the engines represent the part of the ship's propulsion system (the main engines) as well as the part of the ship's electric power plant (the auxiliary engines).

Every combustion engine is characterised with a transformation energy process where the chemical energy is transformed into thermal energy that is subsequently transformed into

mechanical work. The production of mechanical work as well as chemical reactions during fuel combustion process in the engine's cylinders are tightly associated with the series of undesirable phenomena that have essential impact on a technical state of the construction structure components and especially their workspace areas. Chemical reactions representing the result of combustion process cause heat and exhaust creation. The exhaust represents a gas mixture, which can be polluted by solid combustion products. The solid components of the burning process can create difficult removable deposits on surfaces of the engine's workspace Futhermore, the hard mineral pieces of and other hard solid body flowing in thermodynamical medium cause erosion processes on surfaces of the workspace areas structure. Moreover, anhydride of sulphurous and hydro sulphuric acids begin to exist as the burning products. The acids represent the reason for chemical corrosion of engine's components (especially in the region of engine's workspace areas) [10,15].

Another reason for appearing diesel engines unserviceable states is a metal fatigue. Periodically changeable mechanical and thermal stresses represent a main reason for the metal fatigue [1,10,15].

All the foregoing specified fatigue processes and phenomena lead to the degradation of construction structure within diesel engine's workspace areas.

The workspace areas of the marine diesel engines are the research objects considered in the paper, as follow:

- cylinder sections, limited by cylinder liner, crowd along with rings and the engine's head,
- air and exhaust passages connecting engine's cylinders with turbocharger,
- compressor's and turbine's internal channel of the turbocharger set.

A schematic diagram of the relation between particular engine's workspace areas is presented in figure 1. There are distinguished in the diagram particular engine's workspace areas and flow directions of the thermodynamical medium. Moreover, influences (feedbacks) between particular flow machines are shown in the figure as well: working periodically – cylinders of the engine and working continuously – turbocharger's rotor.

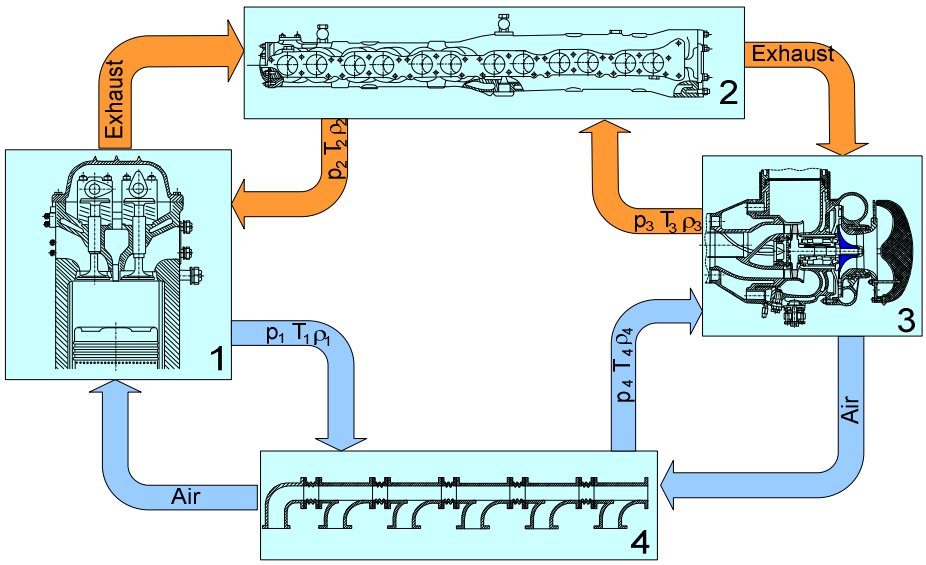

Fig. 1. The relation between particular engine's workspace areas
1 – combustion chamber, 2 – exhaust channel, 3 – turbocharger, 4 – inlet channel

The author's reliability research led to the conclusion that the majority of marine diesel engine's unserviceable states accounts for a consequence of physical and chemical destruction processes [10]. The most often faced failures concern the cylinders sections. They represent the

result of solid burning product's deposits on surfaces of cylinder liners, bottom of crowds and the engine's heads.

The solid burning product's deposits lead to progressive reduction of cylinders volumes. As a consequence a deterioration of engine's running occur (considerable non-uniform loads between the cylinder systems). In other hand, the cylinder volume can increase during engine's operation. The process of volume increasing of the engine's combustion chamber is associated with the increase of bearing clearances between a connecting rod and crowd pin or between a connecting rod and crankshaft. It leads to increase of the load dispersion around the average value as well [12].

The solid burning products can also seat into grooves of piston gas rings. It leads to the loss of leak tightness of the piston-ring-cylinder system (PRC) as well as to leakages of the thermodynamic medium from the combustion chamber [10].

Inlet and outlet valves of the cylinder sections (simultaneously, air and exhaust flow passages). Are another vulnerable components of the engine's workspace areas. Exhaust valves are the most endangered engine's parts with the failures. They work at the severe conditions being flowed by hot, chemical active ("aggressive") exhaust gasses. Such a working environment of the exhaust valves has an essential impact on wear intensity of precision pair: valve stem – guide. In the extreme cases, as a result of forces and torques influences on the valve stem the valve head may "skewed" and the working medium leakage from the combustion chamber may appear [10].

The exhaust channel cooled with sea water represents the next key component of engine's workspace areas. The marine diesel engine's exhaust channels are exposed to degradation of technical structure as a result of operation in unfriendly sea conditions (on the board of worships). Pollutions gathered on channel's interior surfaces, representing solid combustion products, are the reason of failures appearance in the most frequent cases. The pollution process leads to the constant decrease of exhaust channel's face area and decrease of channel's volume. Moreover, the exhaust channel is exposed to activity of aggressive and hot exhaust gasses. Additionally it is exposed to chemical and stress corrosion [1].

Turbocharger's internal passages represent an equally important component of the engine's workspace areas from the reliable functioning point of view. The turbine's internal channels are threaten to solid substance contents in exhaust gases. In the other hand, the compressor is submitted to solid substance contents in the sucked air (especially mineral particles). The solid particles which flow through turbine and compressor's internal channels form deposits on the surface of turbocharger's rotor. The solid deposits cause mass growth of turbocharger's rotor and diminish its rotational speed. As a consequence of this process compression ratio and mass flow rate of the compressor decrease and an efficiency of turbine and compressor are fallen. The decrease of mass flow rate leads to deterioration of the combustion air factor. This process makes the burning process poor and solid particles emission increases. Moreover, the polluted compressor works without a stability margin of the flow process [10, 15].

The turbocharger's rotor might also lost a mechanical stability as a result of the turbocharger's internal passages pollution. The loss of turbocharger's rotor stability leads to mechanical vibration and finally leads to the mechanical resonance phenomenon that causes an accelerated wear process of turbocharger's bearing nodes and fatigue cracks of the rotor's blades [1, 10].

Erosion phenomenon represents a different consequence of turbocharger's internal passages pollution. The phenomenon usually leads to the growth of passages' surface roughness and to the changes of profile geometry of turbine's and compressor's blades [10, 15].

3. The operation strategies of marine diesel engines

Destruction processes worked out inside marine diesel engine's workspace areas are unavoidable and continuous and always associated with the engines' operation in sea conditions.

Searching optimum strategy of the engine's operation represents the only way for minimization of the occurrence probability of primary or secondary failures. The optimal strategy of engine's operation should secure maximum time extension of the failure-free operation. Moreover, the engine should be efficient enough and should assure high dynamic and static performance. The strategy of marine diesel engine's operation should also take into account functioning the diagnostic system, which gives possibilities to detect initial stages of developed states of operational unfitness. The following operating decisions are undertaken on the basis of formulated diagnosis about the engine's technical state: further running without any limits, introduced limitations of permissible engine's loads, mending or cleaning workspace areas. The earlier will be detection and unfitness states removal the cheaper will be costs of damages' repair. Moreover, the precise and early unfitness detection allows shortening the repair time [7, 9].

Three different operation strategies could be distinguished as a result of searching the most efficient operation strategy:

1. Operation according to the overhaul life – assumes the exchange of particular engine's elements after strictly defined period called the overhaul life. This strategy is useful enough in the cases when the engine's elements are characterized with visible dependence between intensity of the defect appearance and the time of the engine's running. This relation should involve a short interval of time. Moreover, this method could be put into practise when the elements have limited monitoring susceptibility and designing the diagnostic system is not remunerative. A typical function course of failures' intensity is shown in figure 2 – curves 1. The overhaul life strategy is effective for the engine's elements, which are endangered for cyclically changing stresses. They drive to the material fatigue, especially within mechanical systems.
2. Operation according to technical state – consist in a periodical control of the technical state of engine's elements which are involve with the diagnostic system. The strategy proves its usability for those construction elements which unfitness dispersion spreads in wide interval of the time and failures develop very slowly. Moreover, the diagnostic system should assure the unfitness's localisation, precision estimation of technical state tendency and should give precision prognosis about the time of correct engine's running. The operation strategy according to the technical state leads to increase of average working time without any damages. It directly drives to diminishing operation costs. This strategy allows short time engine's operation with a slight unfitness it means at slightly lower engine's efficiency. A typical course of the density of engine's elements damages probability function is shown in figure 2 – curves 2. The operation experiences of the engines applied in the Polish Navy warships clearly show that such a strategy could be very useful for the engine's workspace areas.
3. Operation according to the level of reliability concerns the engine's functional systems, for which the time of correct functioning has exponential schedule or when there is not existing a dependence between an intensity of damages occurrence and the working time (there is a random damages occurrence that is independent of the time). The engine's elements are operated up to the damages uprising. The operation system permits the failure's existence which is not dangerous for the engine's reliability and when it could be quickly removed. The technical services are carried out only when they are absolutely necessity and intended unfitness can't be identified with diagnostic activities. A typical course of the density of engine's elements damages probability function is shown in figure 2 – curves 3 end 4. The operation strategy according to the level of reliability is effective enough for electronic components of the engines' control systems.

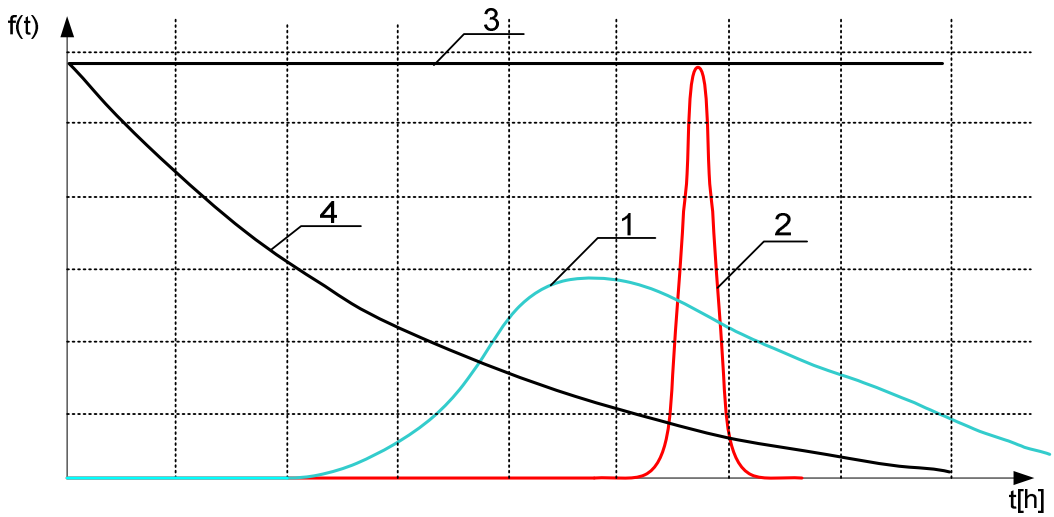

Fig. 2. Time courses of a density of the engine's elements damages probability function while the engine is operated according to: 1- overhaul life, 2- technical state, 3 and 4 - level of reliability

As far as the evaluation of the working spaces technical shape is concerned a proper qualification of the limiting engine's technical states and their classes represents the most important, key diagnostic problem. The example dependences between the states of an engine's efficiency and the states of an engine's technical fitness in an aspect of the parameters of construction structure within exhaust channel are showed in figure 3. The figure 3 takes into account two different cases of the failure's occurrence: natural and sudden [20]. Curves 1 represents a natural case of the failure, curves 2 represents a sudden case of the failure. The natural cases of the failure are typical for the dirt of workspaces areas. The sudden cases of the failure are typical for material fatigues of the engine's elements, for example, like the failure presented in figure 4. There is presented in figure 4 compressor's stator blades with stuck a broken metal piece of the exhaust manifold.

The majority of warship's engines are subject to the operation according to their technical state. Diagnostic tests of the workspace areas base on the results of measurements of intracylindrical pressures. The diagnostic measurements are performed by means of highly specialized pressure recorders equipped with pressure sensors for example OPTRAND type sensors. But there is still an unsolved problem concerning the diagnosing engine's workspace areas while there are no possibilities to measure intracylindrical pressures. In such a situation, while the engine is not equipped with the indicator valves, the workspace areas are only diagnosed with the use of endoscopies. The diagnostic endoscopic tests make it possible to assess the state of visible surfaces limiting workspaces areas [10].

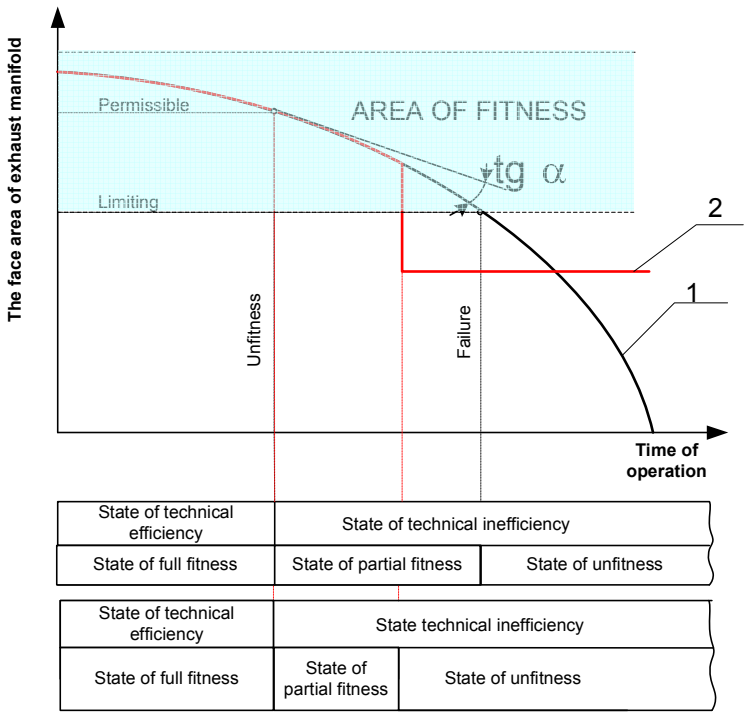

Fig. 3. Dependences between the characteristic states of workspaces areas, for which the technical state can be defined by only one parameter of constructional structure – the face area of exhaust manifold
1 - natural failure, 2 - sudden failure.

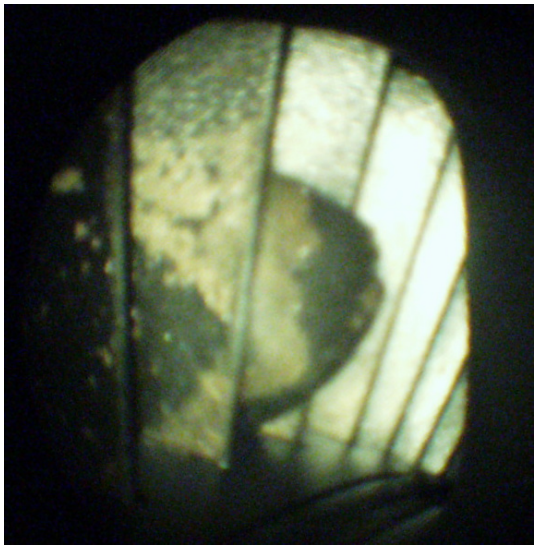

Fig. 4. A metal piece of exhaust manifold stuck into the stator blade cascade of a turbocharger's turbine

The problem "how to diagnose workspace areas of the engines without indicator valves" has become recently very important for the diagnostic team from the Polish Naval Academy [2, 13]. This is a fundamental diagnostic issue because nowadays such engines are in common operation in the Polish Navy. The following engine constructions represent mentioned above a type of the engine:

- main engines ZWIEZDA M520 and ZWIEZDA M520 type, applied on warships 205 and 660 type,

- main engines ZWIEZDA M401A1/A2 type, applied on warships 607 type,
- auxiliary engines DETROIT DIESEL DDA149TI type, applied on warships Oliver Hazard Perry type.

Low diagnostic susceptibility and common application the foregoing mentioned engines enforces the necessity of searching new alternative methods, which make it possible to conduct a parametric evaluation of the engine's workspace areas technical state. The author's scientific experiences, confirmed by results gathered during engines' operation enable formulating the conclusion that the analyze of time pressure courses along the exhaust passages could represent one of the most promising diagnostic method.

An idea of engine's diagnostic tests on the basis of the observation of exhaust pressure's alterations in outlet passages of the working medium is original. So far, gasdynamical processes inside exhaust manifold were analysed only for construction purposes. A wide variety of bibliography clearly shows that a number of polish and foreign researchers specialised with IC engine construction have dealt with gasdynamical processes in the exhaust passages. Many of them can be also very useful in our research, for example publications like [4,5,11,14,19].

Many accessible publications within the scope of diagnostics of marine diesel engines stand for the results of research worked out mainly on automotive engines. Majority of the publications where the authors describe methods of automotive engine's technical state evaluation is directed to construction elements that has the most essential impact on the engine's efficiency, performance and intensity of harmful chemical emission in the exhaust [6]. Only few research teams deal with diagnostic issue of the engines that have different assignment like marine engines. The issue of diagnosing the IC engine's construction modules has been also considered in other publication that was very useful for the authors [1, 2, 3, 10, 13, 16, 18].

4. The research problem

The literature review, author's experiences in marine diesel engines' operation and diagnosing as well as results of diagnostic examinations worked out by the scientific centres in the country and abroad make it possible to formulate a research problem, as follow:

How to conduct diagnostic research aimed an evaluation of the technical shape of marine diesel engines' workspace while the engines are not equipped with the indicator valves in current operation?

The immediate, quantitative and qualitative assessment of cylinders processes is not possible for the engines mentioned above hence the diagnostic problem how to diagnose diesel engines without indicator valves" become an essential operation problem. It results from the fact that those type of engines are in common use in the Polish Navy warships. In the light of the conducted analysis on the possibilities of diagnosing the considered engines there has been formulated a following thesis:

The alterations of the technical state of engine's workspace areas generate deformations within the courses of pressure waves along the exhaust manifold powered a turbine of the turbocharger. Such alterations determine an energy flux of the exhaust in front of the turbine and in the same way – turbine's power, delivery of the supercharged compressor, in general the engine's performance and efficiency. That's why there is possible to distinguish adequate diagnostic parameters from the file of gasdynamical parameters which characterize pulsation flow of exhaust gasses discharging the engine's cylinders .

5. Main purposes of the research

An elaboration of the diagnostic method of the engine's workspace areas on the basis of the exhaust pressure measurements in the channels connecting the engine cylinders and turbocharger's turbine represents the main aim of the research works undertaken. The elaborated methodology of the diagnostic research enables:

- estimation of the load inequality among the cylinder sets,
- identification of those cylinders the working process of which are significantly different from the remaining ones,
- identification of unserviceable operation states of the functional engine subsystems that have an impact on the course of the fuel burning process inside the combustion chambers.

6. The fundamental assumptions of the research methodology

A consideration of gasdynamical phenomena in exhaust manifolds of marine diesel engines enforces an elaboration of a research realisation scheme. The research's scheme (figure 5) consists of classical (according to Cannon's theory) approach to gasdynamical processes in diesel engines, like: a physical model, mathematical model, simulating experiments on the real object and on the elaborated mathematical model. Diagnostic blocks like: alterations of the research object's structure parameters and gathering results of research in data base "unfitness – symptoms" represent the innovated elements in an issue of processes' mathematical modelling called "simulating diagnostics". A scheme of the research performance is presented in figure 5.

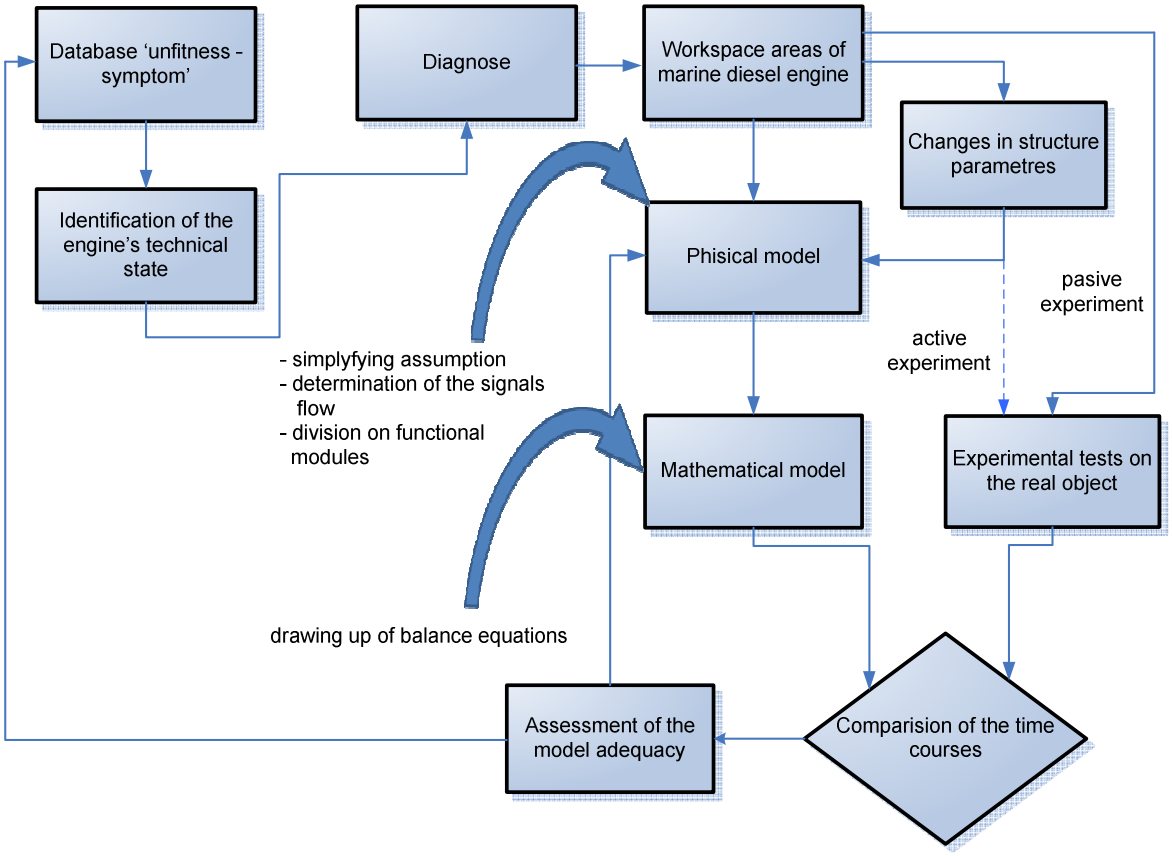

Fig. 5. The research scheme of gasdynamical processes examinations for diagnostic purposes of marine diesel engines

According to the introduced algorithm of the research conduction, investigations on real objects and the mathematical model elaboration have been worked out simultaneously. The time courses of the observed gasdynamical parameters represent the result of conducted measurements. During the realization of investigations on laboratory SULZER engine 6 AL 20/24 type a possibility of modifying constructional structure of its working spaces was foreseen. However in case of ZWIEZDA engine M401 type and DETROIT DIESEL engine DDA 149 TI type a passive experiment on large population of operated engines was assumed. A necessity of the passive experiment application results from the lack of possibility in introducing alterations into the constructional structure of working spaces of engines being currently operated.

7. Conclusion

Considerations presented in this article stand for an introduction to the elaboration of diagnostic method of marine diesel engines working spaces having low supervisory susceptibility. It results from non providing of them in indicator valve. A lack of indicating possibility of the engine's cylinders excludes the possibility of an accomplishment of the quantitative and qualitative comparative analysis of the changeability of intracylindrical pressures courses. By this way a qualification of the technical state of the engine's working spaces could not be done during engine's operation.

As a result of the analysis of accessible professional literature as well as the conducted preliminary investigations the thesis, aims and basic assumptions of the methodology concerning an investigation of the processes worked out in working spaces of the marine diesel engine for diagnostic purposes were formulated.

It is expected that the worked out methodology of diagnostic investigations makes it possible to implement the strategy of engines' operation according to their technical state into operation system of the Polish Navy warships. It will contribute to enlargement of their reliability and durability.

Bibliography

[1] Girtler, J., i inni, *Identyfikacja stanu technicznego układów korbowo – tłokowych silników o zapłonie samoczynnym, ze szczególnym uwzględnieniem emisji akustycznej jako sygnału diagnostycznego,* Opracowanie w ramach projektu badawczego MNiSW nr: N504 043 31/3480.

[2] Bruski, S., *Zastosowanie metod analizy częstotliwościowej drgań skrętnych wału napędowego do identyfikacji stanu technicznego wtryskiwaczy paliwa średnioobrotowego silnika okrętowego w eksploatacji*, Rozprawa Doktorska, AMW, Gdynia 2005.

[3] Czajgucki, Z., *Niezawodność spalinowych siłowni okrętowych*, WM, Gdańsk 1984.

[4] Dornseifer, T., Grobel, M., Neunhoeffer, T., *Numerical simulation in fluid dynamics*, SIAM, Philadelphia 1981.

[5] Dzierżanowski, P., Łyżwiński, M., Szczeciński S., *Silniki Tłokowe*, WKŁ, Warszawa 1981,

[6] Günther, H., *Diagnozowanie silników wysokoprężnych*, WKŁ, Warszawa 2002.

[7] Hebda, M., Mazur, T., Pelc, H., *Teoria eksploatacji pojazdów*, WKŁ, Warszawa 1978.

[8] *Jane's Fighting Ships 2005-2006*, jfs.janes.com, GB 2005.

[9] Kluj, S., *Diagnostyka urządzeń okrętowych*, WSM, Gdynia 2000.

[10] Korczewski, Z., *Endoskopia silników okrętowych*, AMW, Gdynia 2008.

[11] Kordziński, C., Środulski, T., *Silniki spalinowe z turbodoładowaniem, WKŁ, Warszawa 1970.*

[12] Lus, T., *Historia jednej niesprawności silnika okrętowego 6TD48*, Wydawnictwo Uczelniane Politechniki Szczecińskiej, Szczecin 2006.

[13] Łutowicz, M., *Identyfikacja procesu sprężania okrętowego tłokowego silnika spalinowego dla potrzeb diagnostyki jego przestrzeni roboczych*, Rozprawa Doktorska, AMW, Gdynia 2006.
[14] Szczeciński, S., *Lotnicze silniki tłokowe*, MON, Warszawa 1969.
[15] Piaseczny, L., *Technologia naprawy okrętowych silników spalinowych*, WM, Gdańsk 1992.
[16] Tomczak, J., L., *Metodyka bezpośredniego określania położenia kątowego wału korbowego silnika okrętowego i jej wykorzystania w indykatorze elektronicznym*, Rozprawa Doktorska, PG, Gdańsk 2001.
[17] Wajand, J.A., Wajand, J. T., *Tłokowe silniki spalinowe średnio i szybkoobrotowe*, WNT, Warszawa 2005.
[18] Wisłocki, K., *Studium wykorzystania badań optycznych do analizy procesów wtryski i spalania w silnikach o zapłonie samoczynnym*, WPP, Poznań 2004.
[19] Wiśniewski, S., *Obciążenia cieplne silników tłokowych*, WKŁ, Warszawa 1972.
[20] Żółtowski, B., Ćwik, Z., *Leksykon diagnostyki technicznej*, ATR, Bydgoszcz 1996.