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DIAGNOSTICS SYSTEM OF MARINE ENGINES AND AUXILIARY MACHINERY

SYSTEM DIAGNOSTYCZNY SILNIKÓW OKRĘTOWYCH I URZĄDZEŃ POMOCNICZYCH

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Abstract*: Presently, as a result of the technical progress, more and more complicated machines are being used in our everyday life. This is even more the case in relation to technology used at sea, where highly specialised services are needed. Sophisticated marine devices require special diagnostic methods that take into account the specific conditions of use of this type of machinery. In this paper we present the diagnostic systems elaborated to support the exploitation of the vessel power. Marine engine is a complex technical object. For the purpose of diagnostics it is convenient to divide the engine into several units – subsystems such as: piston –crank assembly; working medium exchange system, fuel supply system, lubricating system, cooling system, starting up – reversing system; combustion chamber, etc. The organization of the marine engine and auxiliary machinery diagnostic process can usually come down to two stages, general diagnostics and damage location. Most popular in marine engine diagnostics have been the periodic run analyzers, called pressure analyzers, electronic indicators. The diagnostic system of marine engine is able to assess the current engine condition and give forecast concerning its future operation in a complex way with the use of computer technology. Working out operating decision was based on proper preparation of operational parameters which were processed in a computer according to defined algorithms.*

Keywords: *technical diagnostics, piston engines, gas turbine engines, vessel power plants*

Streszczenie: *Silnik okrętowy jest złożonym obiektem technicznym. Dla celów diagnostycznych korzystnie jest podzielić ten obiekt na na kilka jednostek – podsystemów takich jak: układ tłokowo-korbowy; system wymiany czynnika roboczego; system paliwowy; system smarowania; system chłodzenia; system rozruchowo – nawrotny; komora spalania; itp. Organizacja diagnostyki silnikow okrętowych i mechanizmów pomocniczych zazwyczaj sprowadza się do dwóch poziomów, diagnostyki ogólnej oraz lokalizacji uszkodzen. Najczęściej stosowaną metodą diagnostyki silnikow okretowych jest okresowa analiza pracy oparta na analizatorach ciśnienia zwanych indykatorami elektronicznymi. System diagnostycznysilnika okrętowego jest w stanie ocenić bieżący stan techniczny obiektu oraz opracować prognozę dotyczącą dalszej eksploatacji, na podstawie kompleksowych analiz komputerowych. Wypracowanie decyzji operacyjnej opiera się na parametrach obliczonych przez komputer na podstawie odpowiednio skonfigurowanego algorytmu.*

Słowa kluczowe: *diagnostyka, silniki tłokowe, turbiny gazowe, siłownie okrętowe*

1. Operating conditions of marine engines

Marine engines operate under specific conditions which have a considerable influence on their characteristics change and can cause their increased wear and even failure [1].
Marine engines run in constant rolling conditions. Although rolling does not directly affect the characteristic change it can cause systematic wear of engine components i.e. bearings.
Most components of control systems and ship engine safety systems are related to fuel system. These installations require high purity of fuel which can constitute a serious problem on board vessels due to the possibility of water getting into fuel. Polluted fuel can cause engine start up problems, deterioration of load changes and can prevent proper work of control systems because of the structure change in relation to particular elements of automatic systems.
Fuel contamination with water can occur in ship conditions and can cause the wear of bearing units, which cannot be repaired on board vessels.

2. Engine technical condition identification – parameters number reduction

Type and number of technical parameters that require assessment without disassembling can affect diagnostic method and indirectly influence the costs of a diagnostic system [2]. The most numerous are the engine construction parameters which are as follows:

- components dimensions in their wear areas;
- clearances;
- condition of working surfaces and their wear geometry;
- assembly and adjustment settings;
- cleanness of heat exchange surfaces and flow of working medium ducts;
- parameters characterizing static connections condition (bolts tension etc.).

The parameters that characterize the quality of lubricating oils , fuel, cooling water should be included in the set of engine technical condition parameters. Engine technical condition parameters with their graphic values and the frequency of overhauls and checks are given in operating manuals by the manufacturers. It appears that the number of engine technical condition parameters is about 50 only for one section of medium speed engine Sulzer type AL 20/24 for instance [4]. If this number is multiplied by the number of cylinders and they are added to parameters characteristic for the whole engine, its machinery and systems – the total number will be enormous and as a result the task of technical condition evaluation without disassembly will practically be impossible. In marine engine diagnostics the evaluation without disassembly of most of these parameters is rejected and attention is paid to the most relevant parameters from the point of view of engine reliability, economical work and cost effective operation. Therefore each engine is divides into particular functional, tribological units.

One of the methods used for further limitation of the number of engine technical condition parameters is to determine the leading parameter considering the intensity of changes due to wear. Classical determination of engine technical condition is very often rejected and is related to symptomatic parameters of technical condition changes.
The change in reproduction level of technical condition evaluation requires proper testifying documents. Otherwise it will not be approved by ship owners, and especially by classification societies. However, it not easy to achieve classification societies approval of a new diagnostic method and measurement system as a substitute for a traditional overhaul with disassembly.

3. Description of test equipment

Contemporary exploitation of machines requires certain level of supervision, due to their high level of complication of the structure. That kind of supervising relay on detection of pre-failure states and evaluation of condition of elements or modules. In the frame of development of research capacity in Mechanical Faculty of Gdynia Maritime University, has been developed the exploitation decision assistance system for industrial machinery, including marine mechanisms, in the way of building from scratch the laboratories of:

- Technical Diagnostics
- Tribology
- Surface Engineering

Those three laboratories, which equipment was funded by Ministry of Science and High Education are expected to enable realization of advanced research programs and contracted research in diapason of technical diagnostic, technical security engineering, analysis of mechanisms reliability, tribology and surface engineering [3].
The Technical Diagnostic Laboratory consist of equipment listed below:

- Vibration Analyzer PULSE by Brüel & Kjaer,
- Acoustic Emission Set by Vallen System,
- Analyzer/Recorder of working process by Sefram Instrumens & Systems,
- Mobile Gas Analyzer by Testo,
- Industrial Video endoscope XLG3 by Everest,
- Thermo vision Camera by NEC Avio Co.,Ltd,
- Electronic Indicator of cylinder pressure of the piston engine

Vibroacoustics

Vibration signals are carrying much information about technical condition of a machine and are a base for utilization in signals' monitoring systems as a condition trends factor of a machine. Spectral analysis of signals enables an identification of a failure type. Vibration signals monitoring is useful also for evaluation of bearing nodes, condition of shafts, and frictional couplings, including gears meshing and blades arrangements into rotary machines.

The vibration analyzer is the 6. channel recorder type 3050-A-60, the module LAN-XI 51,2 kHz (CCLD, V) Brüel & Kjaer. The set includes also the acoustic calibrator 4231 and the calibration's exciter 4294. The set consist also the tachometer probe MM360, set of microphones 4189-A-021 and the accelerometer 4515-B. Measurements and analysis are carried out using computer program PULSE time (FFT analysis program, harmonic analysis, signals' recorder). All is governed by the central station. The range of output voltage for typical accelerometer/microphone with build-in amplifier CCLD is 120 dB for broad band 10 Hz – 51 kHz, and 160 dB for narrow band 6 kHz. Maximum peak voltage is 10 V, and linearity ± 0,03 dB in the range of 120 dB. Data processing in the analyzer is 24 bit mode. Registered frequencies band is DC – 51 kHz.

Oil spectral analysis

The spectrometer is analyzing traces of radicals coming from: oil additives, wear processes and outer contamination. Comparison of results with previous ones and permitted limits enables observation of the normal mechanical wear process or early detection of potential damage at its early stage. Moreover, enables evaluation of oil condition in reference to content of additives. It concerns mostly synthetic oils.
The spectrometer measures contents of radicals dissolved or floating particles in mineral or synthetic products, using the method of a rotational disc electrode. Basic configuration of the spectrometer enables detection of 22 radicals, ie. : Al, Ba, B, Cd, Ca, Cr, Cu, Fe, Pb, Mg, Mn, Mo, Ni, P, K, Si, Ag, Na, Sn, Ti, V, Zn.
The spectrometer range can be extended, what let detection additional radicals: Sb, Bi, As, In, Co, Zr, W, Sr, Li, Ce and detection of radicals in cooling liquids and water.

Video endoscope research

Video endoscope Everest XL G3 enables evaluation of technical condition of internal spaces, for example marine engines and machines, permanent and mobile pressure tanks, pipelines and masts, with possibility of dimensional evaluation of defects, visualization at LCD display and video recording. 3D phase measurement enables inspection and measurement of defects by only one lens, what eliminate necessity of its replacing by measurement lens. It lets scanning and measurement in 3 dimensions every detected discontinuity. Phase measurement analyzes available in observation zone (105°) surface, and creates 3 dimensional movable model. Working probe in the system XL G3 is exchangeable.

Thermo vision research

Thermo vision camera Thermo Gear G100 from Japanese manufacturer NEC-AVIO Co., Ltd. enables tracking processes related to changes of temperature or emission in time or related to differentiation of thermal pictures of selected

individual objects. The camera gives to operator many possibilities if measurement. It has a temperature preview function for 5 random points of the picture, with possibility of setting up individual coefficients of emission for every point. The camera enables also maximum/minimum temperature at whole display or in selected area, the value of difference of temperatures between two selected points, or linear profile of temperature.
As the camera is equipped with the optical focus with resolution 2 000 000 pixels, also registration of optical picture is possible. Pictures can be presented separately, parallel (one next to one at the display) or in penetrating mode.
During analysis of the picture one has to put attention at changes of mutual position of pictures in relation to the distance from observed object.
The camera enables broad implementation for diagnostic research of machines and mechanisms as well research of technologic or energetic process.
The camera is equipped with the detector with dimension 320x249 elements. Works in real time, with refreshing frequency 60Hz. It has thermal sensitivity at least 0,08°C at ambient temperature 30°C. The camera can register temperatures in diapason from -400°C to 500°C, divided to two sub- ranges: -400°C to 120°C and 0°C to 500°C with accuracy ±20°C or ±2%.

Acoustic emission measurement method

The AE method relay on detection and analysis of acoustic signal, emitted by a material being under mechanical stress. Emitted elastic waves are a result of interval elastic energy release. Thus energy is a phenomenon related to physical process taking place in materials or at their surface. Processes accompanying by acoustic emission are plastic displacement, cracking, structural and phase changes, corrosion, leaking and fibers cracking in composite materials. Accurate analysis enables definition of sources and kind of acoustic emission.
The set for non-invasive (without disassembling or destroying) measurement of a wear level of machines elements being under stress, deformations or load e.g. the wear of injectors, pumps, hydraulic elements, stress state of a fuselage or a hull sheets, pipelines e.t.c.
The AE measurement set consist of 4 channels signal recorder AMSY 6 and the measurement module ASIP-2/S by Vallen System. The system is equipped with pre amplifier with a frequency range 20kHz to 1MHz and amplification 34dB, and AE signal sensor with range 100 – 450 kHz. The set has the recording module, putting down 8 MB's data bunches for every channel and data registration and analysis program.

Marine engines exhaust gas analysis

The mobile set dedicated for marine engines exhaust gas analysis enables measurement of emission of exhaust gases' toxic substances of different kinds of internal combustion engines, stationary or locomotive.
The set consist of high quality exhaust gas analyzer 350 XL by TESTO, including a industrial probe with particles filter, a infrared sensor calibration system and a rigid case. The analyzer has the Germanischer Lloyd Certificate, giving legacy for tests on board ships, in accordance to MARPOL Convention Attachment VI. Moreover, the set is equipped with the integrated temperature and humidity sensor, and atmospheric pressure gauge.
Sensors are connected by 16 channels digital - analog transducer with industrial computer with dedicated programs, as a recorder. The recorder lets simultaneously connect all gas sensors, ambient parameters gauges and additional 13 random physical values sensors having standard 0-10 V outputs. The recorder has built-in parallel port RS-232, for connection with the recorder of TESTO analyzer. In fig.7. is presented the set of Exhaust gas analyzer Testo 350XL, and in tab.1.,exhaust gas measurement range.

Tab. 1. Gas analyzer measurement range

Parameter	Range	Unit
oxygen - O_2	0 – 21	% Vol.
carbon monoxide – CO	0 – 5000	ppm
carbon dioxide - CO_2	0 – 20	% Vol.
nitric oxide – NO	0 – 2500	ppm
nitro dioxide - NO_2	0 – 500	ppm
sulphur dioxide - SO_2	0 – 3000	ppm
gas temperature at measurement point	0 – 1000	ºC
dynamic pressure	do 20	kPa

Pressure curves analyzers

Up till now, the periodic runs analyzers have been commonly used in marine engines diagnostics. They are designed to measure combustion pressure graphs and to determine their basic parameters and usually serve to measure and define pressure changes in injection pipes [5].
These are devices designated to measure, visualize and digitally record combustion pressure changes, injection and vibration curves in the function of crankshaft

rotation angle at established engine working conditions. For that purpose the analyzer was provided with three 12 bit (100kHz) channels of analogue to digital converters.
The software for the analyzers makes it possible to accept any measuring configuration of the above mentioned values, for example setting to measure vibrations curves in all channels. Therefore the analyzer is suitable for diagnosing both marine powerful engines and car engines.

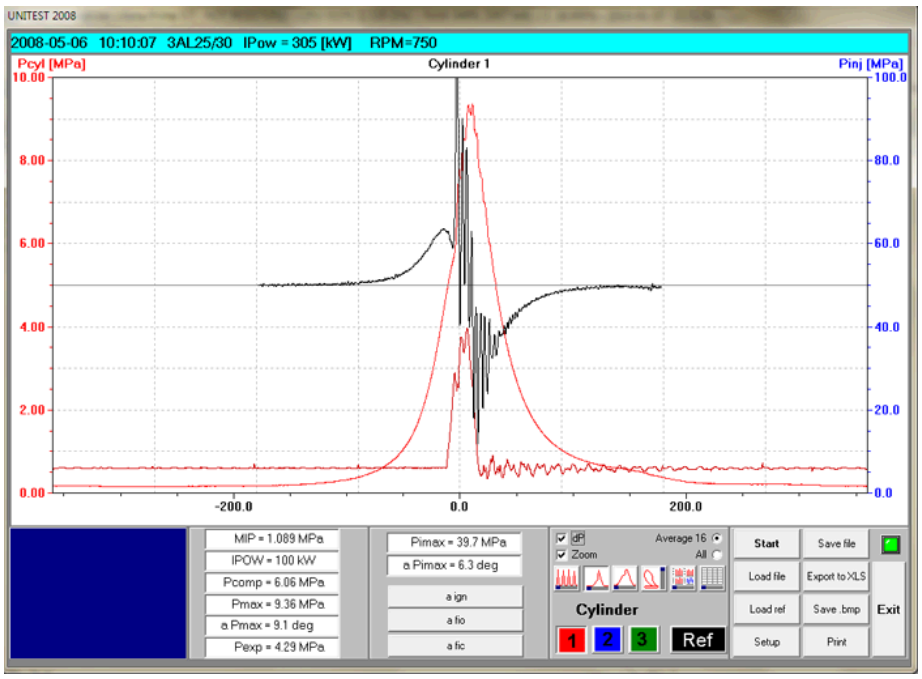

Fig.1. Pressures recorded in cylinder with the use of indicator [6].

Sampling is based on angle axis impulses of $0{,}1^{o}$OWK for n<1600 min^{-1} resolution. The runs are made average by the number of engine working cycles: 4, 16, 64 set by the operator.
The analyzer also performs the function of an automatic calculator of mean indicated pressure, the automatic gauge of basic parameters in a developed indicator graph and the engine speed meter.

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