

## Complex Measurement System for Enhancement of Capability for Marine Engines Diagnostics

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**ABSTRACT:** Modern way of machines' exploitation, due to their high level of structural complication, requires proper level of supervising. That supervising is generally based on detection of pre-failure states and evaluation of machines' single elements or components condition. In the frame of development of the research capacity of the Mechanical Faculty of Maritime Academy in Gdynia, has been developed the Exploitation Decision Aid System for marine engines exploitation. The system was based on existing test bed with the marine diesel engine Sulzer AL 25/30 as a core element. Modernization of the measurement equipment, significantly extended research capacity, what resulted with improvement of quality, extension of the span, and acceleration of conducted research and development works in the domain of safety of exploitation and diagnostics of marine power plants. Investments in modern measurement apparatus enables also an extension of the range of research and expertise related to engines' failures and pollutants emission, in relation to broad spectrum of implemented fuels. The goal has been achieved in way of modernization of engine's monitoring system and stands in Technical Diagnostic Laboratory.

### 1 MARINE DIESEL ENGINE SULZER AL 25/30 TEST BED

Diagnostic system for evaluation of exploitation attributes of marine diesel engines consist of the diesel engine driving electric generator and top class operating station enabling monitoring and recording of working parameters. The operating station also enables remote control of the engine and auxiliaries. Diagnostic stand system consist of:

- three cylinders, four stroke diesel engine type 3AL 25/30 Cegielski Sulzer with power rate of 396 kW, with turbocharger type VTR 160 Brown Boveri
- synchronous, self - excitation electro generator GD8-500-50, 500 kVA
- operating station EMOS

- electronic indicator with Kistler combustion sensors
- electric switchgear
- fan coolers
- fuel tanks with fuel distribution system and the centrifugal
- fuel consumption accurate measurement installation

#### 1.1 Diesel engine

The marine diesel engine type 3 AL 25/30, is four stroke non-reversible self-ignition, turbocharged engine (Fig.1) The engine was manufactured by HCP Cegielski in Poznań, under license of Sulzer.



Figure 1. Marine diesel type 3AL 25/30

Main technical particulars of the engine:

- type - 3AL 25/30
- no. of cylinders - 3
- bore [mm] - 250
- stroke [mm] - 300
- swept capacity [cm<sup>3</sup>] - 14726
- power rate [kW] - 408
- rotational speed [rpm] - 750
- compression ratio - 1:13

Fuel installation malfunctions can be simulated by adjustment of drain screw installed at high pressure fuel pump at 2<sup>nd</sup> cylinder, for simulation of leakage, and by installing of specially prepared injecting valves with partly clogged or enlarged sprayer holes for simulation of injection faults.

## 1.2 Operator station EMOS

Operator station EMOS is dedicated to current control, visualization and archive of the working parameters of the engine Sulzer 3AL 25/30.

General view of the station is presented in Fig. 2.

The station is equipped with personal computer with two displays (19" and 40") and operator board, consisting the set of control lights and elements of engine's systems work control. The station is also equipped with safety devices system, and system of auxiliary mechanism monitoring and steering, both are governed by PLC programmable Logic Controller) Schneider Modicon.

PLC Schneider Modicon is based on 4 basic processors with Modbus communication, and 3 processors for integration of 2 within 3 communication lanes (CANopen, Ethernet and Modbus) each. Every processor has a port USB mini-B, which is the programming port and also connecting port for graphic panels Schneider Electric. The system Modicon M340 is build up basing on the board enabling configuration of full spectrum of amplifiers, processors and in/out modules with "hot swap" function what means broken element exchange without switching off the system. In/out modules are: analog, digital (64 channels) and fast counters.

All parameters controlled by operator station are available for outer recorders.

The operator station fulfils tasks as follow:

- operator access to all controlled working parameters
- constant display of alarms list with alarm on, alarm off and acknowledge time,
- acknowledgement of appearing alarms using the keyboard or the mouse,
- possibility of setting four alarm threshold levels for analog signals,
- possibility of setting time delays of alarm signals,
- changing of configuration of measurement channels, selection of measurement ranges and calibration,
- constant archiving of data and simple mode of files outlook,
- recording of trends of analog data and trends of changes based on records history,
- Data export to outer receivers for subsequent analysis and processing,
- Printing of the rappers and data sets,
- Independent work of two monitors enabling display of two pictures in the same time.
- In Table 1 are presented all parameters measured and recorded by the system EMOS

Table 1. List of parameters recorded by EMOS

	Name of parameter	Symbol	Unit	Range
1.	Oil pressure before engine	P1	MPa	0 – 1 MPa
2.	Jacket water pressure	P2	MPa	0 – 1 MPa
3.	Sea water pressure	P3	MPa	0 – 1 MPa
4.	Charging air pressure	P4	MPa	0 – 1 MPa
5.	Sea water after intercooler pressure	P5	MPa	0 – 1 MPa
6.	Sea water after cooler	P6	MPa	0 – 1 MPa
7.	Jacket water after cooler pressure	P7	MPa	0 – 1 MPa
8.	Air inlet pressure	P8	MPa	0 -100 kPa
9.	Charging air temperature	T1	°C	0 – 100°C
10.	Jacket water outlet temperature	T2	°C	0 – 100°C
11.	Sea water before engine temperature	T3	°C	0 – 100°C
12.	Sea water after cooler temperature	T4	°C	0 – 100°C
13.	Sea water after oil cooler temperature	T5	°C	0 – 100°C
14.	Sea water after cooler temperature	T6	°C	0 – 100°C
15.	Lubricating oil temperature before engine	T7	°C	0 – 100°C
16.	Exhaust gas temperature after cylinder 1	T8	°C	0 – 600°C
17.	Exhaust gas temperature after cylinder 2	T9	°C	0 – 600°C
18.	Exhaust gas temperature after cylinder 3	T10	°C	0 – 600°C
19.	Exhaust gas temperature before turbocharger	T11	°C	0 – 600°C
20.	Exhaust gas temperature after turbocharger	T12	°C	0 – 600°C

21.	Engine rotational speed	n1	rpm	0 - 1000
22.	Turbocharger rotational speed	n2	rpm	0 - 1000
23.	Power of electro generator	NE	kW	0 - 500
24.	Fuel rack index	W0	-	0 - 10
25.	Air temperature after turbocharger	T13	°C	0 -100

In the case of occurring the alarm, EMOS system initiates visual alarm in the form of a blinking light and a horn acoustic signal. The alarm initiation delay can be set on individual determined for every alarm channel.



Figure 2. Operator station EMOS

For measurement of variable pressure in cylinders and high pressure fuel pipes, electronic indicator Unitest has been used. It is six – way indicator with piezoelectric sensors of combustion pressure Kistler type 6353A24, light pipe sensors of injection pressure Oprand AutoPSI-S-2000 and impulse head type MOC. It enables pressure measurements with discretion 0.5° of crankshaft angle.

Kistler sensors are connected by dedicated adapters, enabling measurement of combustion pressure before indicators cocks. Solution like that lets avoid errors of value run due to interference of the cocks. In this case, automatic recording of indicator charts *on-line* mode is possible.

Electronic indicator Unitest 2008 can be placed in a group of Mean Indicated Pressure (MIP) calculators. That device is a stationary indicator dedicated to measurement, digital recording and visualization of the runs of combustion pressure and fuel injection pressure in domain of crankshaft angle.

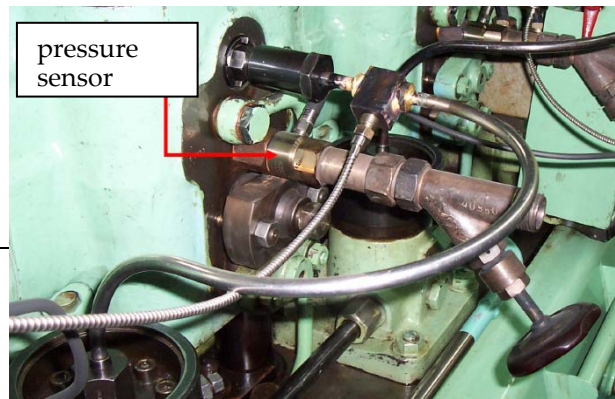


Figure 3. In cylinder gas pressure sensor installed at the indicator cock

The most important elements of the indicator are: pressure sensors, injection sensors, crankshaft angle sensor, signal amplifiers, analog-digital transducers and personal computer. Diagram of in-cylinder pressure measurement is presented in Fig. 4.

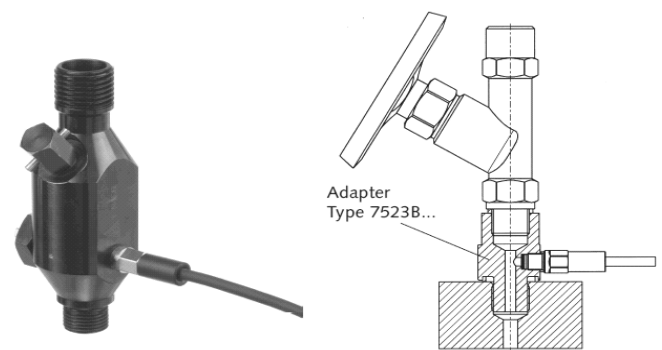


Figure 4. Sensor's connecting adapter before the indicator cock

The indicator has been equipped with special program enabling measurement and visualization of pressure runs. Example of a window with combustion and injection pressure charts is presented on fig. 5.

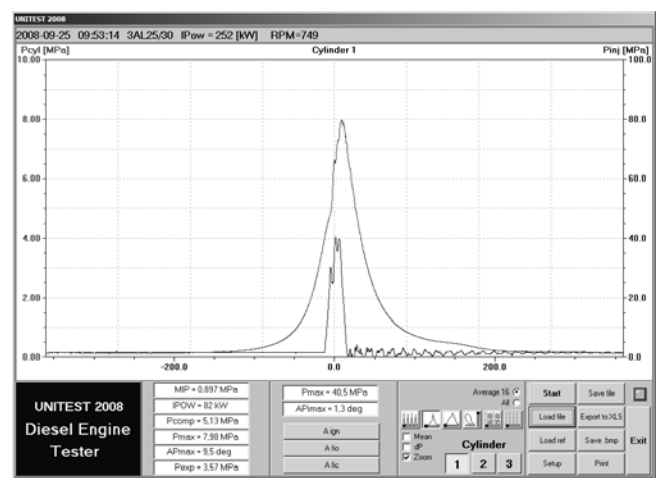


Figure 5. Electronic indicator program window

The indicator program includes wide spectrum of options for easy analysis gathered runs of combustion and fuel injection. Extension of selected parts of a picture is possible, and run of functions can be related to mean values of all cylinders and values of

reference. Apart from graphic analysis of runs, automatically following parameters of combustion and injection are determined:

- indicated power of the engine;
- mean indicated pressure;
- peak of combustion pressure;
- angle of combustion pressure peak;
- expansion pressure (at angle 360 after TDC);
- peak injection pressure;
- angle of injection pressure peak.

Above stated elements are as follow laboratory: 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.

## 2 THE TECHNICAL DIAGNOSTIC LABORATORY

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,

### 2.1 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  $\pm 0,03$  dB in the range of 120 dB. Data processing in the analyzer is 24 bit mode. Registered frequencies band is DC – 51 kHz.

### 2.2 Oil spectral analysis

The spectrometer analyze 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.

Picture of spectrometer Spectroil Q100 is presented in Fig. 6.



Figure 6. Picture of spectrometer Spectroil Q100

Moreover, this spectrometer 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 (RDE). 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.

### 2.3 Video endoscope research

Video endoscope Everest XL G3 presented in Fig. 7 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.



Figure 7. Video endoscope XLG3 Everest

It lets scanning and carry measurement in 3 dimensions of every detected discontinuity. In Fig. 8 is shown an example of damage dimensions evaluation.

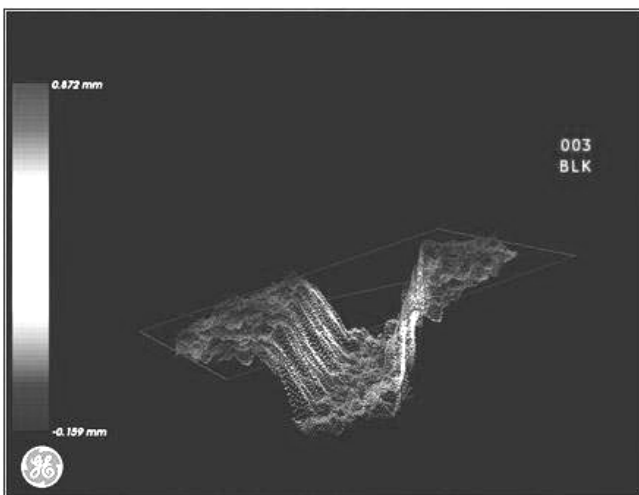


Figure 8. Sample of evaluation of damage parameters

Phase measurement analyzes available in observation zone (105° surface, and creates 3 dimensional movable model). Working probe in the system XL G3 is exchangeable.

#### 2.4 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  $\pm 20$  °C or  $\pm 2\%$ .

#### 2.5 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 etc.

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.

#### 2.6 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.



Figure 7. Exhaust gas analyzer Testo 350XL

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. In Table 2 are presented broad spectrum of gas measurement ranges.

Table 2. Gas analyzer measurement range

Parameter	Range	Unit
oxygen - O <sub>2</sub>	0 – 21	% Vol.
carbon monoxide - CO	0 – 5000	ppm
carbon dioxide - CO <sub>2</sub>	0 – 20	% Vol.
nitric oxide - NO	0 – 2500	ppm
nitro dioxide - NO <sub>2</sub>	0 – 500	ppm
sulphur dioxide - SO <sub>2</sub>	0 – 3000	ppm
gas temperature at measurement point	0 – 1000	°C
dynamic pressure	do 20	kPa

### 3 CONCLUSION

Modernization of the engine and extension of diagnostic base, will enable carrying out research specified below:

- diagnostic research based on active experiment, leading to determination of diagnostic parameters' data base;
- diagnostic research of the engine's functional systems, especially turbo charging, fuel injection and piston-connecting rod ensemble;
- research related to the utilization of combustion pressure charts, high pressure fuel fluctuation analysis and acoustic emission, for marine engines diagnostics;
- research on influence of alternative fuels implementation at the engine exploitation parameters including exhaust gases composition and toxic;
- research on possibility of utilization of data base information for automatic gathering of knowledge (inductive methods of machine learning and knowledge reveal methods).
- research on influence of mode of the engine exploitation at its elements condition, including elements after recovery treatment;

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