Operational Evaluation of Piston-Rings-Cylinder Liner Assembly Wear in High Power Marine Diesel Engines

Abstract:
This paper presents an operational evaluation of piston-piston rings-cylinder liner (PRC) assembly wear in marine diesel engines of high power. It is based on visual inspection through cylinder liner scavenge ports. Clearance measurements of piston rings in piston grooves and piston ring gap measurements were used to evaluate the extent of wear of the PRC assembly. Moreover, it is shown that piston ring gap measurements can be used as a reference parameter in wear trend analysis to predict the length of time periods between overhauls (TBO). Furthermore, it has been shown that controlling the wear of chromium (protective) layers of piston ring working surfaces by measuring their thickness with induction and eddy current methods is highly useful. They were accepted as a source of information on PRC lubrication correctness and as a symptom of its technical condition. Factors indicating the necessity of an overhaul and introducing operational methods of improving working conditions between the tribological pair – liner and piston rings have been determined.

Key words: tribological wear, piston–piston rings–cylinder liner assembly, high power diesel engines, marine main propulsion, the top layer, scavenge ports.

Introduction

The global economy crisis and continuous growth of fuel prices have forced ship owners to look for drastic reductions of operational costs. It can be achieved by ship’s speed reduction to Economical Speed at 60% of Maximum Continuous Rate (MCR) ensuring sufficient value of air charging pressure that is not forcing auxiliary blowers to run or to “Super Slow Steaming” at 50% of MCR or “Extreme Slow Steaming” at 30–35% of MCR of the main engine. However, since it results from operational experience, the reduction in ship speed and thus reducing the engine load leads to the possibility of various operational difficulties, which...
are very different from predicted in projects, causing, among others, a more pronounced wear of the elements of the ship main power system and, in particular, those of the main engine such as cylinder liners and piston rings. This issue is of special importance in the case of large marine diesel engines rated 6000 kW by cylinder type.

The piston–piston rings–cylinder liner assembly (PRC) is under significant mechanical and thermal loads due to the action of mass (inertial) forces and combustion pressure changes. Running on cheaper residual fuel (HFO) of lower quality than the distilled one (MGO), at engine loads lower than the designed ones, the reduction of cylinder oil feed rate in relation to load and the extension of maintenance periods for piston overhauling makes the maintenance of the PRC assembly a difficult task. A significant role is played here by sulphur contained in the combusted fuel and the quality of cylinder oil [L. 1, 2].

The wear in the PRC assembly causes a decrease in sealing/ tightness of engine’s combustion chamber [L. 3], and this in turn affects the overall efficiency and the "environmental performance” of engine operation. Mathematical models of the PRC seal can be very useful while assessing the effect of wear on this seal [L. 4, 5]. These models allow one to predict changes in wear and can also be used in the prognosis of the PRC durability [L. 6].

Yet, the PRC, as the one of the most important subunits, determines the reliability and economical operation of the engine as a part of main propulsion unit. Therefore, its operational evaluation of the wear and technical condition is a very important factor in proper lubrication, fuel burning, and observing of an adequate maintenance schedule. Various diagnostic methods are used to assess of the PRC’s technical condition [L. 7, 8]. There are also created models designed to support decision-making strategies in the operation of diesel engines based on an assessment of their condition [L. 9].

So far, concerning specific engines, there are no explicitly implemented operational strategies based on the actual technical condition analysis – Condition Based Maintenance (CBM) – with the use of up-to-dated methods and measuring tools. There are less advanced strategies applied, such as Planned Maintenance (PM) referring to the implementation of measures to maintain the engine on a schedule, consisting mainly of preventive methods – Preventive Maintenance (PrM) – with varying degrees of implementation focused on reliability – Reliability Centered Maintenance (RCM) – strategy by Time Between Overhauling (TBO), and the authorized strategy of the existence of the machine and mixed strategy. The most common maintenance in planned-preventive strategy – Planned Preventive Maintenance (PPM) – is performed based on the time of use. This approach is called the "by time" or "time-based" – Time Based Maintenance (TBM). In practice, only some of the listed maintenance strategies are chosen for use, which originated this study.

Service and maintenance based on the results of an assessment of the actual condition, compared to planned maintenance, enables significant reduction of costs and/or the increase reliability of machines and ship engines. However, uncertainty/ failure of automatic surveillance systems, not always diagnostic systems, presently means that the main and most trusted source of information about the technical condition of the PRC assembly is a direct operational assessment. Diagnostic systems, if any are available on board, are at their best used to support operational making decisions (second-generation systems), and the range of applied and undertaken maintenance are determined on the basis of the practical operational method of the direct assessment of the wear degree in PRC. The aim of this article is to summarize the authors’ own experience and the presentation of a developed method for the condition assessing the tribological system.

**VISUAL EVALUATION OF PISTON RING WEAR AND CONDITION THROUGH SCAVENGE PORTS**

The first and primary activity in the assessment of piston ring wear and its condition is a visual inspection through scavenge ports in which the following points are evaluated:

- The amount of deposits on the top of the piston crown and skirt,
- The elasticity of piston rings (if not broken) and their contact with liner (there is no blow-by),
- The possibility of the movement of the piston rings in the grooves on the vertical motion from the Top Direct Centre (TDC) to the Bottom Direct Centre (BDC), and
- The condition of the working surfaces of the PRC assembly.

This inspection is carried out during maintenance procedures through scavenge ports according to special procedures listed in the manual for the evaluation of the PRC’s technical condition [L. 10]. It comprises an inspection of all mentioned elements and possible faults in all engine cylinders in reference to classified measures. As an example, Fig. 1 presents the condition of working surfaces of the PRC assembly of a low-speed, two-stroke, and crosshead diesel engine of high power of the MHI 7UEC 85LII type after 901 hours of operation. Next to the figure, organoleptic evaluations of the PRC assembly are presented. The photographs show smooth, clean surfaces without scratches, indicating an almost ideal sealed combustion chamber on the piston rings and cylinder liner side. Piston rings are in a very good technical condition with a clearance in grooves. There is a visible protective layer and a measurable working layer. The surface of the cylinder liner shows traces of soot deposits.
on the piston skirt and clean piston bottom confirm the optimal cylinder oil feed rate and the proper setting and operational parameter maintaining of the fuel and air exchange – scavenge systems. This case can be considered as a reference model.

An analysis of operational wear observed during inspections through scavenge ports leads to the establishment of tribological wear forms characteristic for pistons (Fig. 2), piston rings (Fig. 3), and cylinder liners (Fig. 4).

Cracks shown in the cylinder skirt presented in Fig. 2a and burnt areas in the piston crown visible in Fig. 2b may be the consequence of the temperature increase between the piston-working surface and cylinder liner causing the increased abrasive wear of both surfaces. It is the consequence of the faulty operation of fuel injection valves, which atomize the fuel in an inappropriate way. A part of the fuel rate, in the form of droplets, gets into the combustion chamber initiating combustion together with after-burning, thus increasing the thermal load on the surfaces of both the cylinder liner and the piston. The increased temperature deteriorates lubricating properties, lowers viscosity and the thickness of the lubricating oil film. When the cylinder oil feed rate is too high, soot and calcium deposits can be formed on the piston crown, as shown in Fig. 2c.

Processes of this character intensify when fuel of low sulphur content is used and then abrasive wear increases [L. 1, 2].

Additionally, the cylinder skirt is equipped with two rings made of lead bronze with some copper to lower the risk of cylinder jamming. The criterion for

![Fig. 1. An example of a PRC liner assembly for main engine MHI 7UEC 85LII after 901 RH in perfect condition](image)

Rys. 1. Przykład stanu układu TPC silnika głównego MHI 7UEC 85LII po 901 godzinach pracy przyjętego za wzorcowy

![Fig. 2. The examples of abnormal wear of piston: (a) crack in piston skirt, (b) burn away in piston crown, (c) cylinder oil additives formation on piston crown](image)

Rys. 2. Przykłady zużycia tłoka: a) pęknięta część prowadząca (płaszcz) tłoka, b) wypalenie w denku tłoka, c) osady na denku (koronie) tłoka po zastosowaniu dodatków uszlachetniających olej cylindrowy
their replacement is a loss of ring thickness that causes its inability to function in the PRC assembly.

The occurrence of combustion deposits, such as carbon or soot, on the piston rings points to gases being blown-by through cracked or broken piston rings, which is shown in Fig. 3a. This could be the result of a loss of piston ring movement (sticking in a groove, Fig. 3c), whereas a partially damaged piston ring (broken off locking part) shown in Fig. 3b still possess the ability to hold the seal, which is restricted in relation to the size of the breakage.

Sharp, hard abrasive particles that have their source in fuel oil, e.g., aluminium and silicon catalyst fines [L. 11], and in air, e.g., industrial dusts, as shown in Figs. 3b and 5a, cause scratches on ring surfaces formed in the direction of the cylinder movement. Their presence in the areas between grooves and rings may be responsible for the jamming of the piston ring in a groove. When particles pass down the ring pack, via the ring joint gaps, they will cause a “sand blasting” effect on the upper edge of the ring and “the trumpet-shape” scratches on the run-in surface. Micro-seizures and mild adhesive wear is the “normal” wear that takes place, mostly at the top direct centre (TDC) where the oil film is not sufficiently thick to completely separate the piston ring from the liner surface.

Corrosive wear on piston rings and cylinder liners shown in Fig. 4a is the consequence of a chemical reaction of sulphuric acid, formed from sulphur trioxides and water. These oxides appear in the products of the burning of residual fuel containing sulphur. They are the products of the “low-temperature corrosion” generated by sulphuric acid that condenses on the cylinder liner when the temperature is below saturation point and/or when humid cooler air is supplied to the cylinder liner. Appropriate operational parameters of the engine and alkali lubricating additives in the cylinder oil neutralize the process of the formation of acidic burning products. Therefore, it is a phenomenon that occurs only sporadically on cylinder liner surfaces, whereas, on piston rings, the continuous abrasive smoothing process eliminates it.

Cylinder liner “polishing” with hard contact marks and worn out oil micro-grooves (wave cut forms of machining or honing) and, in consequence, the loss of required roughness (RA =1.5-2.5 µm [L. 12]) are the factors pointing to the need of liner replacement or repairing through honing (Fig 4b).

In engines supplied by distilled fuels with low sulphur content, the phenomenon of cylinder liner lacquering usually takes place just over scavenge ports in the so-called cooler part of the liner. Cylinder liner surfaces are covered with deposits of transparent yellowish and brown resins formed in reactions between cylinder oil components and water. Layers of lacquer depositing in the oil micro-grooves remaining after machining or honing smoothen them and deteriorate lubricating conditions. The areas where such layers are observed are shown in Fig. 4c. At subsequent application of the residual fuel containing sulphuric acid formed at burning, the resin lacquer dissolves cleaning the surface of the cylinder liner, which excludes the necessity to replace it [L. 13].

All elements of the tribological PRC assembly are at high risk of wear. Contacting surfaces experience adhesion processes with severe heat development. This results in the friction welding of the surfaces and the subsequent hardening of the surfaces (white cast iron) leading to extremely high wear rates. Abrasive wear occurring together with adhesion, which is the result of oil film break out, is called scuffing. In such a case, there are many points of adhesion and the surface on the whole circumference of PRC assembly gets more porous and the surface is matted. The consequences of excessive wear are manifested by numerous vertical scratches shown in Fig. 5a [L. 12].

Scuffing may be mild in form, if it recedes when lubricating improves and the progress of wear

![Fig. 3. Examples of abnormal wear of piston rings: (a) broken piston ring opposite ring gap, (b) abrasive wear of 1st ring and pulled out part of the 2nd ring near the gap, (c) blow-by through piston rings no. 1 & 2, stuck into ring groove, and gas seal is completely broken.](image_url)
Estimation of Piston Ring Wear via Piston Ring Gap Measurement

The traditional way of estimating piston ring wear is to perform direct measurements of their thickness and height using a micrometre. It is only possible at PRC overhauls performed after the engine has been temporarily switched-off. However, such measurements do not give information in relation to lubricating quality/correctness or to the cooperation of PRC elements that could be useful in the process of operation to estimate the time horizon of reaching limiting wear. Therefore, geometrical measurements during inspections through scavenge ports are also used. They comprise the following:

- Measurement of radial wear in piston rings carried out by measuring piston ring gaps, and
- Measurement of axial wear in piston rings carried out by clearance measurement of piston rings in piston grooves.

Measurement of radial wear in piston rings/clearance \( t \) in the piston gap can be achieved in piston BDC on the condition that they are visible through the scavenge ports. The measurement itself can be performed by direct or indirect ways. The simplest one is the “finger prints” obtained on a piece of paper stuck to a soft layer, e.g., Styrofoam. The “print” is then measured with an...
accurate linear tool, e.g., Vernier calliper. However, it is an indirect method and thus less accurate, giving only rough values. They can only be used for initial evaluation of piston ring wear. More accurate measurements can be obtained using special Vernier callipers or dial meters [L. 15]. Radial wear of piston rings \( h \) is determined from the following equation (1):

\[
h = \frac{t - (t_o + \Pi (d - D))}{2 \Pi}, \tag{1}
\]

where:
- \( h \) – estimated piston ring wear (radial) [mm]
- \( t \) – measured ring gap length [mm]
- \( t_o \) – initial ring gap length (in accordance with the specifications in the manual, e.g. in Tab. 1 [mm])
- \( d \) – liner diameter (near scavenge ports) [mm]
- \( D \) – liner diameter (nominal size) [mm]

The cylinder liner diameter \( d \) used in the equation is the result of its last accessible measurements at the height of scavenges ports or the result of measurements after manufacturer’s tests or before the installation of a new cylinder liner. The estimated value of radial wear of a piston ring \( h \) may also be obtained from a graph for its calculation and checking its acceptable values [L. 15]. Results of measurements obtained in this way can be used for calculating the total wear and for evaluating partial wear as a consequence of operating a certain number of hours according to the procedure and relations shown in Tab. 1.

The values of total wear and as well as the trend of wear after 1000 working hours are correct, both in the case of acceptable values and the estimated value of wear in subsequent working hours. They show that there is a possibility of safe engine operation until the shipyard overhaul which takes place after 18 000 working hours. It is also noticeable, which is typical for piston engines, that the first piston ring from the side of the combustion chamber is more worn than the remaining ones. Moreover, cylinder no. 6 in this case possesses a set of new piston rings, which was the result of their replacement with ones of the new type under terms of the warranty. Therefore, the results of their measurements and calculations are in accordance with the reference dimensions of new rings.

A special separate issue of the measurement of radial wear in piston rings through scavenge ports is the measurement of groove wear of the piston relief groove rings (CL ring) using a special Vernier calliper [L. 15]. As CL type rings are only used for top piston rings, this method can only be used for these rings.

Measurements of axial wear in piston rings through scavenge ports of the cylinder liner are carried out by measuring the clearance piston rings in grooves of the piston using a special Vernier calliper or a feeler gauge. The obtained measurements are compared to those previously obtained and with the trends of wear after 1 000 working hours with the reference depth of 2 mm. An example of such an analysis for two rings of a chosen cylinder liner nr 5 of HHI MAN B&W 6S90MC-C in the form of a graph and a table is shown in Fig. 6.

The results of the measurements obtained during the inspections at various hours of operation were taken from 3590 to 15090 over the lifetime of the ship ratio, in this case, 2.5 years, i.e. since its delivery from the shipyard (new PRC assembly) to the time

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**Tab. 1. The example of piston rings’ gap measurement report for Mitsubishi 7UEC85LII**

<table>
<thead>
<tr>
<th>Vessel</th>
<th>ORIENTAL JADE</th>
<th>Engine Type</th>
<th>MHI 7UEC85LII</th>
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</thead>
</table>

<table>
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<tr>
<th>No.</th>
<th>54</th>
<th>Reported</th>
<th>11-Mar-11</th>
<th>At Port</th>
<th>Yesu</th>
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<tr>
<td>Measured Date Fresh</td>
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<td>Preise</td>
<td>11-Mar-11</td>
<td>10539</td>
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<tr>
<td>Cyl. No.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
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<tr>
<td>Top</td>
<td>15.22</td>
<td>15.26</td>
<td>17.90</td>
<td>14.15</td>
<td>10.75</td>
</tr>
<tr>
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<td>1.30</td>
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<td>1.74</td>
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<td>0.16</td>
<td>0.17</td>
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<tr>
<td>2nd</td>
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<td>8.600</td>
<td>7.760</td>
<td>7.900</td>
<td>8.160</td>
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<td>Clearance wear</td>
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<td>0.121</td>
<td>0.143</td>
<td>0.054</td>
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<td>0.004</td>
<td>0.011</td>
<td>0.013</td>
<td>0.005</td>
</tr>
<tr>
<td>Clearance wear</td>
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<td>0.342</td>
<td>0.110</td>
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<td>0.182</td>
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<tr>
<td>Clearance wear rate</td>
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<td>0.003</td>
<td>0.010</td>
<td>0.003</td>
<td>0.017</td>
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<tr>
<td>4th</td>
<td>9.850</td>
<td>10.940</td>
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<tr>
<td>Clearance wear</td>
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<tr>
<td>Clearance wear rate</td>
<td>0.039</td>
<td>0.009</td>
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<td></td>
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</tbody>
</table>

**Cylinder Oil**

- **Engine Room Temperature**: 32
- **Line Temperature**: 70

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*Subject to result of measurement at least once in 1000 running hours.*
it reached the repair yard in order to maintain the class. The results are measurements based on trend analysis of axial wear in piston rings (comparison in courses of various series, changes in their maximum values and the calculated values of wear per 1,000 working hours) allowing one to assess their present condition and to predict the wear degree, while estimating the time horizon of their future changes during the process of handling the engine according to the TBO strategy. The measured series No. 5 for both rings indicates the achievement of limit values at the reference depth of 2 mm, after exceeding 15,000 of working hours, while maintaining the correct wear changes per 1,000 working hours, according to the manufacturer and authors' own experience. This fact points to the need to exchange piston rings during the next review in the shipyard. In addition, these measurements make it possible to indicate the need to plan earlier repairs in the event of detected irregularities in the changes of piston rings' clearances in the piston grooves in a particular cylinder and the application of safety measures against possible damage by, e.g., a periodic increase in dose cylinder oil.

**ALTERNATIVE METHODS OF PISTON RING WEAR**

Apart from the above presented methods of assessing the condition and wear of PRC during inspections through scavenge ports, there are other alternative methods of direct measurements that can be used. They rely on the measurement of run-in coating surfaces of piston rings. They are relatively common, although their application for high power marine diesel engines is different, depending on the engine manufacturer. The most commonly used coatings include the following:

- Top coatings (outer layers) are used for initial run-in after engine installation or after the PRC assembly replacement for the running-in stage and gradual increase of power. Their task is the safe minimization of time required for finishing the running in of tribological coupling. They are soft plasma thermal sprayed coatings of graphite, Cu, or Sn characterized by high scuff resistance. After approximately 500 hours, these coatings are worn out, and this can be evaluated visually via scavenge ports.

- Coatings improving tribological properties, i.e. increasing wear resistance are plasma thermal sprayed coatings of Mo/ NiCr/ Cr-C, which are

<table>
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<th>0.30</th>
<th>0.35</th>
<th>0.40</th>
<th>0.45</th>
<th>0.50</th>
<th>0.55</th>
<th>0.60</th>
<th>0.65</th>
<th>0.70</th>
<th>0.80</th>
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<td>20</td>
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<td>35</td>
<td>25</td>
<td>25</td>
<td>10</td>
<td>5</td>
<td>2</td>
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<td>500</td>
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**Fig. 6. Part of cylinder condition report – groove profile for HHI MAN B&W 6S90MC-C**

Rys. 6. Przykład analizy luzów pierścieni tłokowych w rowkach tłoka dla silnika HHI MAN B&W 6S90MC-C
worn out with engine operation. Their thickness can be measured with lepto-scopes utilizing electromagnetic (induction) methods of ferrous layer measurement. These measurements can be done via scavenge ports.

The results of thickness measurements of coatings improving tribological properties used as a function of coating wear in reference to the number of working hours of piston rings can be a reliable argument for evaluating tendencies of their wear and for estimating service life until the overhaul time. Total wear of these coatings is connected with the necessity to replace piston rings, because their resistance to any form of tribological wear is significantly lower. Application of results of such measurements are presented in the example of changes in the thickness of chromium layers for piston rings of Mitsubishi, DU Sulzer, and Mitsui B&W engines, at Figs. 7a, b, and c.

Based on the presented courses of changes in the thickness of chromium layers, it may be noted that these have been worn after about 16,000 of working hours, which corresponds to cycles between repairs related to the replacement of piston rings - Figs. 7a and c. This is particularly visible for the upper rings in Mitsubishi and B&W engines, where, after exceeding 10,000 hours of engine operation, the trend of wear is faster than before. This is also confirmed by measurements of the thickness of the layers for DU Sulzer engine, which were taken at 0 - 10,658 hours operation of the engine – Fig. 7b.

On line methods, where there is no need to stop the engines, belong to the more effective ways of evaluating the wear of PRC assembly which can be used in the operation of crosshead two-stroke ship engines. At engine operation, from special drain pipes located in under-piston areas, samples of cylinder oil drain (CDO) are collected [L. 14]. Then, the oil is analysed to determine the content of ferromagnetic particles inside it in ppm. On this basis, it is possible to evaluate the extent of the PRC assembly wear. Operational practice shows that wear is not stable, and it can vary according to changing operational conditions including the conditions of combusting, lubricating, and the amounts of formed deposits that can play the role of abrasives for the piston rings and cylinder liner. Fig. 8 is an example of this instability. The measured number

Fig. 7. Chromium layer measurement: (a) Mitsubishi 7UEC85LII, (b) DU SULZER 6RTA84T, (c) Mitsui B&W 7S80MC-C
Rys. 7. Wyniki pomiarów warstw chromowych: a) silnik Mitsubishi 7UEC85LII, b) DU SULZER 6RTA84T, c) Mitsui B&W 7S80MC-C
of ferromagnetic particles (ppm) increases, which is a correct result when the measurements were carried out in the running-in stage after an overhaul or in the case of a new engine (Fig. 8a), and after operating for a certain number of hours it decreases (Fig. 8b).

Reference examples of pictures of different contents of ferromagnetic particles are shown in Fig. 9.

A value up to 150 ppm is defined as “normal wear,” 150-250 ppm as significant wear,” and values exceeding 250 ppm are defined as “excessive wear.” Systematic analysis of CDO oil in regular time intervals with simultaneous recordings of engine load (measuring combustion pressure and power in particular cylinders) is a source of information on engine operation conditions, such as the quality of the following:

- The functioning of the lubricating system – proper cylinder oil feed rate and maintaining of lubrication conditions;
- The functioning of fuel injection system and the performance of combustion process; and,
- The cooperation of elements in the PRC assembly, in particular, its piston rings and cylinder liner.

Application of spectrographic analysis enriches the information on the condition of PRC elements and the causes of the formation of ferromagnetic particles [L. 14] within the following:

Fig. 8. Results of Iron Powder Test – analysis of cylinder oil drains for main engine MHI 7UEC 85LII: (a) 100 ppm after sea trial 50 RH, (b) 50 ppm after 250 RH.
Rys. 8. Wyniki testu na zawartość cząstek ferromagnetycznych – analiza ilościowa próbek oleju cylindrowego z komór podtłokowych dla silnika MHI 7UEC 85LII: a)100 ppm po 50 godz. pracy, b) 50 ppm po 250 godz. pracy

Fig. 9. Reference pictures of various Fe-content with magnification x10 and x100 [L. 16]
Rys. 9. Obrazy referencyjne różnych zawartości cząstek ferromagnetycznych w oleju cylindrowym przy powiększeniu 10- i 100-krotnym [L. 16]
• The effectiveness of neutralization of sulphur from the burnt fuel;
• Appropriate lubrication (a possibly too high cylinder oil feed rate of too alkali character with simultaneous burning of fuel with low sulphur content – indicated by measuring the Total Base Number (TBN) and the presence of calcium deposits in the CDO area);
• Correct burning – indicated by higher viscosity (fuel pollution) and the presence of vanadium in CDO;
• Fuel contamination of a catalytic type, indicating the presence of aluminium and silicon in CDO; and,
• Micro jamming of piston rings, caused by water penetrating into the combustion chamber, indicated by increased viscosity in CDO and emulsion type.

CONCLUSIONS

Searching for savings in shipping by sea has changed the rules and conditions of the operation of cargo ships main power systems.

Based on operational possibilities to assess the technical condition and wear of piston rings through the cylinder liners scavenge ports, extended by additional measurement procedures, damage and technical conditions (worn out parts) may be revealed. This helps to determine the need to make an operational decision on the replacement of certain elements of the PRC assembly in the earliest convenient future. The most important ones noticed in the process of operation include the following:

• Cracks on all elements of the PRC;
• Deep scoring - abrasive wear and scuffing on PRC working surfaces;
• Burnt out areas on piston crowns exceeding acceptable limits;
• The wear of copper wear ring on the piston skirt;
• The wear of piston rings (increased gap clearance, achieved limits in dimensions of relief grooves CL - Groove);
• Achieving maximum clearance in the piston ring groove;
• A cracked, broken or "stuck" ring;
• The loss of seal tightness of piston rings due to "blow-by";
• The total loss of the running-in layer; and,
• A “polished” cylinder liner surface and worn out oil micro-grooves (wave cut forms of machining or honing) – loss of roughness.

The presented method of wear evaluation based on clearance measurements in piston ring joints turns out to be serviceable. The results of clearance measurements are sufficiently reliable measures of the extent of wear of PRC assembly elements. However, in the operational analysis of wear trends, to predict the time between overhauls, it is not sufficient. At PRC inspections, the results of alternative measurements based on the wear of running-in coatings- performed using induction or eddy currents should be applied. The obtained results of tribological wear should be verified using the analyses of cylinder oil sampled from CDO. They were accepted as an additional source of information on the appropriate lubrication of the PRC assembly and as a symptom of a change in its technical condition. Such proceedings will ensure the correctness of operational decisions determining the necessity of overhaul or introducing adjustments to the conditions of operation/lubrication of the cylinder liner – piston rings – cylinder assembly.

The presented method will favour meeting the operational requirements of the engine, including prolonging the time between overhauling (TBO), while maintaining correct functioning of engine systems, i.e. cylinder oil, fuel oil, air exchange – scavenge, and cooling.

The following should be the goals to achieve:

• The application of new constructional and operational solutions to reduce the wear of piston rings and the use of an electronically controlled engine cylinder liner lubrication [L. 17]; and,
• Performing a complete inspection involving, not only visual methods but also a comprehensive measurement, archiving and identification of wear trends [L. 18].

REFERENCES