

FAILURES' IDENTIFICATION OF CYLINDER LINERS OF MARINE DIESEL ENGINES IN OPERATION

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Abstract

Within this paper there have been presented selected issues concerning the endoscopic diagnostics of cylinder liners of marine diesel engines. The considerations have been focused on theoretical bases of normal wear and tear process of the cylinder liners in the aspect of identification, localization and genesis of the well known and recognizable operational unserviceable states. There have been also demonstrated selected results of endoscopic exams carried out on marine engines operated on the Polish Navy warships, concerning cylinder liners' failures.

Keywords: *marine diesel engines, cylinder liners, operational wear and tear process, endoscopic diagnostics*

1. Introduction

A rational operation of a marine diesel engine requires precise knowledge of the degradation process's course within construction structure of functional systems. The process intensity is determined, among the others, with an alteration character of mechanical and thermal stresses in structural of the engine become during conversion of the chemical and thermal energy into mechanical work. The product of mean effective pressure and average piston's velocity represents a measure of dynamical stresses. The higher is the product's value the earlier an acceleration of the wear and tear process of the engine structural elements is expected [9]. The engine lifespan and reliability being expressed with, respectively: time and time's probability of the work correctness.

Many research workers all over the world and our country deal with the issue of wear and tear kinetics of the structural elements during engine usage [1,4,6,7]. The achievements in this domain of L. Piaseczny are well known in the environment of diesel engines engineers. He published widely results of operational examinations of the limiting and permissible wear and tear of the structural elements and an impact of operation condition in the very wide meaning [5]. Research elaborations of A. Niewczas and A. Sitnik are also very vital from the point of of marine diesel engine operation. The elaborations are concentrating on mathematical modeling the wear and tear kinetics of combustion engine elements [4,6].

A very important conclusion results from the worked out reliability examinations. The usage potential of the contemporary marine engines is determined with limited wear and tear of crankshaft and its bearings as well as structural elements of the piston-cylinder system, timing gear system of the working medium and precise pairs of the fuel fed system. A process of the structural elements wearing for all the above mentioned systems represents a complex physical-chemistry process considering friction, impact of high and quick changeable pressures and temperatures, non-uniform temperature distribution, considerable velocities of mutual movement of the friction pairs and changeable lubrication conditions [9].

The main aim of diagnostic research taken over by the author is to determine a dominant form of the wear for the vulnerable structural elements of the marine engines operated in the Polish

Navy. More than twenty years of operational examinations confirm that cylinder liners of medium and high speed engines are characterized with considerable intensity of wear and tear as well as occurrence of failures [11]. The application of endoscopic methods for their searching and recognition prevents further development of serious secondary failures of the engine's functional systems leading usually to the engine's total operational unserviceability.

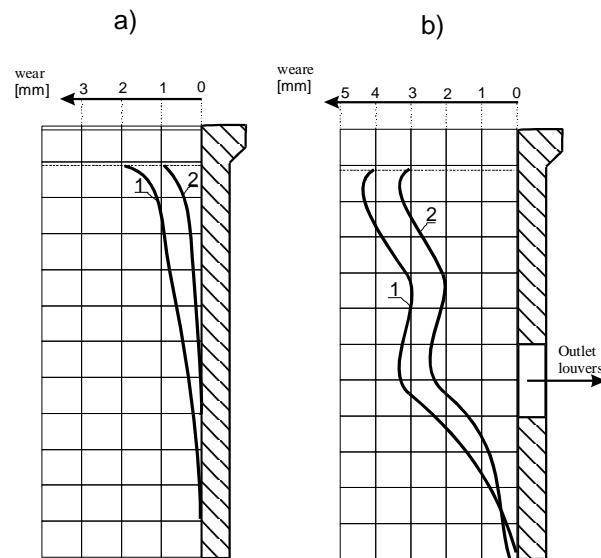
2. Forming mechanism of cylinder liners' failures

During valve's running its structural elements are subject to the considerable mechanical and thermal loads talking about a value and changeability in terms of time. The mechanical stresses caused by gas forces becoming as a result of thermodynamic processes worked out in cylinders as well as inertial forces of the masses of a piston-crank system's elements carrying out rotational and reciprocating motion, are especially essential from the kinetic cylinder liner wear's point of view.

Taking into consideration the forces' system reacting on the cylinder liner sliding surface during cooperation between the liner, piston and piston rings there could be concluded that a dominant wear and tear process would be the non-reversible wear of the abrasive elements making by normal forces (crosswise) on the liner's sliding surface as well as friction forces occurring in the contact points of the sliding surface and piston rings. There also must be considered a fact the system represents the dynamical forces' system where a load changes in constant way. The proceeded processes of micromachining metal particles loosening (as a result of multiple plastic strain) as well as a deep pulling metal particles caused by the friction connection (so called friction welding) are mainly dependent on intensity (conditions) of the cylinder liner lubrication in the way of piston's moving. The loss of required surface state and geometric shape as well as required dimensions of internal liner diameter represent the consequences of cylinder liner sliding surface's wear. A deflection research carried out on four-stroke engines shows that the biggest intensity of a wear takes place at the upper parts of a cylinder liner in the plane of crank's rotation – fig. 1a [5,9]. As a consequence, a characteristically shaped, elliptic wear threshold occurs, mostly in the top dead centre (TDC) in the region of contact between the cylinder liner sliding surface and the first two sealing piston's rings – fig. 6d. This is usually caused by a friction action of the carbon deposits layering on the walls of the combustion chamber, as a result of incomplete fuel burning. Carbon particles, getting into radial clearance between a cylinder liner and piston, disturb a layer of lube oil, causing an intensive attrition of the tip layer in the places of their biggest concentration. Besides carbon deposits other deposits occur on the walls of internal spaces of a cylinder liner. They have the form of lake layer of the dense and viscous substance getting into points piston gas rings and making difficult their free movement in the piston's grooves. It is also possible rings "hanging up" in the grooves. This phenomenon remains typical lengthwise attrition traces on the cylinder liner sliding surface – fig. 7f. Other reasons deepening destructing effects of friction and enlarged intensity of a wear of the cylinder liner sliding surface on the upper parts are mentioned below:

- high unitary pressure in the space limited with the first pair of piston's gas rings and cylinder walls, while the piston takes position of TDC at the end of compression stroke and beginning of discharge stroke – compressed air and gaseous combustion products being forced through ring clearances in the pistons grooves cause rings' expanding, what increases a side thrust on the sliding surface;
- high temperature of the combustion chamber walls – during engine running a temperature of the upper part of a cylinder liner achieves 523 – 533 K [1,9]. Hence, metal particles of cylinder liner's material demonstrate increasing mobility. This phenomenon is loaded in favour of a plastic deformation of the tip layer because of friction forces' reaction;
- unfavourable lubrication conditions – in the close vicinity of the combustion chamber lube oil evaporates and burns out making hard carbon particles along with combustion products;

- corrosion impact of the combustion products on the cylinder liner sliding surface at high temperature.



*Fig.1. Wear and tear of IC engine's cylinder liner: a) four-stroke engine, b) two-stroke engine
1 – wear curie in the plane of crank's rotation, 2 – wear curie in the plane walking through the crank shaft axis*

Defect research has shown that threshold occurs on the upper part of cylinder liners of the marine engines M400 type made of nitroalloy steel after working lifespan hours guaranteed by the producer. This is tightly connected with the considerable decreasing a thickness and hardness of the nitric layer [1]. Additionally observed defect of the cylinder liner sliding surface resulting from the loss of plasticity of the tip layer (nitrided) consists in its spalling in the form of characteristic areas close-fulfilled with minute erosion pits, so calle “rush” – fig. 5a. The producer of M400 engines adjusts a limiting value on the cylinder liner sliding surface on the level of 0,4 mm. After its exceeding, because of an inadmissible, critical decrease of nitric layer. There might be expected the accelerated, very intensive abrasive wear and tear process of the liner [1].

There also might be concluded, on the basis of numerical data presenting the wear character of two-stroke engines' cylinder liners (fig. 1b) that the application of louver timing gear introduces some singularities into this process [9]. Well, there might be observed that an intensity of the wear of the cylinder liner sliding surface in the vicinity of outlet louvers increases and in the extreme case a wear might exceed the wear in the liner's upper part. Such a specificity of the wear character explains following factors:

- corrosion impact of the hot outlet exhaust gas,
- high temperature of the cylinder liner's walls which are not cooled in this areas,
- unfavourable lubrication conditions of the cylinder liner sliding surface,
- cylinder liner's deformation.

Very practical, operational conclusions result from statistic data of the defect research have been carried out. Well, an average wear of the cylinder liner sliding surface of the marine medium and high speed engines achieves 0,02 – 0,21 mm per 1000 running hours, depending on achieved speeding and intracylinder pressures [1]. But the number of carried out start-up processes and transient processes has got a deciding significance for the wear intensity of cylinder liners. In such processes a chemical corrosion, activated with acid vapors as well as unsteady process of hit exchange and associated with – thermal deformation of cylinder liner's walls represent the main factors [1]. The corrosion appears as a consequence of vapors condensation on the cylinder liner's walls at the temperature below the daw point.

The loss of required surface smoothness caused by the piston attrition in the cylinder liner stands for other failure of the cylinder liner which is met very often in the engines' operation. In the extreme situation it is also possible the piston's material rolling on the cylinder liner sliding surface. This phenomenon usually leads to total piston's seizing in the cylinder liner and self lay-out process of the engine [5,9]. During routine endoscopic examinations of the marine diesel engines the alterations within the "honing" structure of the cylinder liner sliding surface (a depth of "honing" scratches equals from 0,01 mm up to 0,1 mm depending on the diameter and structural material of the cylinder liner) and presence and depth of corrosion-erosion defects as well as surface scratches (admissible depth is 0,5 mm, width – 1,0 mm and length – not more than 80 – 100 mm, depending on the engine's type) [5]. The overall level of a cylinder liners' degradation, intensity of the cylinder liner sliding surface's wear as well as a trend of its development are evaluated on the basis of the research, endoscopic results [1].

Cylinder liner's cracks are the most dangerous failures for the engine's reliability. They are usually caused by exceeded mechanical and thermal stresses occurring within the walls creating the combustion chamber – fig 7c and 7d. The covering cylinder liner's external walls with boiler scale disturbing hit abstraction from cylinder liners and pistons represents the most frequent reason of the cracks existence for the cylinder liners cooled with water. As a consequence the considerable thermal gradients within cylinder walls and excessive thermal deformations occur. Additionally, lubrication conditions get worse what causes cracks of structural material [5]. Thermal deformations of cylinder liner in the vicinity of TDC achieve more than 100µm [8].

Strength features weakening of the applied structural material and even its perforation caused by intensive erosion and corrosion processes of the cylinder liner's external surface represent other reason of cylinder liners' cracks, which quite usually occur during marine diesel engines operation. This kind of primary failures develop very quickly and being not detected in the right time usually lead to so called water hammers in the engine's cylinders, endangering widespread destructions.

3. Cylinder liners' examinations of the marine engines in operation

Modern diagnostic examination methods are more and more common in marine diesel engines operation. Endoscopy, earlier used only in medical practise, dynamically develops and represents very useful and even irreplaceable diagnostic tool for assessing the technical state of marine machines.

Endoscopy is a disassembling – free method of visual – optical examination of internal spaces of machines and facilities with the use of speculum devices called endoscopes.

In order to carry out endoscopic examinations of the engines operated in the warships of the Polish Navy the endoscopic equipment is provided. The equipment consists of OLYMPUS IF8D4-15 fiberoscope and boroscope set that differs each other with the length, diameter and observation angle of the optics: 90cm/8mm/90⁰, 55cm/8mm/90⁰, 45cm/8mm/90⁰, 50cm/6mm/90⁰, 30cm/4mm/0⁰, 30cm/10mm/120⁰ - fig. 2. This apparatus enables visual inspection and working out fotodocumentation internal engine's parts through the inspection holes at the diameter more than 5 mm. A special digital OLYMPUS photo camera C-2500L typ is applied to perform dimension analysis of the detected failures, their visualization and storage in the computer data base. This camera is connected to the boroscopes and fiberoscope by means of special adapters (couplings).

The fiberoscope can be introduced through the inspection holes of the diameter greater than 8 mm. Its elastic light-pipe is 1500 mm long. It has the replaceable ends, which enable observation within 60⁰ and 80⁰ face sectors and 80⁰ side sectors. Thanks to this features the manual possibilities of the inspection, through the internal spaces of the air and exhaust flow passages within the engine and turbocharger, considerably increase.

Boroscopes having different length of the stiff lens system enable carrying out observation at side and face sectors, within wide range of visual angle alterations. The optics of 30cm/10mm/120° represents especially useful tool in diagnostic investigations of the engines' combustion chambers in the region of valve seats mounted on the low board of the cylinder's head. Boroscopes are also very useful tool during inspections of the guide and rotor blades' edges of the turbocharger. In order to perform inspection every one of rotor blades, the inspection should be carried out simultaneously with turning the rotor around – by hand or by means of compressed.

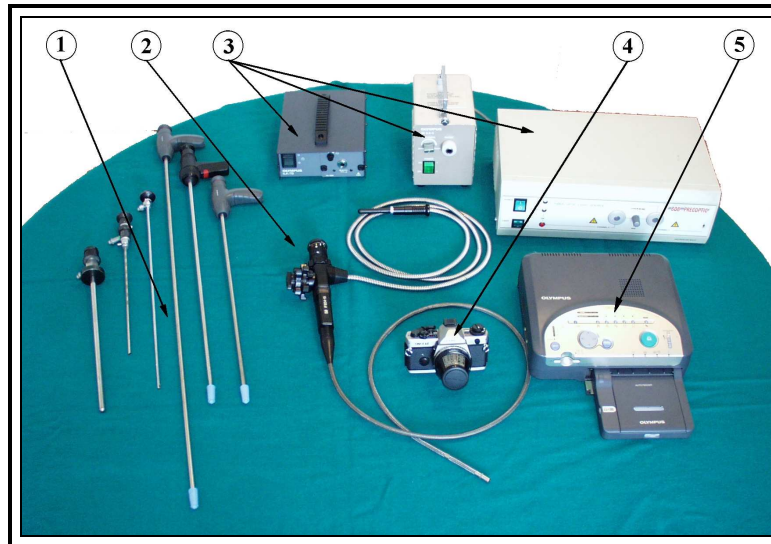


Fig. 2. OLYMPUS diagnostic endoscope set: 1 – boroscope set, 2 – fiberoptic set, 3 – light sources, 4 - photo camera, 4 – light source, 5 – photo printer

In figure 3 there is presented the way of performing diagnostic examinations of the marine engine's cylinder systems by means of boroscopes and fiberoptic. Figure 4 demonstrates how to get access and introduce optics through the inspection holes into internal spaces of the cylinder liner during endoscopic inspections of the marine engines M401A-1(2) and Detroit Diesel 16V149TI type.

a)



b)

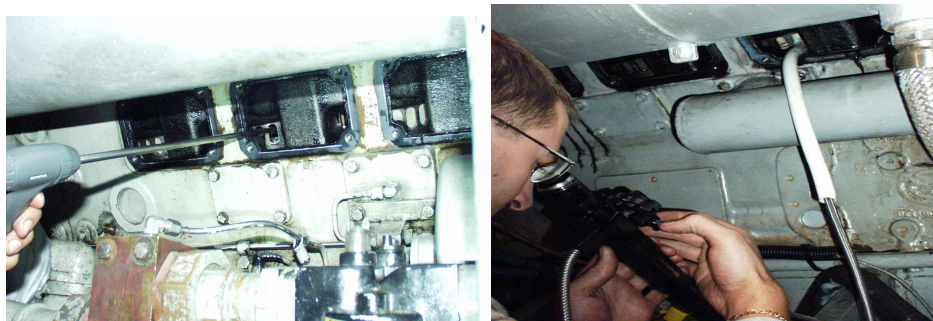


Fig. 3. The way of introducing boroscope and fiberoscope endings into cylinder space
 a) M401A-1 engine- through the holes after removing fuel injectors,
 b) Detroit Diesel engine 16V149TI type – through the inlet air slots on the cylinder liner.

A fiberoscope (boroscope), after fuel valve removing, gives an operator opportunity to look through the flexible optic system on the piston crown, cylinder liner, cylinder head and other parts within one, such as fuel valve nozzle, inlet and exhaust valves, starting air valves and others (fig. 4). This method plays important part in multi-block and multicylinder engines. For example in “star-shape” engines M503A and M520A series, lower monoblocks and lower parts of reduction-reversing gear are not easy accessible in small ship’s compartments. So, during overhauls engines together with gears must be uncoupled with propeller shaft, bind up, take up and sometimes even turn up in engine room to get access to the first or seventh monoblock. From our operation experiences results that a fiberoscope with elastic and long enough optic system allows avoiding some of these difficult and dangerous inconveniences hence, allows saving time and money even by 25-30% [7].

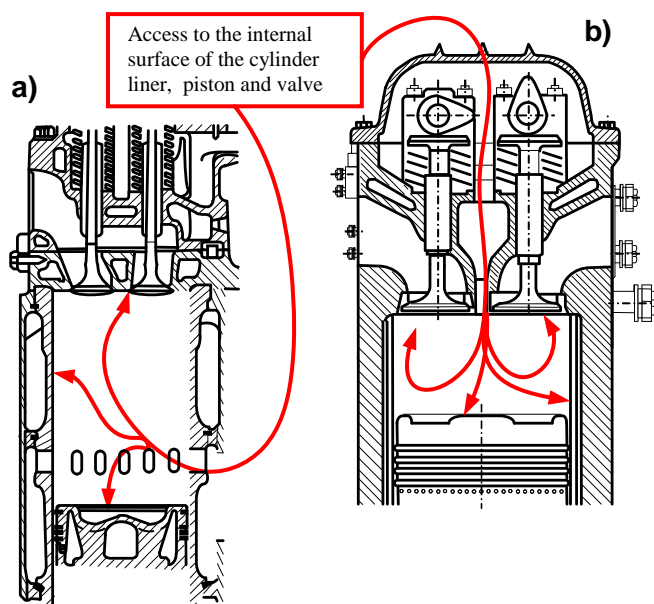


Fig. 4. Endoscopic examinations of the marine engine – access to the internal spaces of the cylinder liner: a) Detroit Diesel engine 16V149TI type b) M401A-1(2) engine

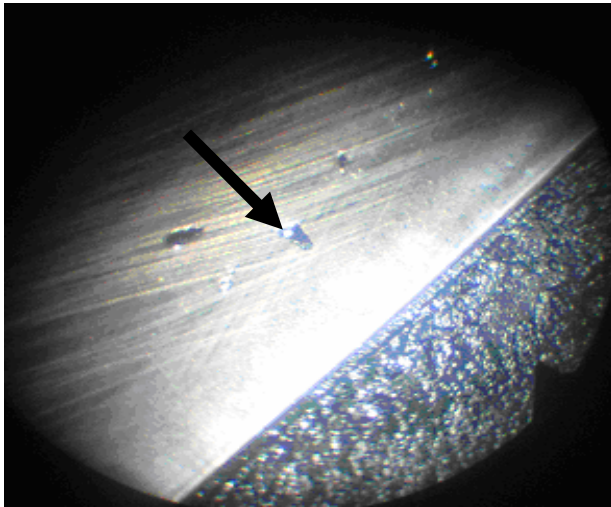
4. Failures of the marine engines’ cylinder liners

The systematic periodical endoscopic investigations of the engines operated in the Polish Navy should be carried out in the following situations:

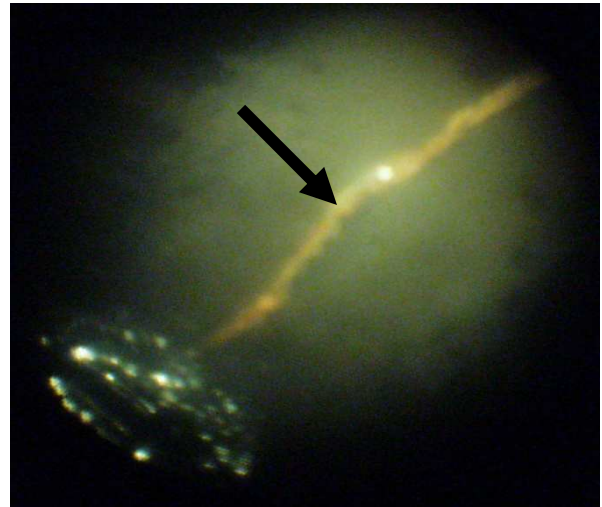
- ⇒ during prophylactic surveys (at least once a year),
- ⇒ during assessment of engine technical state when extension of between – repair period is necessary,

⇒ in the case of excessive vibrations, metal filings detected in lube oil, deviations of the trend line of the average indicated pressure's values (indicated power) from the cylinder, excessive exhaust temperature, drop of power, excessive smoking, etc., when disassembling the engine heads is difficult and time consuming.

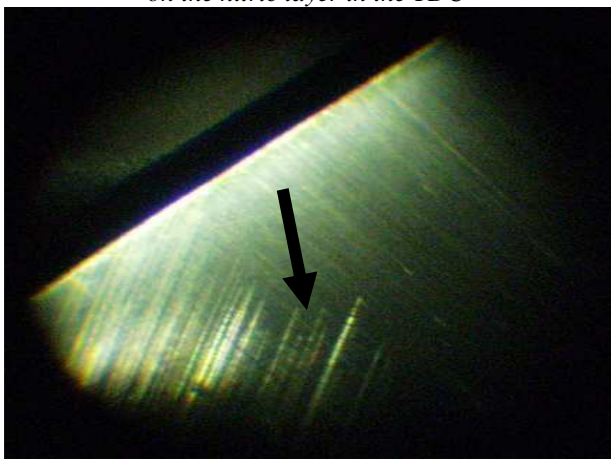
On the basis of perennial endoscopic examinations of the marine engines there have been elaborated methods of the technical state evaluation in the operation conditions. The methods include the range and chronology of the performing internal space inspections enabling defects detection of the engine functional systems' parts. There have been also elaborated detailed guidelines for the diagnostic research performance with the usage of fiberoscope and boroscope set. The detected defects are photographically recorded to file them in a computer data base and establish their trends. The most frequent defects of the cylinder liners of the examined marine diesel engines are presented in fig. 5, 6 and 7 [2,3,11].



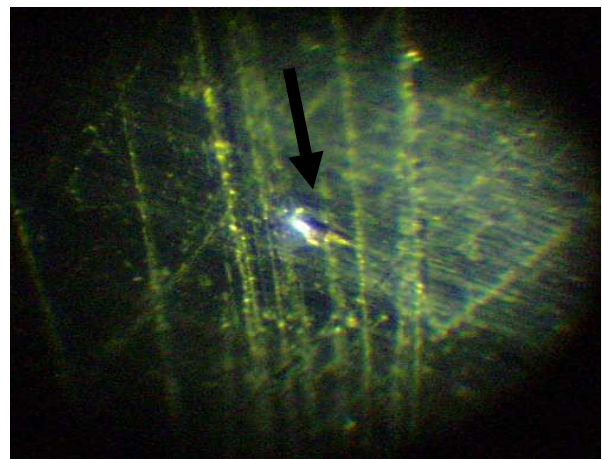
a) Cylinder liner sliding surface of four-stroke 3516 CATERPILLAR engine – erosion pits so called „rush” on the nitric layer in the TDC



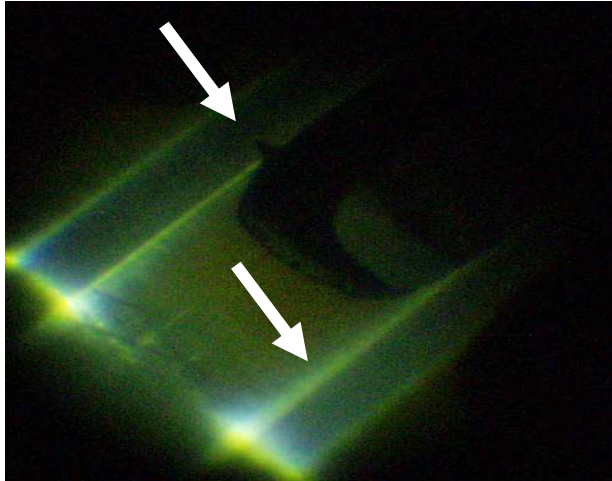
b) Cylinder liner sliding surface of four-stroke high-speed M503A ZVEZDA engine – cylinder liner cracks



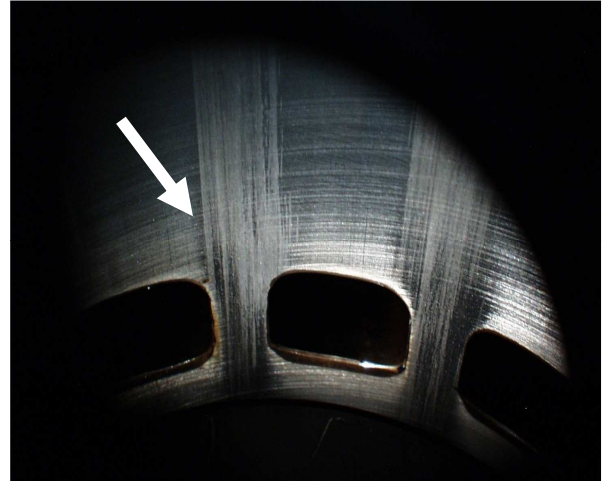
b) Cylinder liner sliding surface of four-stroke 6AR25/30 SULZER engine – insignificant friction wear traces, clear visible “honing” boundary



b) Cylinder liner sliding surface of two-stroke low-speed 6TD48 SULZER (ŚWIĘTOCHOWICE) engine – a local corrosion source

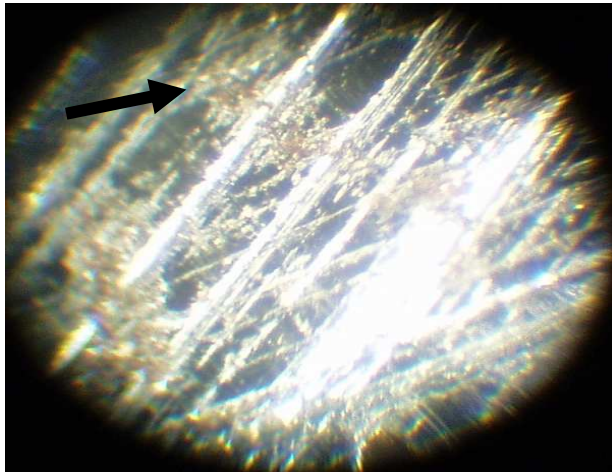


e) Outlet louver of timing gear system of two-stroke low-speed 6TD48 SULZER (ŚWIĘTOCHOWICE) engine – material dent on the louver's edge as well as visible friction traces

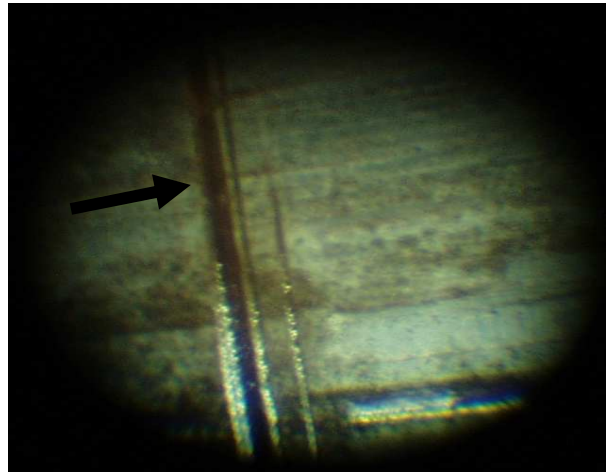


f) Cylinder liner's lower part of two-stroke low-speed 6TD48 SULZER (ŚWIĘTOCHOWICE) engine, in the vicinity of timing gear louvers – clearly visible friction traces on the cylinder liner sliding surface

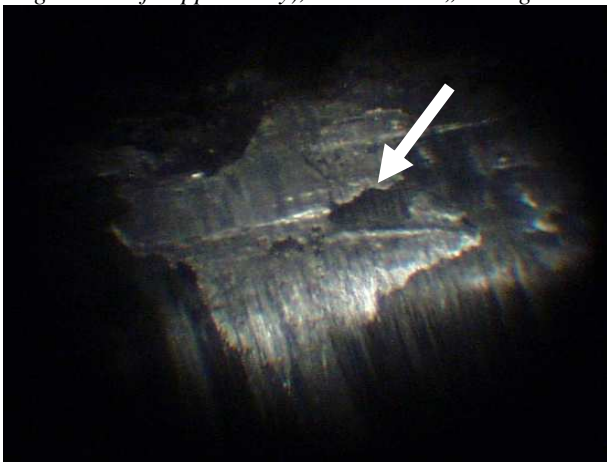
Fig. 5. Marine engines' cylinder liner defects identified during endoscopic inspections



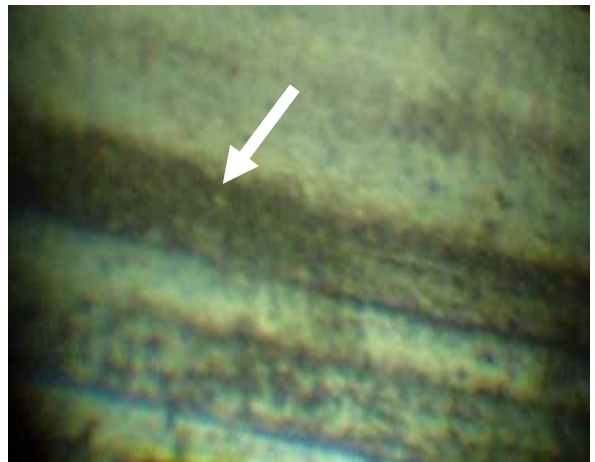
a) Cylinder liner sliding surface (enlarged piece) of two-stroke low-speed 6TD48 SULZER (ŚWIĘTOCHOWICE) engine – remained products of friction wear (leading rings made of copper alloy), rubbed into „honing” traces



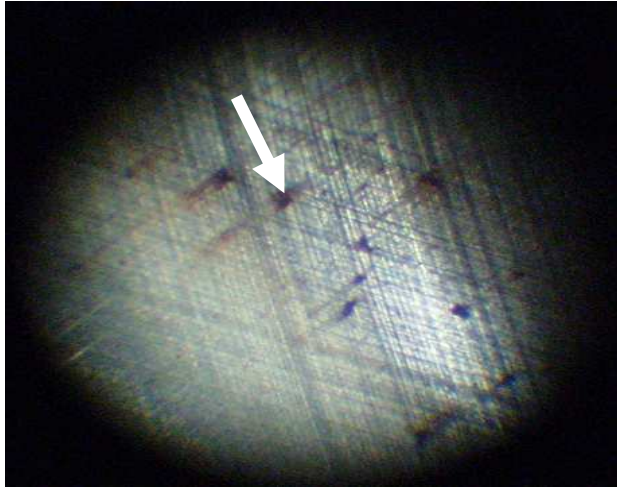
b) Cylinder liner sliding surface (enlarged piece) of two-stroke low-speed 6TD48 SULZER (ŚWIĘTOCHOWICE) engine in the upper part – deep scratch in the plane of crank's rotation



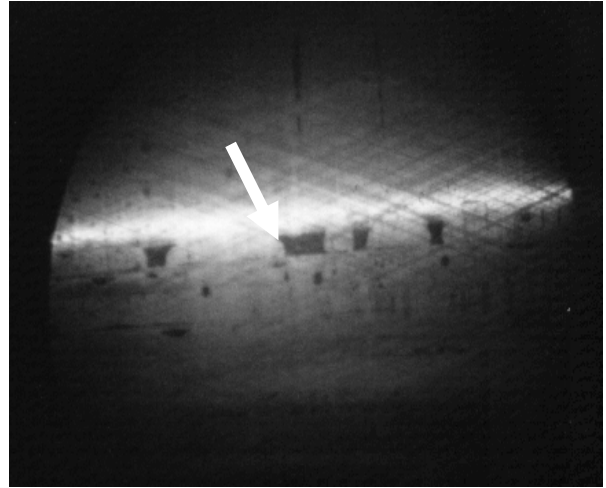
c) Cylinder liner sliding surface of four-stroke M401A2 ZWIEZDA engine – traces of piston's seizing in the cylinder liner



b) Cylinder liner sliding surface (enlarged piece) of two-stroke low-speed 6TD48 SULZER (ŚWIĘTOCHOWICE) engine in the upper part – piston ring wear traces

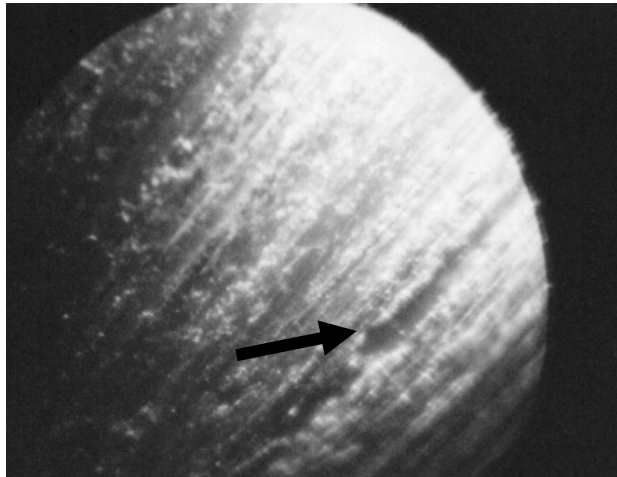


e) Cylinder liner sliding surface of four-stroke 4.400E/ESC NANNI DIESEL engine – local corrosion sources

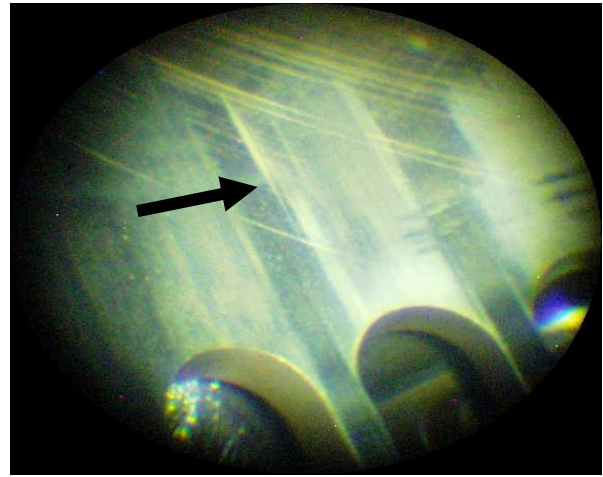


f) Cylinder liner sliding surface of four-stroke 6ATL25/30 SULZER engine – corrosion and erosion scars

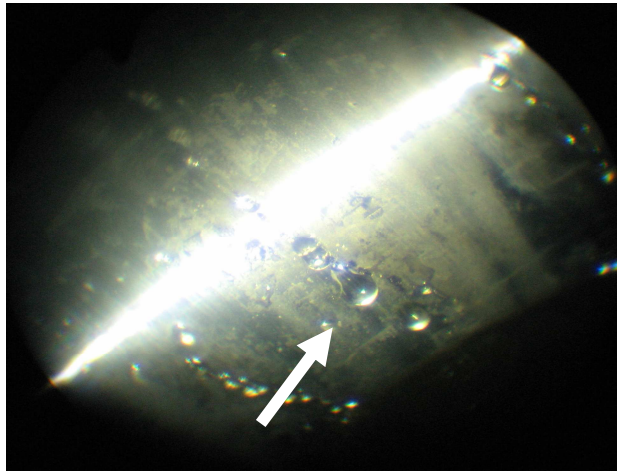
Fig. 6. Marine engines' cylinder liner defects identified during endoscopic inspections



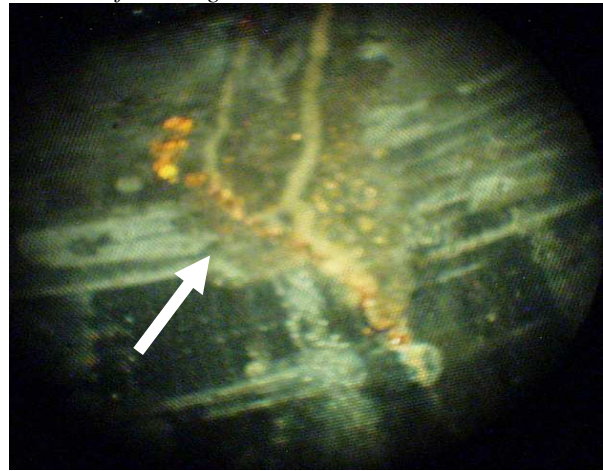
a) Cylinder liner sliding surface – 216 NOHAB POLAR engine – catastrophic friction traces



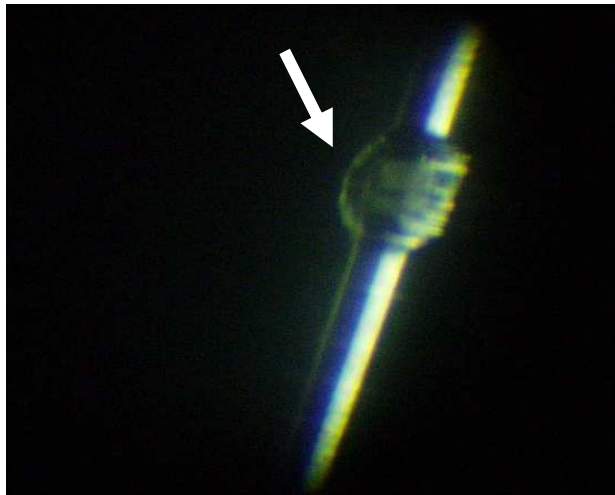
b) Cylinder liner sliding surface two-stroke 16V149TI DETROIT DIESEL engine in the vicinity of air louvers – the wane of "honing" traces



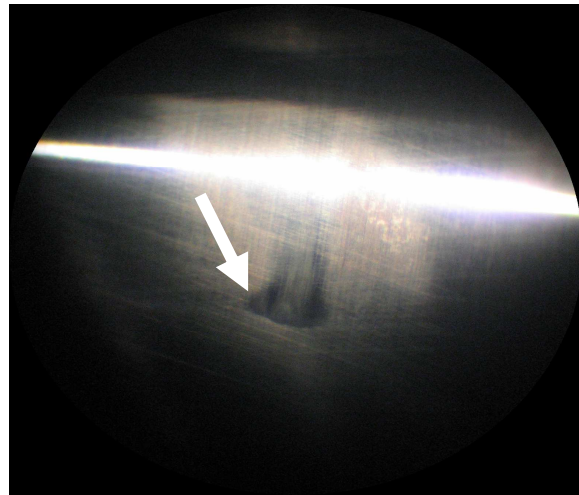
c) Cylinder liner sliding surface of four-stroke M401A2 ZWIEZDA engine – a presence of water drops testifying the cylinder liner's crack



d) Cylinder liner sliding surface of four-stroke M401A2 ZWIEZDA engine – cracked cylinder liner



e) Cylinder liner sliding surface of four-stroke M401A2 ZWIEZDA engine – visible friction wear traces



f) Cylinder liner sliding surface of four-stroke M401A2 ZWIEZDA engine – a lengthwise friction wear trace originated by the piston ring being “hung up” in groove

Fig. 7. Marine engines' cylinder liner defects identified during endoscopic inspections

5. Conclusions

The endoscopic investigations carried out during almost 15 years periodical prophylactic surveys of naval diesel engines demonstrated that the method was very effective and usage of the applied instruments was relatively easy. Many material defects of the structural elements, which could be dangerous for the engine in the case of their uncontrolled growing, were identified in result of the examinations. Detail description of the detected defects can be found in the relevant annual reports [11].

The wane of the “honing” traces on the cylinder liner sliding surface represents the observable symptom of the marine diesel engines' wear and tear process. Endoscopic methods being introduced into routine diagnostic examinations of the engines operated in the Polish Navy give the possibility of wear and tear intensity evaluation and prognosis as well as failures' detection within combustion chambers (cylinder sets) in advance (in due time) which threaten the engine with a break-down. This advantage enables the engine's operator an efficient planning the usage according to the engine's actual shape, at considerable costs' diminishing even by 25-30%.

6. References

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