Laboratory test stand for evaluation of effectiveness of cleaning of marine engines exhaust gases

The paper presents test stand allows broad span of engine’s vary load. Modernization of the stand was forced by necessity of carrying out of the researches related to evaluation of effectiveness of different methods of exhaust gases cleaning, being an aim of European Research Program in which, from polish party was IMP PAN (Polish Academy of Science), RAFAKO and TELECHEM. Further modernization was due to preparations for another research project in frames of Applied Scientifical Research conducted by consortium, consisting of Institute of Fluid – Flow Machinery of Polish Academy of Science, Gdynia Maritime University and RAFAKO. The scope of modernization was adaptation of the engine for combusting various fuels, reconfiguration of exhaust piping in order to direct exhaust gas stream to adequate devices and mounting of the electronic torque meter and fuel consumption meter.

1. Introduction

Researches related to various methods of exhaust gases cleaning from SOx, NOx, soot particulars and sub particulars, required specific laboratory engine stand, which enabled feeding the cleaning system with exhaust gas with variable proportion of contamination components, coming from burning of different fuels, under all range of engine’s load.

Modernization of the engine, significantly extended research and measurement capacity, what has resulted with improvement of quality, extension of the span, and acceleration of carried out research and development works in the domain of safety of exploitation and diagnostics of marine power plants. Above stated investments enables also an extension of the range of research and expertise related to engines’ failures and exhaust gases emission pollution, in relation to broad spectrum of implemented fuels. The goal has been achieved in the way of the test equipment modernization including: effective pressure sensors, high pressure fuel sensors, monitoring and visualization of the engine systems’ parameters,
2. Diesel engine L-22 test stand

Experimental engine L22 was constructed in Warsaw University of Technology in year 1968 taking as a base the engine BAH22 produced by factory Zgoda Świętochłowice. That engine is a part of laboratory stand in Mechanical Faculty of Gdynia Maritime University. The construction of the engine is two stroke, one cylinder, vertical scavenge, crosshead, direct injection and air charged by Root’s blower. Cylinder diameter is \(D=220\) mm, stroke \(S=350\) mm, nominal power \(N_n=73.5\) kW, nominal revolutionary speed is \(n=600\) min\(^{-1}\).

In Fig. 1 is presented sketch of test stand (in Phot. 2. is shown the photography of the stand). The engine is connected to water brake made by Junkers.

![Fig. 1. Sketch of test stand of the engine L22](image)

Fig. 1. Sketch of test stand of the engine L22

1 – indicator cock (place for electronic indicator); 2 – exhaust manifold; 3 – tachometric gauge and shaft position indicator; 4 – torque meter; 5 – water brake „Junkers”; 6 – water inlet; 7 – inlet regulation valve; 8 – valve regulation handle; 9 – water outlet; 10 – dynamometric device; 11 – filling water tank; 12 – water pump; 13 – water tank.

The connection is by shaft and elastic coupling. At the shaft is mounted modern system for torque and revolutionary speed monitoring (4) [2]. The water brake has the dynamometer (10) which allows setting up proper torque load in controllable way. The brake water circulation is forced by gravity from the water tank (11) by filling valve (6). The water filling level control is done by regulation of inlet (6) and outlet (70) valves.

3. Stand equipment

In Fig. 2 is presented stand of marine diesel engine type L22.

For registration of important parameters below stated gauges are implemented:
- electronic indicator – for measurement of in-cylinder pressure [3],
- Torque meter [2],
- viscometer,
- tachometer – for measurement of revolutionary speed,
- temperature and pressure gauges,
• temperature, pressure and viscosity of fuel before engine (range -200 °C, 0-10 bar, 0-30 cSt)
• exhaust gas temperature, (range 0-600 °C)
• heating oil temperature, (range 0-250 °C, 0-10 bar)
• blower speed, (range 0 – 2000 rev/min)
• engine speed. (range 0-300 rev/min)

4. Fuel system

Researches were conducted with using of different kinds of fuels use to consist of sulphur, fuel density and method of production (i.e. biofuels). Because of above reasons, the fuel system was constructed in way enabling implementation of different fuels and decent treatment (heating) for obtaining proper viscosity before injection. Fuel is heated in electric heater, equipped with viscosity meter which is an element of temperature regulation. Fuel system configuration allows using of diesel oil and heavy oil and also alternative oils (plant oil). The system consist of viscometer, control panel, heating oil heater, fuel heater, tanks and mixing tank.

In Fig. 3 is presented sketch of fuel and heating oil system:

5. Technical diagnostic laboratory

For evaluation of impact of different kinds of fuel at engine’s technical condition, its working parameters, components of exhaust gas emission and for evaluation of effectiveness of gas cleaning installations, diagnostic laboratory equipment were used.

The Technical Diagnostic Laboratory consist of equipment listed below:
- stationary cylinder pressure indicator,
- vibration analyzer pulse by brüel&kjaer,
- 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 AvioCo.,Ltd.

6. Stationary cylinder pressure indicator

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 Kirstler type 6353A24, light pipe sensors of injection pressure Operand AutoPSI-S-2000 and impulse head type MOC. It enables pressure measurements with discretion 0.5° of crankshaft angle [4].

Kirstler 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. The most important elements of the indicator are: pressure sensors, injection sensors, crankshaft angle
sensor, signal amplifiers, analog-digital transducers and personal computer.

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. 4.

Fig. 4. Electronic indicator program window

7. 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.

8. 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 (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.

9. 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.

10. **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%.

11. **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 an industrial probe with particles filter, an 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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen O₂</td>
<td>vol.%</td>
<td>0-21</td>
</tr>
<tr>
<td>Carbon monoxide CO</td>
<td>ppm</td>
<td>0-5000</td>
</tr>
<tr>
<td>Carbon dioxide CO₂</td>
<td>vol.%</td>
<td>0-20</td>
</tr>
<tr>
<td>Nitric oxide NO</td>
<td>ppm</td>
<td>0-2500</td>
</tr>
<tr>
<td>Nitro dioxide NO₂</td>
<td>ppm</td>
<td>0-500</td>
</tr>
<tr>
<td>Sulphur dioxide SO₂</td>
<td>ppm</td>
<td>0-3000</td>
</tr>
<tr>
<td>Gas temperature at measurement point</td>
<td>°C</td>
<td>0-1000</td>
</tr>
<tr>
<td>Dynamic pressure</td>
<td>kPa</td>
<td>up to 20</td>
</tr>
</tbody>
</table>

13. **Torque meter system**

Instantaneous and mean value of torque can be carried out using photo-optical torque meter ETNP-10, fabricated by the P&R Enterprise
ENAMOR Ltd. The torque meter has two toothed rings, 30 teeth and slots each installed at the shaft between flywheel and water break. Distance between discs is 400 mm, what ensure decent value of torsion angle. Sampling is done by laser sensor with photodiode, on the way of counting impulses when slot is crossing a laser ray (value “1”) and when a tooth is crossing a laser ray (value “0”). Number of counted impulses (emitted with constant frequency 16 MHz) represent width of the slot at instant angular velocity. Differential value between two subsequent slots is the measure of torsion of the shaft. Also Instantaneous Angular Speed (IAS) can be measured and recorded taking one disc data one disc is enough, thus two discs mounted on shaft can be assumed as one disc with double slots number, or two independent measurements with a phase shift. One disc has an additional narrow slot, which role is to mark 1st cylinder TDC position. Measurements data are recorded at a memory card of PLC (Programmable Logic Controller) SAIA PCD 3. Data, after conversion by dedicated computer program, can be transferred to MS Excel format, for further analysis.

14. 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 for marine engines diagnostics;
- research on influence of alternative fuels implementation at the engine exploitation parameters including exhaust gases composition and toxic;
- research on influence of mode of the engine exploitation at its elements condition, including elements after recovery treatment.

REFERENCE


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