



OPERATIONAL EVALUATION OF PISTON RING WEAR IN LARGE MARINE DIESEL ENGINES

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Abstract

This article presents operational evaluation of piston ring wear in large marine diesel engines based on inspection through cylinder liner scavenge ports. It contains a description of verification methods of piston rings based on visual inspections, clearance measurement of piston rings in piston grooves and piston rings gap measurement. Moreover, it is indicated that piston ring gap measurements can lead to an evaluation of piston ring wear and by calculating into running hours can be treated as a reference parameter at next inspections and a parameter determining wear trends. Furthermore, application of chromium layers on working surfaces of piston rings enforces the need to control chromium layer wear by measuring the layer thickness by induction and eddy current methods. Concluding, the authors discussed constructional – operational methods of improvement between tribological pair – liner and piston rings in working conditions .

Keywords: *large marine diesel engines, tribological pair, wear, piston rings, chromium layer, piston gap*

1. Introduction

Global economy crisis and continuous growth of fuel prices have forced ship owners to look for drastic reduction of operation costs. It can be achieved by ship's speed reduction to Economical or Slow Steaming Speed. However, the reduction in ship's speed and thus the reduction of the engine load leads to the possibility of various operational difficulties which can include, among others increased wear of cylinder liners and piston rings.

Piston rings in large marine diesel engines rated 6000 kW by cylinder are under significant mechanical and thermal loads as an effect of action of mass (inertial) forces and combustion pressure changes. Besides, due to engine operation, reduction of cylinder oil feed rate in relation to load and extension of maintenance periods for piston's overhauling, the technical condition, correct fitting to liner's circumference and existence of chromium layer on working surfaces increasing resistance for abrasion and thermal resistance, are the significant factors in safe and economical operation of diesel engines and have decisive influence on their reliability.

Therefore, operational evaluation of wear and technical condition in tribological pair cylinder liner - piston rings is a highly important factor in maintaining proper maintenance schedule. Due to

the size of the problem authors limited this issue to operational evaluation of wear and technical condition of piston rings.

2. Visual evaluation of piston ring wear and condition through scavenge ports

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

- amount of deposits on the top of the piston crown and skirt;
- elasticity of piston rings (if not broken) and their contact with the liner (there is no blow-by);
- movement of piston rings into the grooves on the motion TDC-BDC;
- condition of working surfaces, fig. 1.

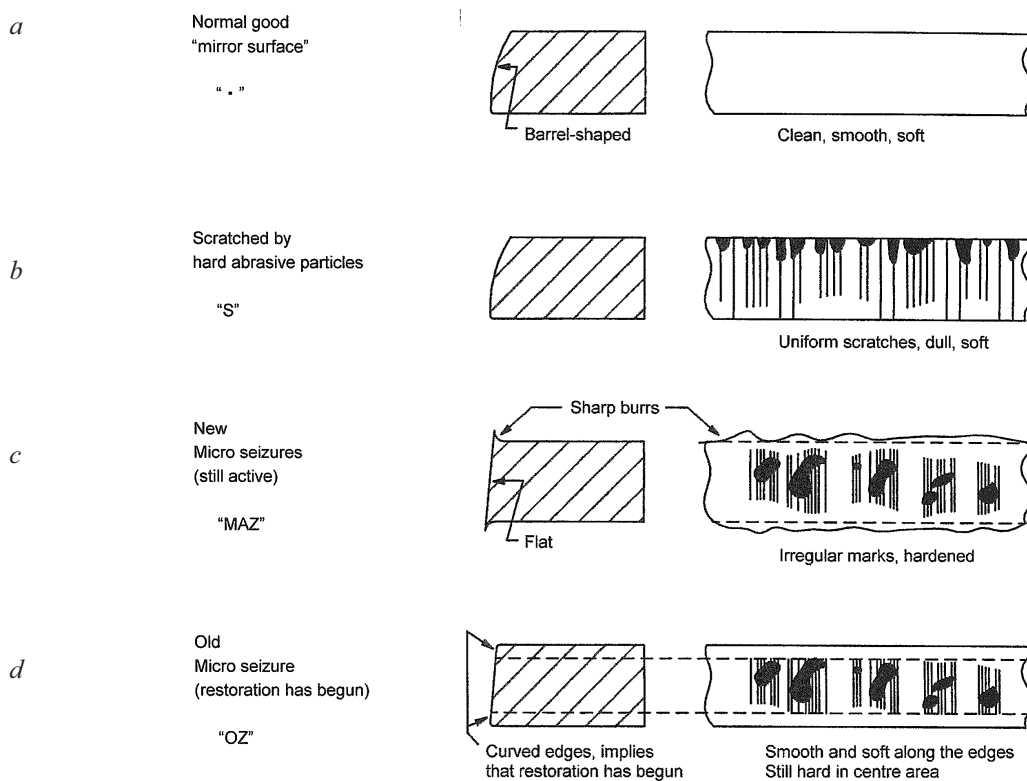


Fig. 1 Inspection through scavenge ports: Instruction for evaluation of piston rings [1]

Running surface of piston rings is the indicator of the cylinder condition in general. "Polished mirror surface", smooth, clean and without scratches is a normal good running condition, fig. 1a & 2a. Piston rings surfaces with vertically scratches caused by sharp, hard abrasive particles that have the source in fuel oil, e.g. catalyst particles and in air e.g. sand, are presented in fig 1b. These hard grains wear down the surface by continuous ploughing and scratching. With higher levels of abrasive wear, the surface displays vertical scratches, the size of which depends on the dimensions of the particles involved. These particles can also affect the sides of the rings as they jam in the ring groove, thereby causing "pitting" of the surface. 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 below, which protrudes from the piston ring groove and "the trumpet-shape" scratches on run-in surface. In this situation, fuel oil and turbocharger intake filter have to be maintained clean and piston rings condition has to be monitored with temporary increased cylinder oil feed rate.

Corrosive wear on piston rings and cylinder liners is caused by chemical attack on the metallic surface caused by sulfuric acid formed through a chemical reaction in the combustion chamber. Alkaline lubricating oils make it possible to keep the corrosive wear within tolerable limits,

despite the use of heavy fuel oil. Observations of corrosive attacks on piston ring running surfaces are very rare, as there is a continuous abrasive polish, which is normally more severe than the corrosion.

Micro-seizures (new – still active, fig. 1c and old – restoration has begun, fig.1d) and mild adhesive wear is the "normal" wear that takes place mostly at the top dead center where the oil film is not sufficiently thick to completely separate the piston ring from the liner surface. Severe adhesive wear or scuffing takes place when the temperature, the sliding speed or the load exceeds a critical value. This usually starts at a very small part of the contact surface but spreads rapidly due to the significant deterioration of the surface. The friction is so intense that the surface is melted and forms the so-called "white layers", which are very hard and brittle. When they crack, small, hard particles flake off and plough the surface, producing the typical scuffing appearance, fig. 4a & d. If it covers ¼ circumference of piston ring, it should be replaced.

The presence of combustion deposits (carbon) is the results of gases blow-by through piston rings caused by loss of seal due to excessive ring breakage, lost of piston ring movement – sticking/ sluggish in groove, fig. 2b or due to broken piston ring, fig. 3a. However, a partially broken piston ring, fig. 3b can still hold the seal. In the mentioned circumstances, piston rings should be replaced at the earliest opportunity.

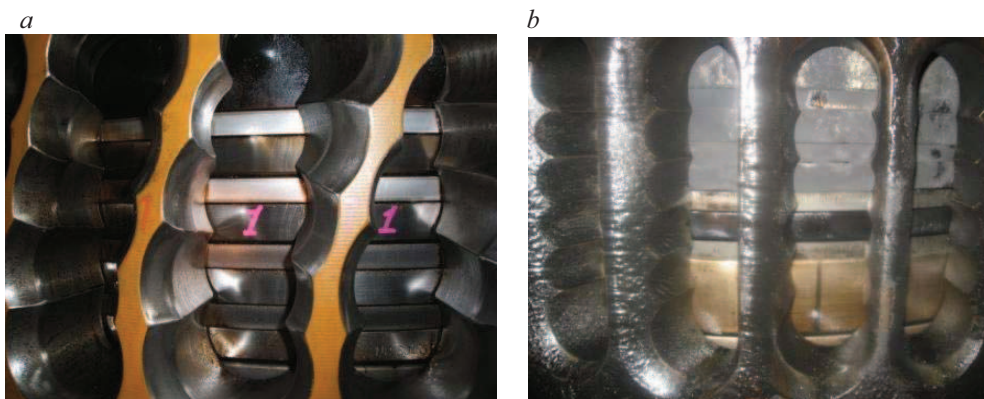


Fig. 2 Piston rings inspection through scavenge ports:

a – perfect condition 384 running hours Mitsubishi 7UEC85LII, b – blow-by through piston rings no. 1 & 2 which have stuck into ring groove, gas seal is completely broken, Hitachi B&W 6S80MC-C

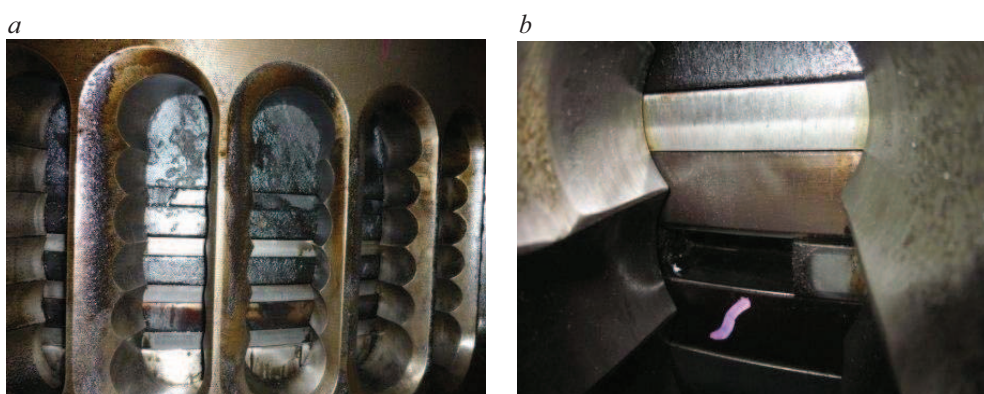


Fig. 3 Piston rings inspection through scavenge ports:

a – broken piston ring opposite ring gap Mitsui 7S80MC, b – broken off part of piston ring near gap Mitsubishi 7UEC85LII

The Chrome-ceramic coating is a lifetime coating [2]. However, the actual wear depends on piston running conditions. A partially worn CC-coating does not necessarily mean that the piston ring has to be changed immediately. If the remaining chrome layer is intact, it is still fit for continued

service. Obviously the scuffing resistance of the ring will decrease accordingly. If the chrome layer is damaged i.e. pieces of coating broken out, or patches of coating peeling off, the ring should be replaced at the earliest opportunity, fig. 4b & c.

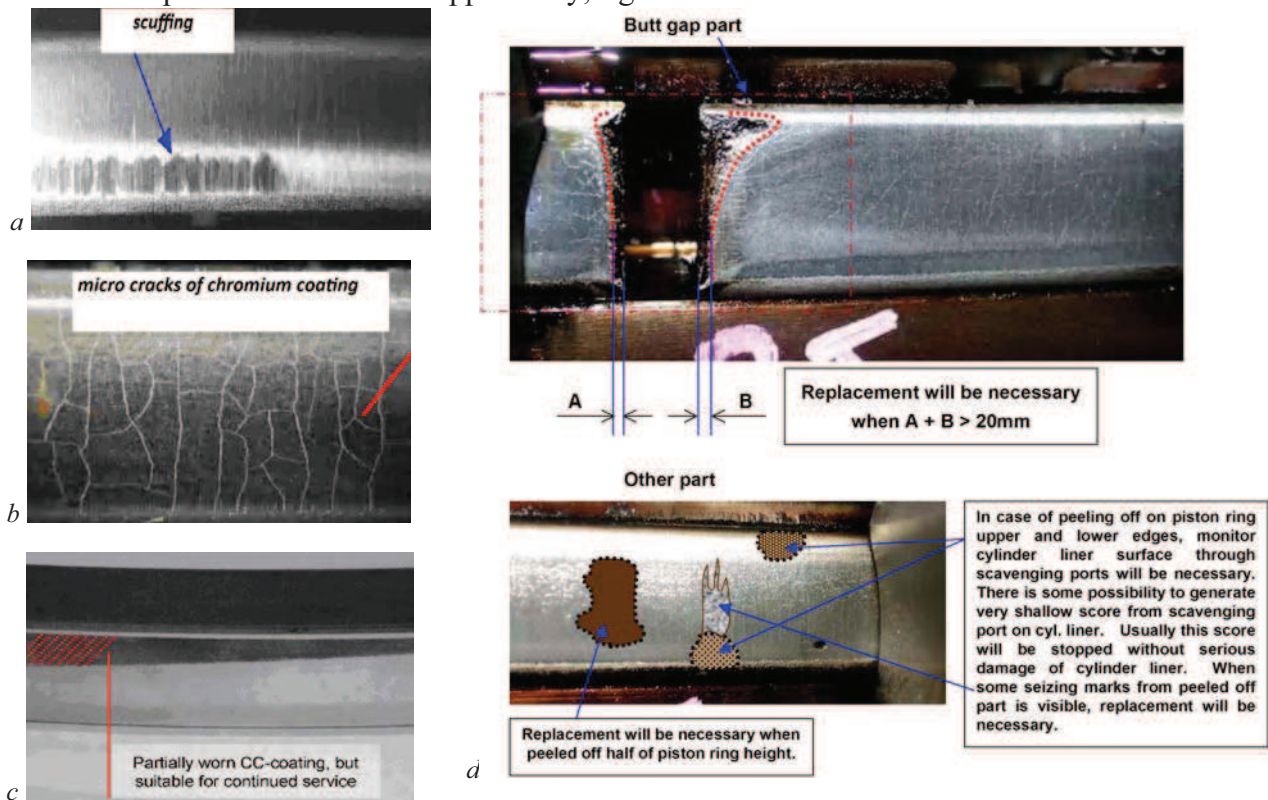


Fig. 4 Examples of piston rings wear [2]

2. Estimation of piston ring wear amount by piston ring gap measurement

During inspection through scavenge ports the following wear amount measurements of piston rings can be carried out:

- measurement of radial wear in piston ring carried out by the measurement of piston ring gap;
- measurement of axial wear in piston ring carried out by clearance measurement of piston rings in piston grooves.

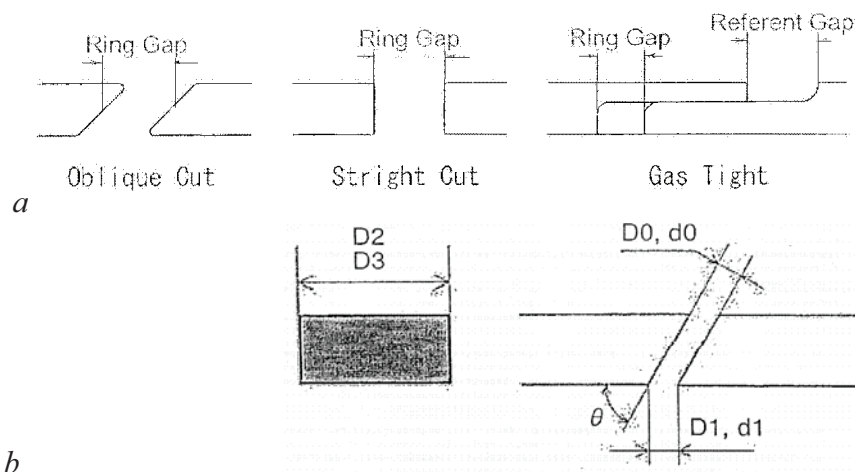


Fig. 6 Measurement of piston ring gap: a – types of piston ring gaps, b – piston ring gap dimensions [4]

To measure the piston ring wear amount, it is customary to remove a piston ring and measure its width by using a gauge. This is costly and time consuming because of the necessity of piston withdrawal. Therefore, a method in which the wear amount can be estimated indirectly by ring gap length is applied hereinafter, fig. 6. However, the diameter near liner ports is a mere assumption, which may cause wide variation of the estimated wear amount, so this method should be regarded as just a rough criterion of the necessity of ring replacement.

With the piston brought near the bottom dead center using the turning gear, the ring gap length (t) is measured through the liner ports. For the cylinder liner diameter near ports (d) the diameter measured last or the initial diameter near ports shown in the shop test result should be used. By substituting these data in the equation (1) the estimated piston ring wear amount (h) is calculated.

$$h = \frac{t - (t_0 + \pi(d - D))}{2\pi} \quad (1)$$

where:

- h: estimated piston ring (radial) wear amount (mm)
- t: ring gap length measured (mm)
- t_0 : initial ring gap length (specification in manual, e.g. in Tab. 1) (mm)
- d: liner diameter (near scavenge ports) (mm)
- D: liner diameter (nominal size) (mm)

Table 1: Data of initial ring gap lengths and allowable wear amount for new piston rings

Engine Type	Cyl. Liner Dia. Nominal [mm]	Initial ring gap length t_0 [mm]	Ring width b [mm]	Allowable wear amount [mm]
Wärtsilä RTA 84	840	6.18	26.5 +/- 0.2	5.3
B&W MC-C 80	800	9.4	25.2	4.2
UEC 85LS II	850	7.0	27.2	4.7

Piston ring wear amount (h) can be also calculated using the calculating chart, fig. 7 that allows to check wear limits for the measured gap.

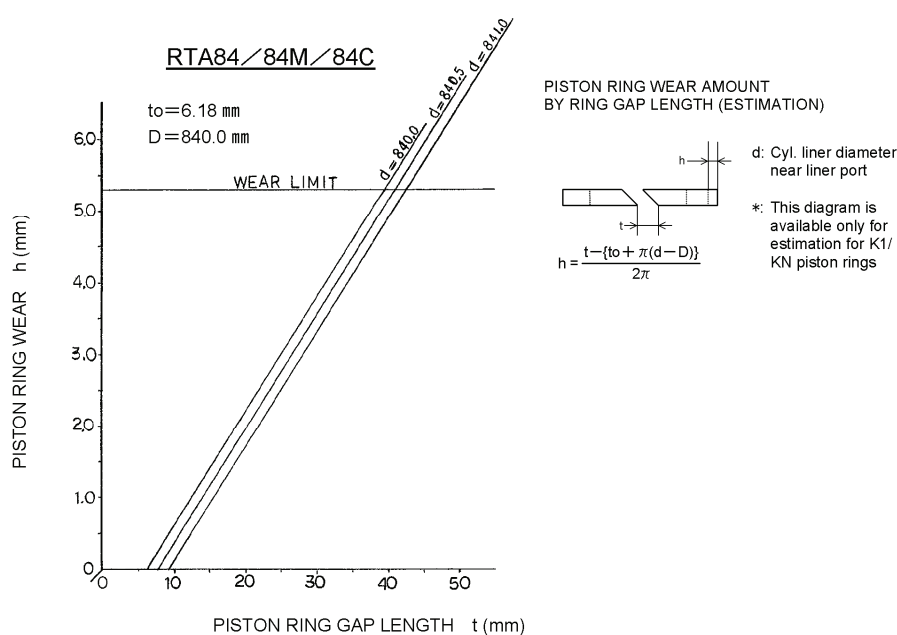


Fig. 7 Calculating chart for piston rings wear and gap measurement [6]

A piston ring gap can be obtained by the so called “finger prints” and measured with a ruler, or measured with special vernier calipers [5].

Another measurement of piston rings (radial) wear amount is carried out by measuring groove depth in piston relief groove rings (CL ring) carried out with special vernier calipers, fig. 9b. Usually, CL piston rings are applied on top piston rings and their presence confirms the usefulness to further operation.

In the next step, the obtained results of the piston ring gap are entered into tables with formulas to calculate overall wear and wear rate per running hours, fig 8.

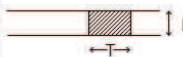
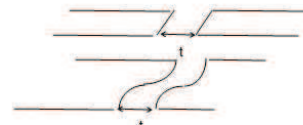
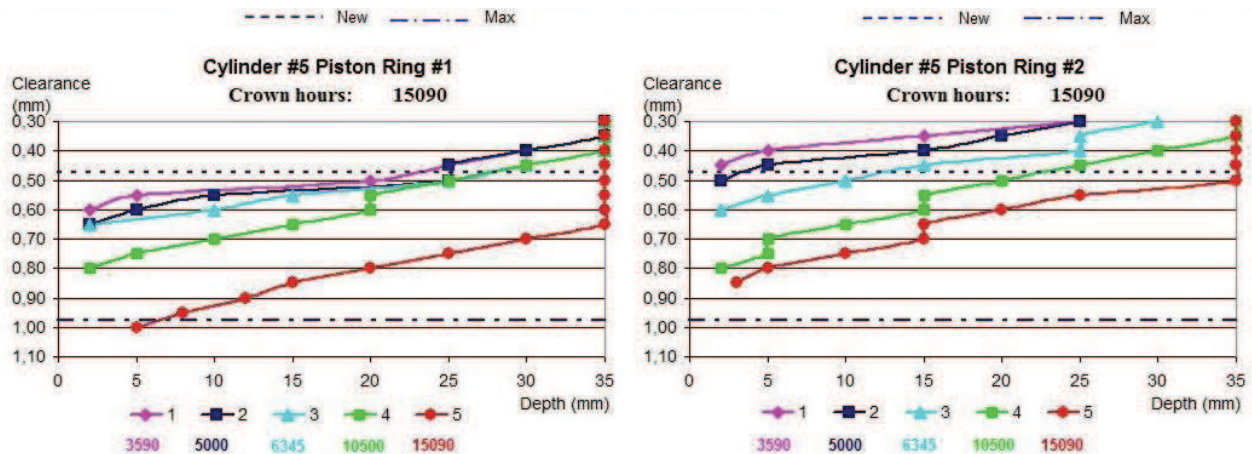
Vessel		ORIENTAL JADE					Engine Type		MHI 7UEC85LS II		
No		54		Reported		11-mar-11		At Port		Yosu	
Measured Date Fresh		08-maj-11		Previous		11-mar-11		Total Working Hours		10639	
Cyl. No.		1	2	3	4	5	6	7	8	9	10
Top	clearance	15,220	16,230	17,960	14,150	10,740	7,000	12,520			
	wear	1,308	1,469	1,744	1,138	0,595	0,000	0,879			
	wear rate	0,123	0,138	0,164	0,107	0,056	0,000	0,083			
2nd	clearance		9,120	8,600	7,760	7,900	6,660	8,160			
	wear		0,337	0,255	0,121	0,143	-0,054	0,185			
	wear rate		0,032	0,024	0,011	0,013	-0,005	0,017			
3rd	clearance		8,450	9,150		7,690	6,770	8,130			
	wear		0,231	0,342		0,110	-0,037	0,180			
	wear rate		0,022	0,032		0,010	-0,003	0,017			
4th	clearance		9,580		10,940			8,820			
	wear		0,411		0,627			0,290			
	wear rate		0,039		0,059			0,027			
Ring Condition	S : Stick	1	W	W	W	W	W	W	W		
	B : Broken	2	B	W	W	W	W	W	W		
	D : Dry	3	W	W	W	W	W	W	W		
	W : Wet	4	W	W	W	W	W	W	W		
CYLINDER OIL											
Engine Room Temperature		32		BRAND		Shell Alexia Oil 50					
Liner Temperature		70		INJECTION RATE		1,08		g/psh			
				$\text{Wear} = \frac{t - t_0}{2\pi}$		t : Measured value (mm)					
Original Size $B = 16,9$ mm $T = 27,2$ mm		Limit $22,5$ mm		$t_0 = 7,00$ mm (Initial value)							
* Subject the result of measurement at least once in 1000 running hours.											

Fig. 8 Piston rings gap measurement report for Mitsubishi 7UEC85LII

Measuring of piston rings (axial) wear amount is carried out by clearance measurement of piston rings in piston grooves by utilization of special vernier calipers or feeler gauges. Next, the results are subject to analyses by comparing to previously obtained results and calculating wear rate per 1000 running hour at the reference groove depth of 2mm, fig. 9.



Clearance (mm)		Clearance (mm)															Wear rate at 2 mm depth (mm/1000 hrs)	
		0,30	0,35	0,40	0,45	0,50	0,55	0,60	0,65	0,70	0,75	0,80	0,85	0,90	0,95	1,00		1,05
CYL 5 PR #1	3590	35	35	30	25	20	5	2										0,083
	5000	35	35	30	25	25	10	5	2									0,0116
Crown hours	6345	35	35	35	30	25	15	10	2									0,0116
	10500	35	35	35	30	25	20	20	15	10	5	2						0,0215
15090	15090	35	35	35	35	35	35	35	35	30	25	20	15	12	8	5	3	0,0401
CYL 5 PR #2	3590	25	15	5	2													-0,0017
	5000	25	20	15	5	2												0,0017
Crown hours	6345	30	25	25	15	10	5	2										0,0083
	10500	35	35	30	25	20	15	15	10	5	5	2						0,0215
15090	15090	35	35	35	35	35	25	20	15	15	10	5	3					0,0302

Fig. 9 The part of cylinder condition report – groove profile for HHI MAN B&W 6S90MC-C

3. Alternative Methods of Piston Ring Wear Amount

Other methods of assessing the condition and wear of piston rings rely on measurement of run-in coating on their surfaces, fig. 10 & 11. The following coatings are presently applied on piston rings in large marine diesel engines:

- top coating (outer layers) for initial run-in property and high scuff resistance, soft plasma thermal sprayed coating of graphite, Cu or Sn to reduce the run in period at initial running. After app. 500 hours this coating is being worn out and it can be evaluated visually;
- undercoating to increase wear resistance, plasma thermal sprayed coating of Mo/ NiCr/ Cr-C – wear-resistant coating that can be measured by lepto-scopes with utilization of electro-magnetic (induction) methods of layers measurement on ferrous base.

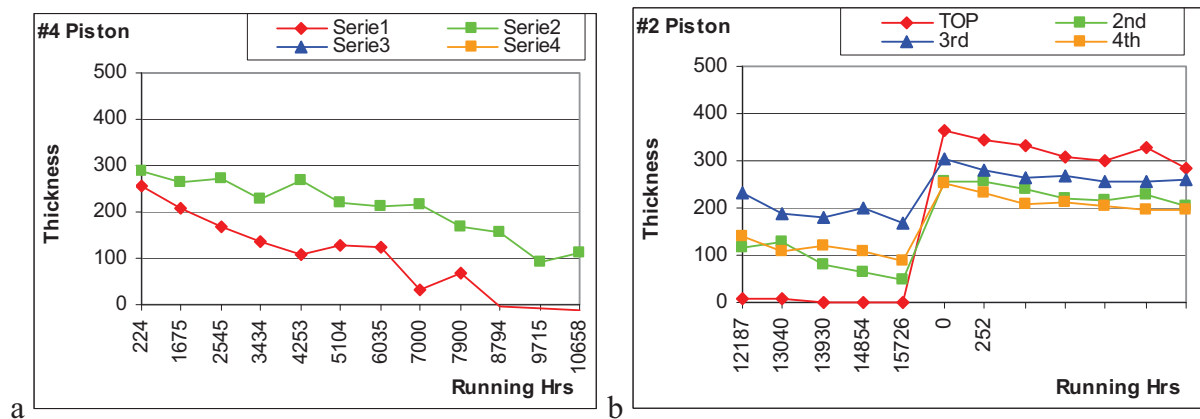


Fig. 10 Chromium layer measurement: a – Mitsubishi 7UEC85LII, b – Mitsui B&W 7S80MC-C

The wear-resistant coating loses its thickness together with the number of hours worked out by the piston rings. The results of such measurements for Mitsubishi, Mitsui B&W and Wartsila engines are presented in fig. 10 and 11. The measurements for Mitsui B&W engine (fig. 10b) were taken before and after dry docking when all piston rings were replaced.

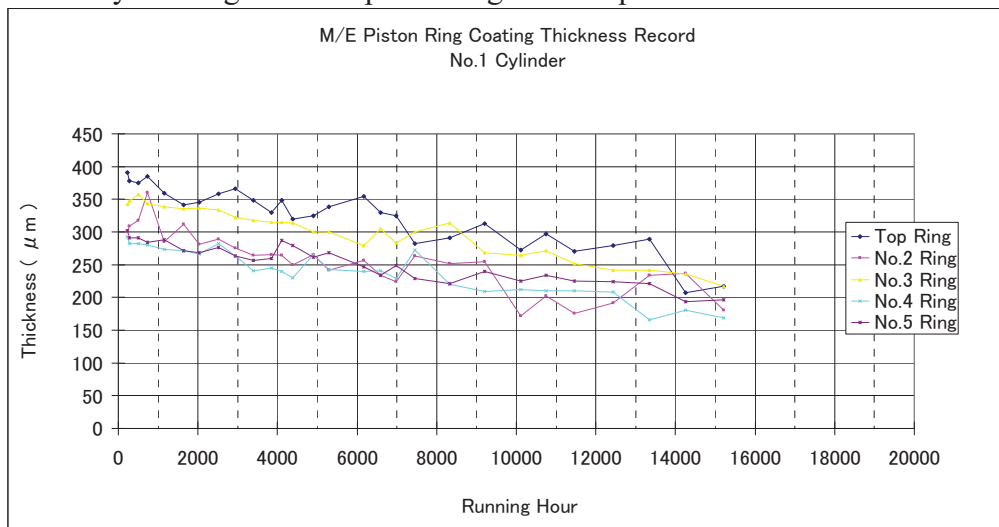


Fig. 11 Chromium layer measurement: Wartsila 7RTA84T

Conclusions

Contemporary requirements of main engine condition maintenance lead to the need to prolong the periods of its satisfactory operation between shipyard overhauls. The basis to perform main overhauls are the trends in changes of the measured operational and condition parameters of main engines. In such a case the role of periodical inspections, in which the measurement of piston ring gaps and ring wear amount take place, increases in importance. Visual evaluation through scavenge ports is sufficient for the purpose of decision making referring to the need of shipyard overhaul. This decision depends on the following:

- wear of piston rings (increased gap clearance, achieved limits in dimensions of relief grooves CL - Groove);
- achieving maximum clearance in the piston ring groove;
- cracked, broken or "stuck" ring;
- loss of seal tightness rings - "blow-by";
- active, deep scoring - abrasive wear on working surfaces, piston rings on the surface of the circuit more than a quarter of the ring;
- total loss of chromium layer;
- loss of material of size greater than half the height of the piston ring.

Based on authors' practical experience with operation of large marine diesel engines, the following the constructional – operational methods of improvement in working condition between tribological pair – liner and piston rings have been mentioned as a countermeasure plans against ring/ liner inconvenience and its safety and economical aims [3, 7, 8]:

- applying gas control rings as top rings (controlled pressure relief ring – CPR ring) – reduced variations in gas leakage from the ring gap and gas seal property in long time use in accordance with increase wear of ring or liner;
- applying as top rings relief groove ring – CL ring, to improve the thermal deformation of ring ends, gas seal performance;
- applying oval rings – reduction in local gas leakage from around the ring gap;
- applying of run-in coating – improved cooling effects from the liner that act on the ring at initial running-in period;

- applying of undercoating to increase wear resistance (chromium coating ring CCring);
- piston cleaning/ anti-polishing rings – PC and APR rings;
- increased jacket cooling water temperature (80-85°C) – reduction of corrosive wear;
- liner insulation – insulated water cooling channels inside cylinder liner;
- increased chromium layer in piston ring grooves;
- adding lubricating groove to liner (multi level lubrication) – reduction of wear caused by poorly permeated cylinder oil;
- applying electronically controlled cylinder oil feed rate (MAN B&W Alpha Lubrication System, Wartsila RPLS: Retrofit Pulse Lubrication System, Mitsubishi SIP System);
- honing of cylinder liner to remove the hard layer on the running surface and to create a good surface profile with oil pockets and roughness
- installing pre-catcher guide plate for water mist catcher to increase total efficiency in separation of condensed water droplets are generated in hot and high humidity areas.

Analyzing constructional and operational solutions used by engine's manufacturers in order to increase durability and resistance to wear of engine components it can be observed that they seek similar directions, deal with the same issues and the differences between them are negligible. However, a common denominator for the benefits arising from their use, which include:

- reduced wear of engine components, in particular the piston rings and the cylinder liner;
- reduced cylinder oil feed rate and consequently reduction in consumption;
- extended Time Between Overhauls - TBO.

Investment costs are quickly offset during operation and changes to existing structures do not require complex operations. In addition, all new engines are built based on these solutions.

Summarize the mentioned in this article issues it can be stated that the present economical situation in shipping industry can meet operational requirements including extension of time between overhauls under the following conditions:

- application of new constructional and operational solutions to reduce wear of piston rings and the use of an electronically controlled engine cylinder liner lubrication;
- performing a complete inspection involving not only visual methods but also a comprehensive measurement, archiving and identification of wear trends;
- maintaining properly functioning fuel and air exchange systems.

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