Structural Modifications for Improving the Tribological Properties of the Cylinder Unit in Two-stroke Slow Speed Marine Diesel Engines

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Increasing the energy efficiency of the marine propulsion systems currently represents one of the priorities that have been placed in front of all subjects of maritime shipping market. More and more ship owners aspired to larger and more powerful diesel engines demanded from the marine engine manufacturers to implement various technological modifications to increase the engine efficiency, extend the life of engine components, and thus prolonge regular overhauling period of them. One of the way to meet these demands, among other things, is to improve the tribological characteristics of engine components. The aim of this paper is to present structural modification of tribological system "cylinder liner - piston ring - piston" of large bore slow speed marine diesel engine to reduce friction problems in mentioned system.

KEY WORDS
~ Friction
~ Wear
~ Material selection
~ Coating tribology
~ TriboPack

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1. INTRODUCTION

The current trend in development of shipping and technology in general has outcome in improving the efficiency of the large two-stroke low-speed marine diesel engines with cylinder unit modifications. Those modifications have resulted in improvement of tribological properties of tribosystem "cylinder liner - piston ring - piston".

This paper clearly shows all the modifications that are today's standard in the construction of large two-stroke low-speed marine diesel engines. The targets of structural modifications are (Wärtsilä Sulzer, 2009):

- To give the customer the best standard to achieve an extended TBO (**T**ime **B**etween **O**verhauling) up to three years for hot parts.
- To allow the customer to reduce the cylinder oil feed rate to values of approximate 1.2 g/kWh with no risk of excessive wear.
- To reduce the wear rate for the cylinder liner to 0.05 mm/1000 working hours or less over a wide load range of the engine.
- To reduce the risk of failing during running-in period as well as sea trial and generally to reduce the running-in time to 10 hours and less.

All structural modifications that are now standard applied are shown in Figure 1.

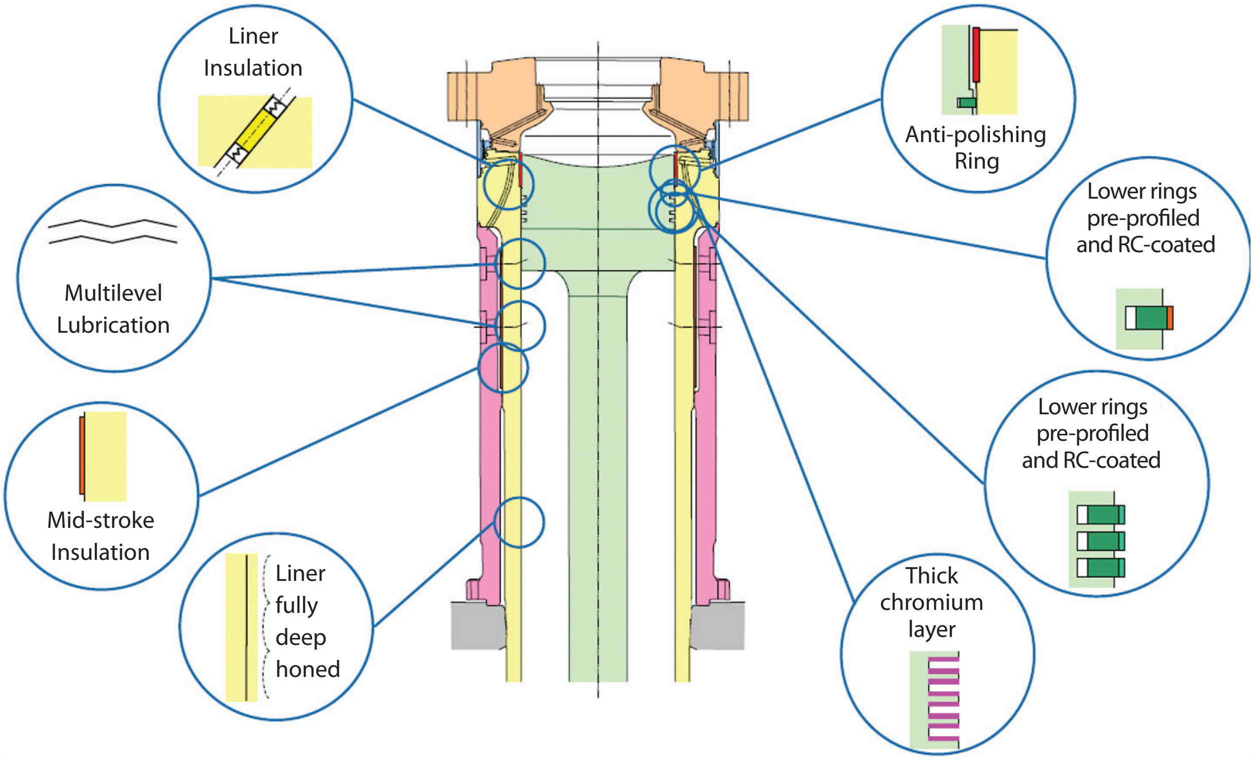

Figure 1. „TriboPack“ structural modifications. Source: „The TriboPack for Sulzer RTA engines“, (2009), Wärtsilä Sulzer.

2. STRUCTURAL MODIFICATIONS

2.1. Cylinder liner insulation

The comparison of temperature of cylinder liner with and without so called tribological insulation is shown in Figure 2. The same two diesel engines Wärtsilä Sulzer RTA84T are taken for comparation. Red line shows the temperature of engine cylinder liners of RTA84T engine without tribological insulation. It is easy to see that the cylinder liner operating temperature overlaps with the dew point temperature of water and low temperature corrosion is presented on almost the entire length of the stroke. Blue line shows the temperature of cylinder liner of RTA84T engine with tribological insulation in the TDC (**T**op **D**ead **C**entre) area and in the middle of the stroke, indicating that the operating temperature of the cylinder liner deviates significantly from the dew point temperature, which leads to specific wear in diameter under 0.05 mm/1000 working hours. The position of instalation of additional insulation and its effect on the specific wear is shown in Figure 3.

Cold liner surface leads to cold corrosion and cold corrosion leads to breaking out corroded hard phase, increased friction and scuffing and high wear rate. The sulphuric acid causes so called low temperature corrosion. That is a well understood problem which is all about temperature control of the cylinder liner running surface. The cylinder lube oil does a part of the job by neutralizing the sulphuric acid but the rest has to be done by the engine design. In this sense both 4-stroke and 2-stroke engines are in a similar position. Because of its longer stroke and its longer residence time of the corrosive combustion residues on the liner surface, the 2-stroke engines needs more accurate temperature control (Figure 3). Using proper tools it is possible to predict quite accurately the liner surface temperature as well as the critical temperature line below where corrosion may take place for different engine ratings (Figure 2). Based on these results the cylinder liner surface temperature can be adjusted by means of insulated cooling bores and midstroke area of the cylinder liner.

Red area (Figure 3) indicates positions with increased friction and scuffing and high wear rate on the engine without tribological insulation. Using additional insulation of the cylinder liner prevents condensation of sulphuric acid and corrosion attack and improves wear rate indicated as blue area in Figure3.

2.2. Multi-level lubrication and improved cylinder liner lubricating oil injection timing

Another structural modification in TriboPack system of slow speed two stroke crosshead marine diesel engines is multi-level cylinder liner lubrication with the use of two rows of cylinder lubricator quills (Figure 4). Multi-level lubrication gives much better control of the oil-film thickness over the whole piston stroke together with an adequate oil refreshing rate, even in the TDC region of top ring travel (Bar, 2005). Two stroke crosshead operation of marine engine has no non-working stroke during which the oil film on the wall can be reformed. However, this problem has also been solved by improvement in lubricating oil injection timing system. A few engine manufacturers have recently developed a lubricating oil injection timing system similar to the fuel injection like MAN B&W Adaptive Cylinder oil Control system and Wärtsilä Sulzer Pulse Lubricating System.

2.2.1. Cylinder liner lubricating oil required properties

A good cylinder lubricant must have essential properties as follows:

- It must reduce sliding friction between the rings and the liner to the minimum, thereby minimizing metal to metal contact and frictional wear. Wear is defined as damage to a solid surface that generally involves progressive loss of material and is due to relative motion between that surface and a contacting substance or substances (ASM International Handbook Committee, 1992). Dispersants and detergents and other additives, which are added to cylinder oil, are additives that are used to suspend oil-insoluble resinous oxidation products and particulate contaminants in the bulk oil. They minimize sludge formation, particulate-related abrasive wear, viscosity increasing, and oxidation-related deposit formation.

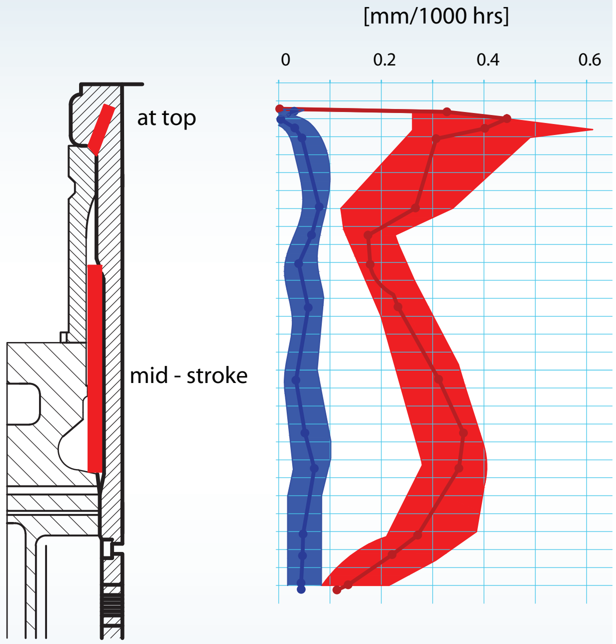

Figure 3. Cylinder liner insulation / temperature control. Source: „The TriboPack for Sulzer RTA engines", (2009), Wärtsilä Sulzer.

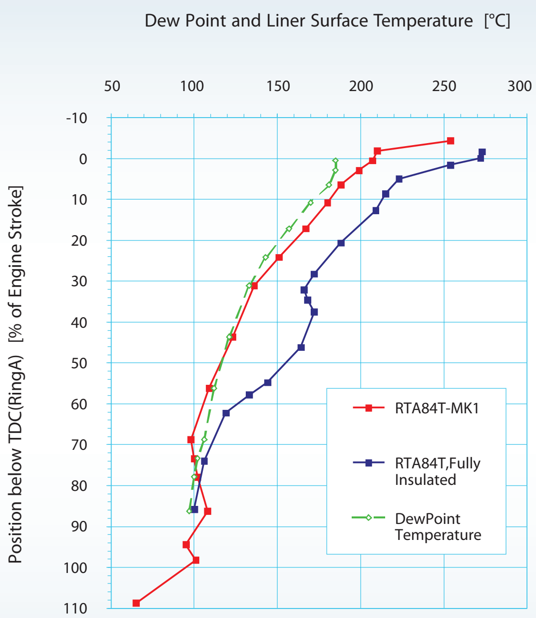

Figure 2. Optimized cylinder liner temperature. Source: „The TriboPack for Sulzer RTA engines", (2009), Wärtsilä Sulzer.

- It must possess adequate viscosity at high working temperature and still be sufficiently fluid to spread over the entire working surface and form a good adsorbed oil film. Multi-level lubrication systems have increased lubricating oil film thickness considerably. The inclusion of additives like polymethacrylates and ethylene-propylene co-polymers (OCP) helps in maintaining the requisite oil film thickness due to its molecular bending with porous cylinder liner.
- It must form an effective seal in conjunction with the piston rings, preventing from gas „blowing-by" and burning away of the oil film and lack of compression. Cylinder lubricating oil is highly viscous, which hampers its spread ability thereby resulting in uneven wear on the cylinder liner. It will ultimately lead to blow down which will aggravate lubrication problems further.
- It must burn cleanly leaving a deposit as little and soft as possible.
- It must prevent effectively building up of deposits in the piston ring zone and in exhaust gas ports of two stroke engines.
- It must neutralize effectively the corrosive effect of mineral acid formed during combustion of the fuel. For example

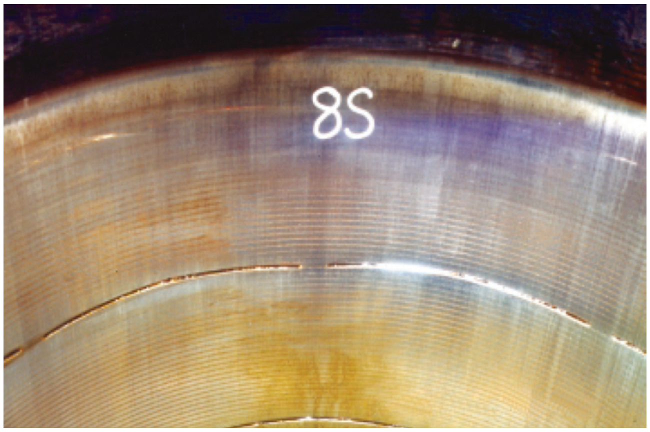

Figure 4. Cylinder liner with multi-level lubrication.
Source: „The TriboPack for Sulzer RTA engines", (2009), Wärtsilä Sulzer.

a typical large bore marine engine developing 20000 kW with a daily fuel consumption of abt. 76000 kg burning a 700 mm2/s at 50°C with a sulphur content up to 3,5% the total weight of sulphur burnt would be 3048 kg or 3 tons. If all these wer converted into SO3 and then into sulphuric acid, these would produce 10 tons of highly corrosive sulphuric acid. But reliable analysis indicates that only 10 to 15% is converted into sulphuric acid, and that amount of 450 Kg of sulphuric acid per day may lead to highly corrosive wear. This probleme can be solved by introduction cylinder liner lubricating oil with higher TBN (**T**otal **B**ase **N**umber) values such as 60-80 TBN. Furthermore it is ensured that the cylinder liner temperature doesn't go below the dew point temperature of Sulphuric acid in the upper zone and thus the corrosion is reduced to a minimum value.

2.3. Cylinder liner fully deep honed as TriboPack structural modification

Honing is a procedure treating the finest metal surfaces in order to achieve the required accuracy and quality of machined surfaces. Honing, as well as the processes of scraping, milling, grinding, or cutting off metal materials in its activity is limited to a relatively thin surface layer of the working piece and is mainly caused by cold plastic deformation, but with not far-reaching influence on the structure and properties of materials.

During the process of honing it is very important that the working surface is washed over with considerable volume of cooling and lubricating liquid. The working surface should be cooled down to avoid structural changes due to recrystallization process and release. In addition to rinsing away the metal dust generated by honing and pulling out grinding wheel particles. Research in this area is focused on the application of new cooling and lubrication liquids. The aim of honing is the extension of service life of cylinders liner and piston rings. Severe operating conditions of large bore marine diesel engines often result in increased wear of the cylinder liners and lead to frequent fractures and damages of piston rings. Today, engines can operate with an average temperature of the cylinder liner surface even over 250° C, in some areas. As a consequence is that the piston rings are subjected to higher loads, which can quickly result in excessive wear of cylinder liners and itself. Thus, the imperfection of the cylinder liner surface, caused by the environment with respect to wear can be corrected and prevented by honing process (Ivić, Smoljan, Pedišić, Perić, 2006).

There are many ways to create detrimental surface properties for a machined surface. One of the most common in the engine industry is so called shatter marks that is normally a result of machine tool vibrations caused by mismatching machining parameters. Geometrical magnitude ranges from only a few microns and thus stays well within normal drawing tolerances. However, the counter surface, the piston rings in this context, sometimes feels them with severe consequences. By honing the shatter marks can be reduced and by deep honing even eliminated. Additionally the deep honing leaves the wear resistant hard phases unbroken, see Figure 5. Neither plateau honing nor wide honing showed the desired improvements in

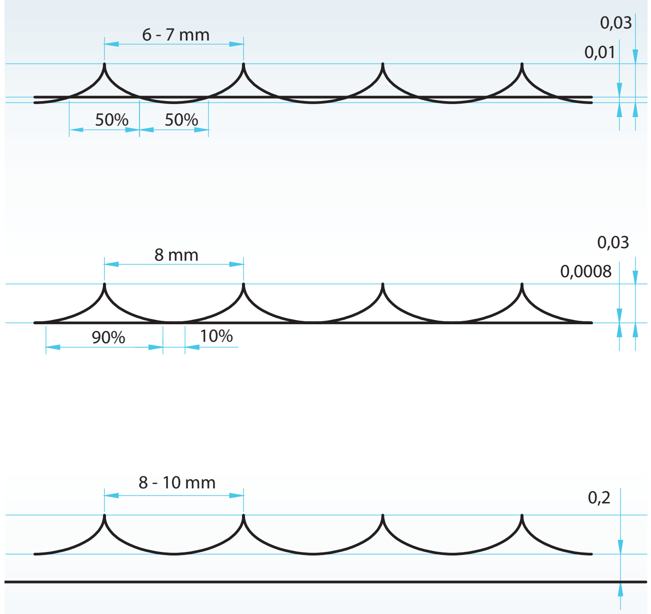

Figure 5.
"Tribo pack" - Cylinder liner machining.
Source: „The TriboPack for Sulzer RTA engines", (2009), Wärtsilä Sulzer.

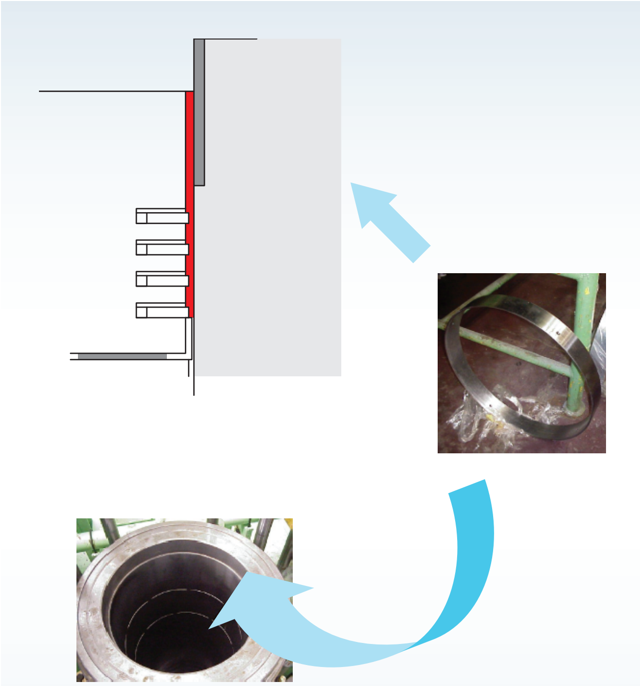

Figure 6.
"Tribo pack" - Anti Polishing Ring position.
Source: „The TriboPack for Sulzer RTA engines", (2009), Wärtsilä Sulzer.

piston running wear. Only deep honing over the full stroke was completly successful with results as follows:

- Deep honing results in a smooth surface without broken hard phase.
- Building-up of a proper hydrodynamic lubrication is only possible on a plane surface.
- Every disturbance on the surface leads to increased friction between protruding materials.

Deep honing is standard for large bore two stroke marine engines since 1997.

2.4. TriboPack anti-polishing ring (APR)

Functions of the Anti-polishing ring (APR), Figure 6, are:

- Reduced liner top diameter with APR, where the piston crown gets in and out.
- Continuous scraping-off of deposits built up on the piston crown.
- Avoidance of contact with the liner wall along the stroke due increased clearance because of removed coke from the crown.
- Undisturbed oil film mid stroke.

Figure 7. "Tribo pack" - Cylinder liner machining. Source: „The TriboPack for Sulzer RTA engines", (2009), Wärtsilä Sulzer.

- Avoidance of liner polishing.
- APR consists of alloyed steel with a high yield point under increased temperature to remain in shape.

The benefit of the APR can be easily judged from the superior cleanliness of the piston top land and piston ring area. Cleanliness is a prerequisite to stable operation over long running period.

Figure 8. "Tribo pack" - Anti Polishing Ring position.
Source: „The TriboPack for Sulzer RTA engines", (2009), Wärtsilä Sulzer.

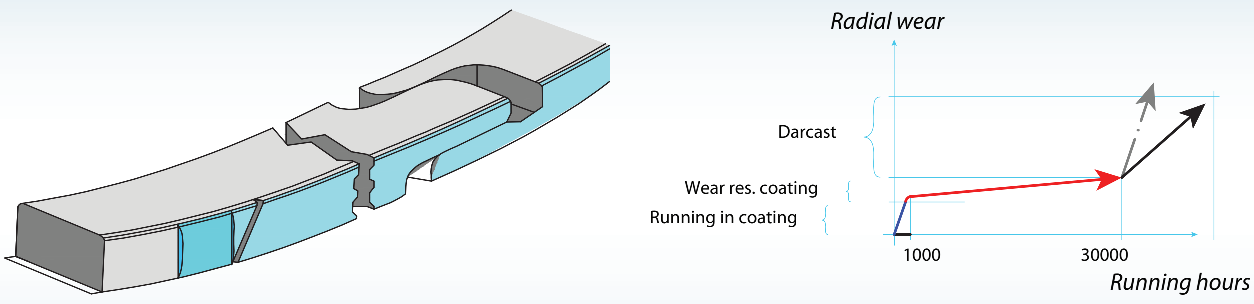

Figure 9. Typical time scale for radial wear of a Hard coated / Semi Alucoat Ring Package. Source: http://www.daros.se/

Figure 7 shows condition of piston crown with installed APR with cylinder liner lubricant oil feed rate of 1,1 g/kWh, while Figure 8 shows condition of the piston crown without APR with same cylinder liner lubricant oil feed rate causing increased deposits on the piston crown.

2.5. Piston rings coatings as TriboPack structural modification

The use of coatings on piston rings has become necessary for optimum time between overhaul on larger marine engines. There is a continuing trend to increase the power output of all engines. Higher power output means higher heat load and higher mechanical load on piston rings and cylinder liners. This has lead to the development of new piston ring coatings with excellent wear properties under increasingly load running conditions.

There are two main categories of functional piston ring coatings that are currently being used in large-bore engines: running-in coatings and/or wear-resistant coatings, Figure 9 (daros.se, 2012).

Running-in coatings

The soft running-in coating is applied to the ring's running face in order to seal properly within the first few hours of operation (during shop-testing or after cylindre unit overhaul). Another function of the running-in coating is to gently finish the running surface on the cylinder liner during the first few hundred hours after installation of a new liner. The running-in coating is applied directly to the base material or as an addition to a wear-resistant coating.

Wear-resistant coatings on running face

Cermets, as a composite material composed of ceramic (Cer) and metalic (Met) materials represent an important family of thermally sprayed wear-resistant coatings. Cermets are applied to the running face of the ring for highly loaded applications. The Cermet coatings prolong the lifetime of the ring package significantly, as shown in Figure 9. All Cermets are applied with plasma-spraying equipment.

Classic example of todays piston rings and related coatings (MAN B&W Low Speed Large Bore Engine - Now with high Power Concentration", 2010) is shown in Figure 10.

2.6. Piston rings groove coatings

It is well known that due to the penetration of hard solid particles in the space between the ring and the piston groves leads to perforation of horizontal working surface of piston ring grove and creates so called "Pockmark surface". Ultimately, this development leads to scuffing of piston ring in its groves, and the loss of its sealing ability. To prevent this problem horizontal

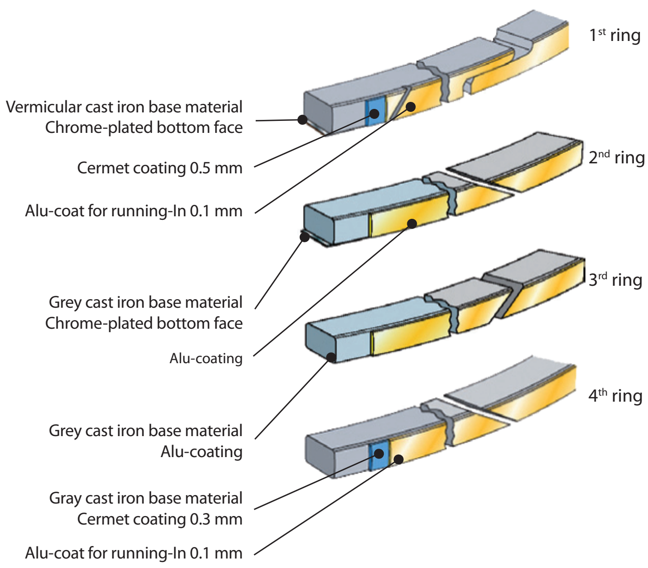

Figure 10. Typical time scale for radial wear of a Hard coated / Semi Alucoat Ring Package. Source: Unknown, MAN B&W Low Speed Large Bore Engine - Now with high Power Concentration, (2010), Copenhagen: MAN Diesel.

surface of piston ring groves is coated with chromium layer, which showed very good results, and contributed to extend time between overhauling of the cylinder unit.

3. CONCLUSIONS

This paper describes the structural modification of the tribological system "cylinder liner - piston rings - piston", so-called "TriboPack", of large bore slow speed marine diesel engines, which is the basis for achieving optimum working results on grooving maritime market. Furthermore, future improvement in overcoming the problem of friction and wear inevitably leads to the construction of even larger and stronger large bore low-speed marine diesel engines that will fully satisfy all requirements of the maritime market.

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