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ENDOSKOPIC EXAMINATIONS OF MARINE DIESEL ENGINES' TURBOCHARGING SYSTEMS

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Abstract

The paper deals with diagnostic issues concerning endoscopic examinations of marine diesel engines. There will be presented selected information about failures of turbocharging systems and accessible diagnostic method enabling their detection. The author focuses only on the endoscopic research and widely presents the possibilities of this quickly developed diagnostic method. There will be also presented representative results of diagnostic examinations carried out on the main and auxiliary marine diesel engines operated in the Polish Navy.

Keywords: *marine diesel engines, turbocharging systems, diagnostics, endoscopic investogations.*

1. Introduction

Maintenance of marine diesel engine's turbocharging system in a state of full technical ability represents the basic condition for achievement of high efficiency of the working processes worked out in the whole range of possible operation load, especially within the range of dynamic loads of a ship motion system. In such a situation the optimum associating the engine's characteristics (as the flow machine of periodical action) with the turbine and compressor of turbocharging system (which are characterised with a continuity of thermodynamical medium flow) represents the basic energetic problem. Additionally, during unsteady processes, these machines differ essentially with inertia of thermal and flow processes what may cause undesirable thermal and mechanical overloads of the engine's constructional elements when the flow passages' technical state gets worse. There is also possible the compressor's entrance in the area of unstable working and as a consequence - serious damages within the turbocharger's rotor and disturbances in the engine functioning [1].

Accordingly, there is the key operation question: the systematic supervision and reproduction of the technical shape of turbocharging system's flow passages (interblades channels of turbocharger's rotor, guide vanes of a turbine, filter as well as diffuser of a compressor, cooler of supercharging air, the channels of air and exhaust gases), and also technical shape of the engine's fuel fed system, as the activities permanently adapting conditions of gasdynamical coupling of the cooperating flow machines.

2. Operational unserviceable states of the turbocharger

During engine operation on a ship, the gas passages of turbocharging system is penetrated with different substances contained , on the one side - in sucking inlet air, on the other - in exhaust gases leaving cylinders of the engine. They create the hard deposable settlings on flow channels' surfaces as well as on surfaces of interblades channels of the turbocharger's rotor. The registered results of endoscopy investigations confirm this phenomenon - fig.1 [2]. The mass of turbocharger's rotor grows up and its rotational speed gets smaller in the result of forming deposits. Moreover, active flow fields of sections in the interblades channels of the compressor and turbine get smaller. The compressor's efficiency, mass flow rate and compression ratio falls as well as a stability margin of the compressor working (particularly during transient processes). Such the compressor's behavior has also negative impact on a quality of the loads exchange process in cylinders as well as the burning process, in this case - incomplete and imperfect.

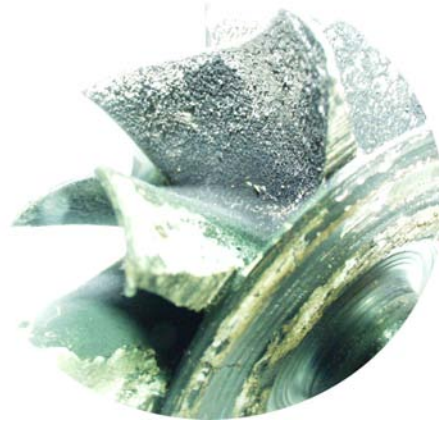


Fig. 1. Failures of turbochargers; a) surface deposits on a turbine rotor of the turbocharger

Fig. 2. Fatigue crack of the turbine rotor blade of the turbocharger

As an effect, the process of carbon deposit formation on passages' surfaces of the turbine part intensifies. This concerns especially stator blades and rotor blades of the turbine as well as labyrinth seals. It deepens the unfavourable phenomena that concurrent a dirt process of the sucking air channel. Additionally, as a consequence of deposits creation on the turbocharger's rotor the loss of stability of turbocharger mechanical system may occur. It also leads to the vibration resonance phenomenon causing in turn the accelerated waste of shaft bearings, and also fatigue cracks of the rotor blades - fig. 2.

From the operational experiences results, that the thickness of deposits layer on the compressor's blades can reach tens micrometers, meanwhile on the turbines blades - even a few hundred micrometers [2]. It makes the significant influence on the turbocharger's performance and efficiency (and obviously a performance and efficiency of the engine) taking into consideration small mass and size of the turbocharger's rotor working at very large rotational speeds (up to 100 000 min^{-1}).

A different operational factor that has very destructive effect on constructional structure of the

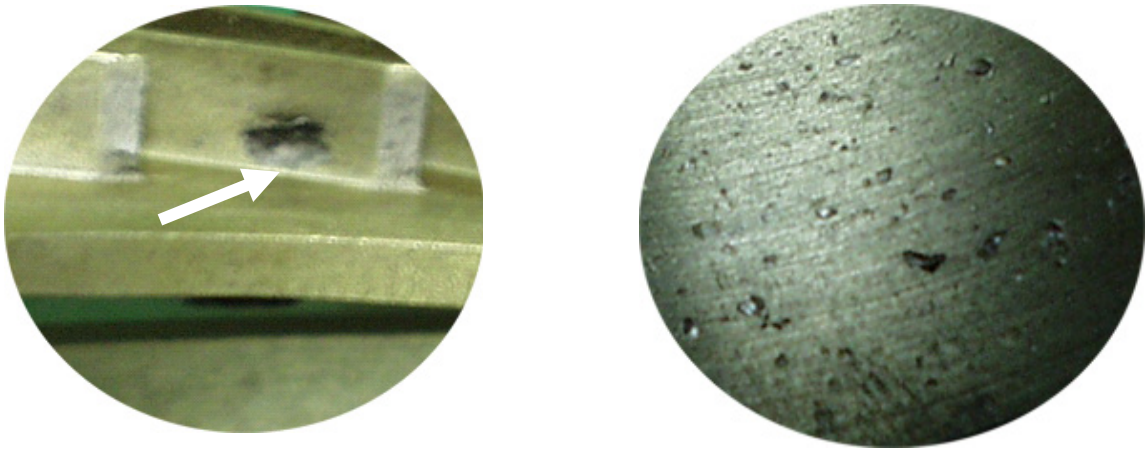


Fig. 3. Erosion pits on guide vanes of the compressor's diffuser

turbocharger is the phenomenon of erosion caused by the presence of hard particles of mineral origin in flowed working medium - in case of air, and the carbon deposit and the pitch substances in exhaust gases, as products of incomplete and improper fuel burning in cylinders as well as the remainders of lubricating oil - fig. 3.

Both the unfavourable phenomena might cause the intensive wearing of gas passages surfaces, alterations of the geometry and shape of interblades channels of the compressor and turbine, and also the enlargement (even the several times) of the surface roughness. As the consequence, the hydraulic losses of working medium flowed in the turbocharging system grow up, at the considerable deterioration of dynamic features. Moreover, inertias in mechanical and gasdynamical system grow up, along with all the consequences for the engine's performance [1].

3. Endoscopy investigation of the turbocharging system

The turbocharging system of a standard (serial) marine diesel engine is usually characterized by the low supervision susceptibility, in an aspect of possibilities of an endoscopy application. An access to the interior of air and exhaust flow passages (cooled with water) is limited, and also an access to the rotor unit of the turbocharger. In such a situation there is necessary applying blank technological openings assigned for physical quantities' transducers. The quantities are observed only during an engine running in conditions of factory tests. Thus, a minimum diameter of the optical probe which is to be introduced to the channel's interior, and adjusted to the diameter of technological openings represents an essential limitation of performing endoscopy examinations. Making additional inspection openings on your own, enabling the introducing an endoscopy probe in the most vulnerable parts of gas passages of the turbocharging system stands for a different, commonly applied solution in such limitations. This especially concerns the following parts:

- rotor blade system of the compressor and turbine,
- stator blades of the compressor's diffuser,
- guide vane of the turbine,
- air channels in the vicinity of the inlet valves,
- exhaust channels in the vicinity of outlet valves.

With regard to complexity of a constructional form of turbocharging system as well as a considerable, sometimes, distance among the inspection openings and the observed surface of gas passages there is often necessary to apply a flexible fiberscope during endoscopic investigations. The elastic fiberoscope possesses the ability of controlling a sector of the deviation of the inspected ending. Because there is often necessary to lead elastic optical parts in horizontal position through the gas passage different inspection leadings of different shape have got very practical utilization – fig. 4. Plastic pipes are perfectly useful to this aim (e.g. the pipes of central heating systems), having the possibility of a plastic deformation and memorization the given

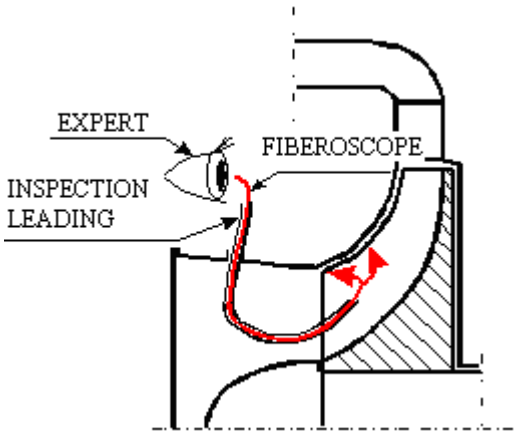


Fig. 4. The way of the inspection leading's usage for endoscopic examinations of the turbine

shape, that is best adapted to the constructional form of observed internal spaces. The way of performing the endoscopic examinations of the marine diesel engines' turbocharging systems by means of the boroscope and fiberoscope is presented in fig. 5.

In which way the access to internal spaces of a turbocharger could be achieved during endoscopic investigations of marine engines Zvezda M401A-1(2) type and Detroit Diesel 16V149TI type is schematically presented in figure 6. Especially elaborated diagnostic methodical guides contain the detailed description of successive procedures of endoscopic examinations, taking into account the specification of diagnostic apparatus as well as the supervisory susceptibility of the engines installed inside the marine power plant [2].

The fiberoscope (more seldom the boroscope), after filter's disassembling in the suction channel as well as the blanks' disassembling of technological openings in the air and exhaust channels gives the operator possibility to carry out technical state's evaluation of a blade system of the turbocharger's rotor and also blade-rings of the turbine's guide vanes and the compressor's diffuser (fig. 6). The largest difficulty during endoscopic investigations of a turbocharger's system represent the proper recognition of surface defects in exhaust channels and turbine's rotor which are usually intensively dirtied with the carbon deposits. There is almost impossible to detect erosion and corrosion pits in due time, while they are concealed under a thick layer of the carbon deposit (fig. 8b). The pits appeared on the turbine's rotor might represent en essential threat for the engine's reliability.

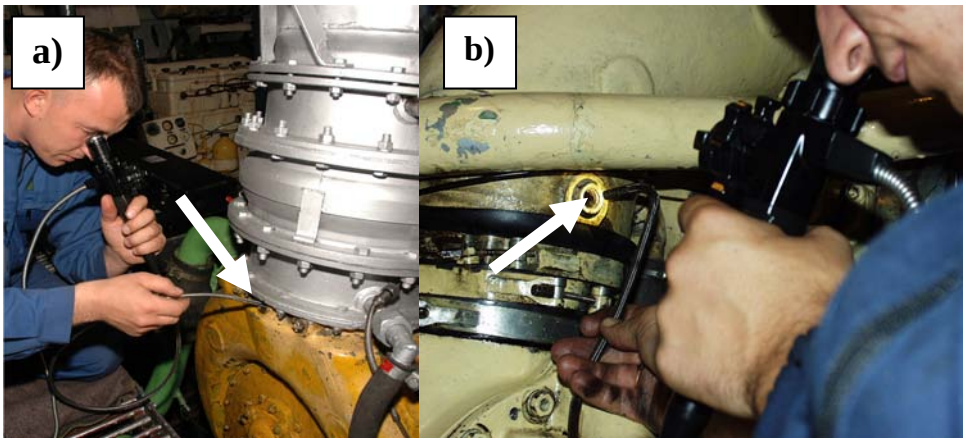


Fig. 5a,b. The way of introducing the inspection endings of the boroscope and fiberoscope into internal spaces of the turbocharger; a) turbine's investigation of the engine of M520 type – through the openings after the removed (dismantled) thermoelement in the exhaust channel, b) turbine's investigation of the engine of M401 type through the openings after the removed (dismantled) blank of measurement connector of the turbine discharge pleasure

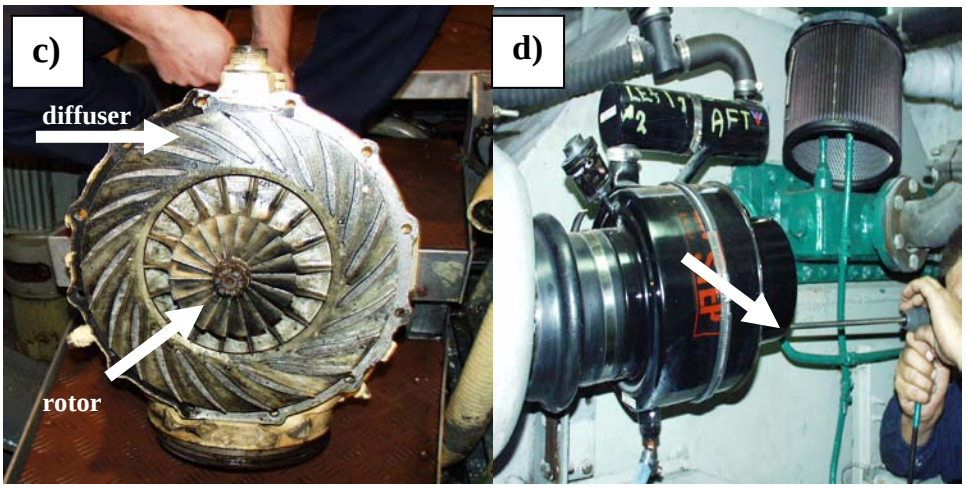


Fig. 5c,d. The way of introducing the inspection endings of the boroscope and fiberoscope into internal spaces of the turbocharger; c) the M401 engine's investigation – the view of the compressor dismantled from the engine, d) the 16V149TI Detroit Diesel engine's investigation – access to the compressor's rotor after the air filter's disassembling.

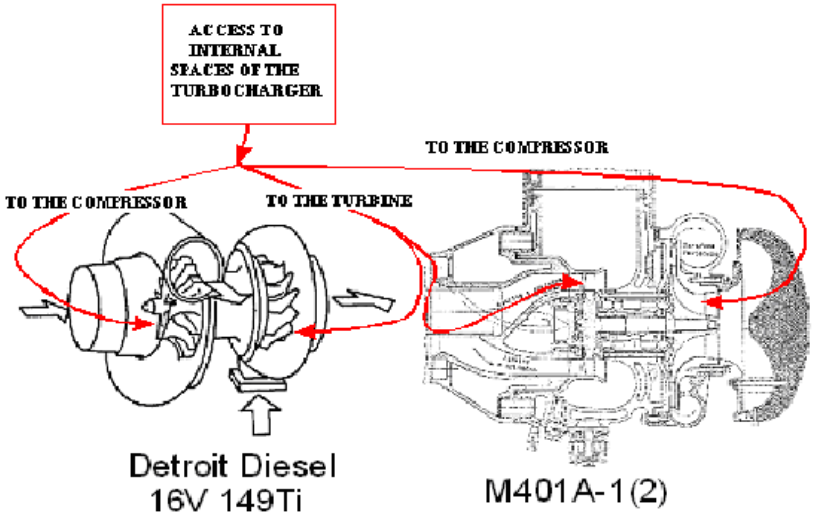


Fig. 6. Endoscopic investigations of Detroit Diesel marine diesel engine 16V149TI type and Zvezda M401A-1(2) type – an access to internal spaces of the turbocharger

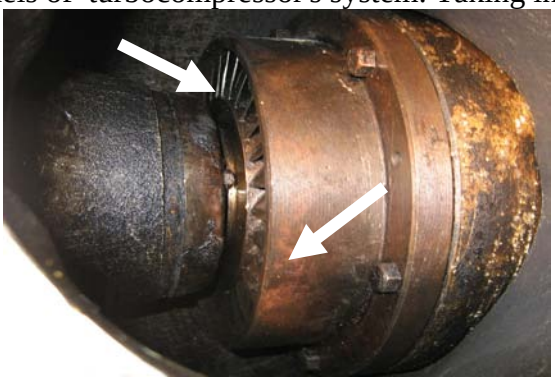
As the result of perennial endoscopic investigations of marine diesel engines there have been entered several cases of so intensive dirt of the turbine's rotor that even its manual (hand) turning makes the operator gigantic difficulties. There were cases when there was totally impossible. It meant practically that the engine worked without supercharging. Because it concerned the engines which were not equipped with turbines' washing (cleaning) installation in standard, there was necessary (in every case) to perform the disassembling of the turbocharger from the engine and then, hand removing the carbon deposit from the interblades channels of the rotor.

4. Endoscopic images of turbochargers' failures

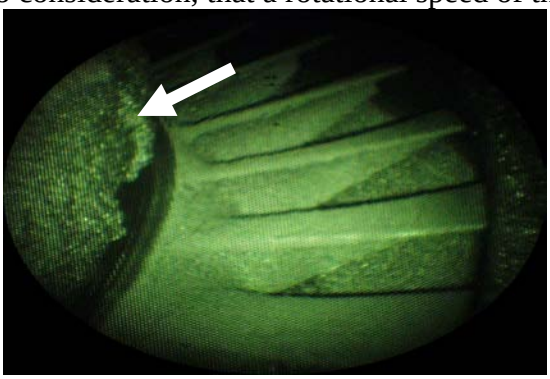
The chosen failures of turbocharger systems of marine diesel engines identified during operational endoscopic investigations are presented in figures 7, 8 and 9 [1,2]. It is highly surprising, that many dangerously looking defects were not effective with noticeable alterations of values of

the observed control parameters of the engine. For example, metallic fragment, introduced in fig. 8a, imprisoned in an interblade channel of the turbine's guide vanes was detected during routine diagnostic investigations of the engine in current operation. As a result of optical inspection of the whole system of exhaust gases (the engine at the configuration of a star - 7 blocks of 6 cylinder liners), the extensive damages of the channel off taking gases from cylinder block number 6 were confirmed. The character of detected cracks and decrements of the constructional material showed, that a low-cycle fatigue of the welded joint, which had been working in the chemical active (aggressive) corossive environment, represented the primary reason of their appearances.

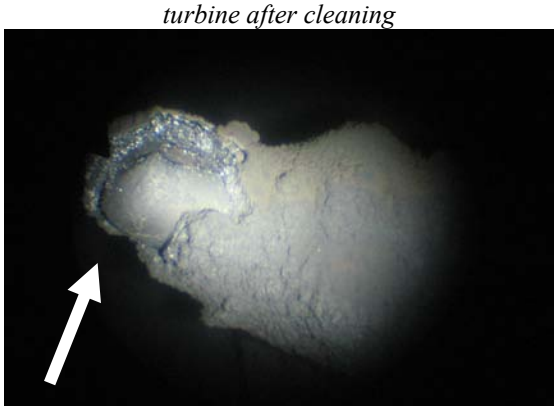
The application of endoscopies allows the user also to detect damages of the compressor's blading that could be dangerous for the engine reliability. Very often there have been found different kind of deformations (fig. 8d , fig. 9d,e), cracks (fig. 7f, fig. 8e,f , fig. 9f) as well as dirt (fig. 7b,c,d,e, fig. 9a,c) of the interblade channels of the compressor's rotor which do not generate the clear diagnostic symptoms that could be identified with the vibration measurements, indicating cylinders or gasdynamical measurements of the working medium in the suction and discharge channels of turbocompressor's system. Taking into consideration, that a rotational speed of the



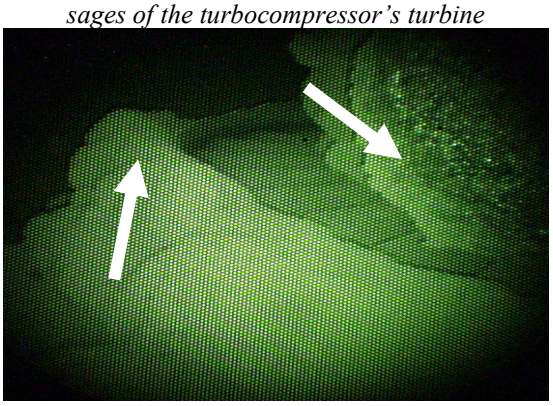
a) Zvezda M401A-2 type 4-stroke engine – exhaust (discharge) passages of the turbocompressor's turbine after cleaning



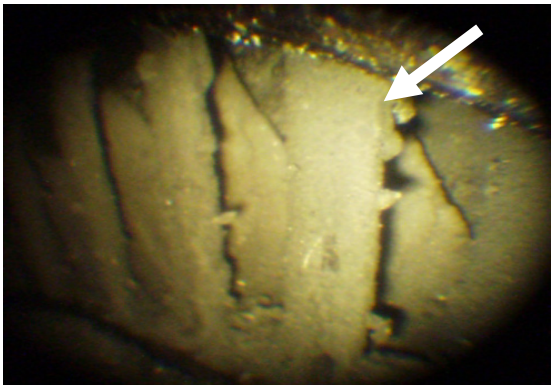
b) Zvezda M401A-2 type 4-stroke engine – intensive carbon deposits on exhaust (discharge) passages of the turbocompressor's turbine



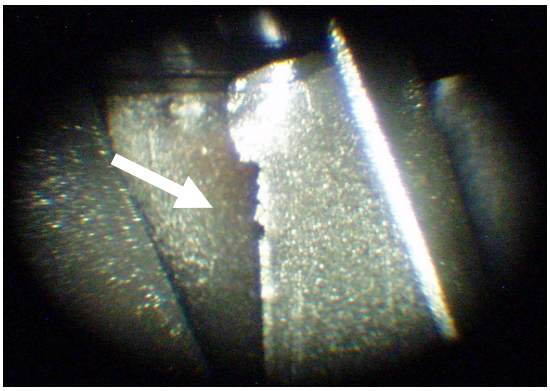
c) Zvezda M401A-1 type 4-stroke engine – intensive carbon deposits on the thermocouple measuring turbine discharge temperature



d) Zvezda M401A-1 type 4-stroke engine – intensive carbon deposits on exhaust (discharge) passages of the turbocompressor's turbine



e) Zvezda M401A-1 type 4-stroke engine – carbon deposits in interblade channels of the turbine

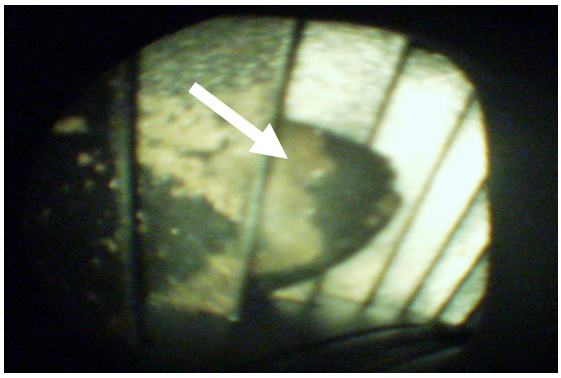


f) Zvezda M503A type 4-stroke engine – material decrements of the turbine's rotor blade

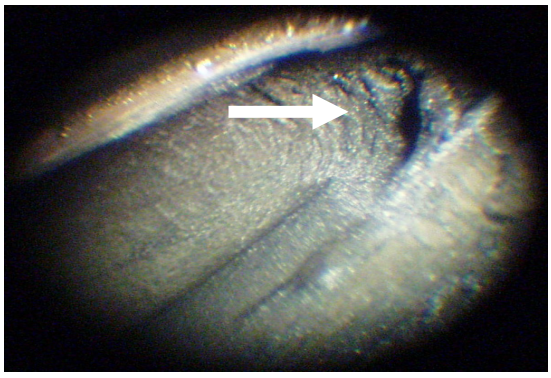
Fig. 7. Defects of marine diesel engines' turbocompressors detected during endoscopic investigations

turbocompressor's rotor unit of a medium- or high- speed marine diesel engine achieve tens thousand of rev/min, it is quite clear that the cracks of the compressor's constructional material not detected in time may cause the extensive secondary damages of cylindrical systems, excluding the possibility of the repair execution in shipping conditions.

It is worth pointing out that there is another, very important aspect resulting from the endoscopic examinations of turbocharging systems. Namely, in exhaust channels thermocouples for temperature measurements of exhaust leaving individual cylinders. The measurement likelihood (authenticity) of such parameters decides about the correctness of exploational decisions undertaken during an engine operation. Whether it is possible to confirm an authenticity of the exhaust temperature's measurement worked out by means of the thermocouple in such a technical state as shown in fig. 7c - or not?

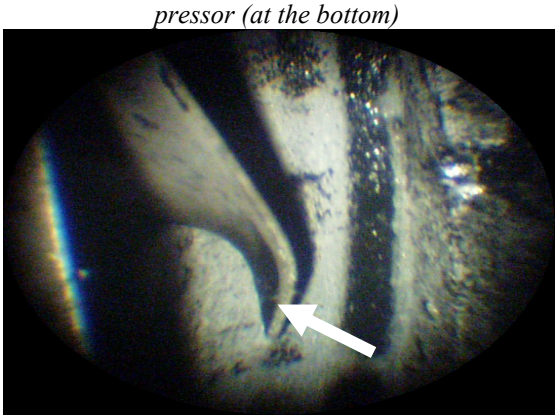


a) Zvezda M503A type 4-stroke engine – metallic fragment imprisoned in an interblade channel of the turbine's guide vanes



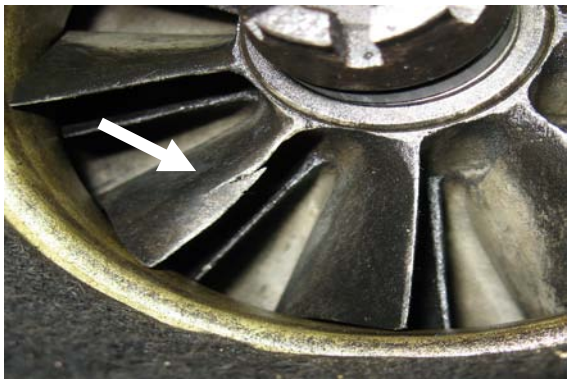
b) Zvezda M401A-1 type 4-stroke engine – an erosion pit in an interblade channel of the compressor (at the bottom)

c) Zvezda M401A-1 type 4-stroke engine – dirt deposits in interblade channels of the compressor

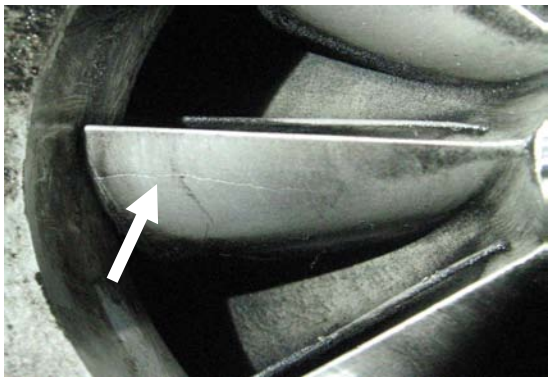


d) Detroit Diesel 16V149TI type 2-stroke engine – a curved rotor blade of the compressor on the edge

of attack



e) Zvezda M401A-2 type 4-stroke engine – an edge crack of the rotor blade of the compressor

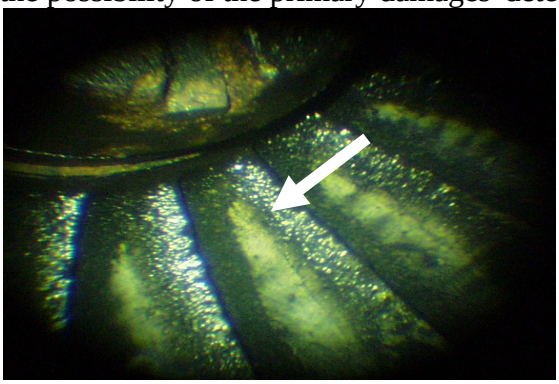


f) Detroit Diesel 16V149TI type 2-stroke engine – a crack of the compressor rotor blade

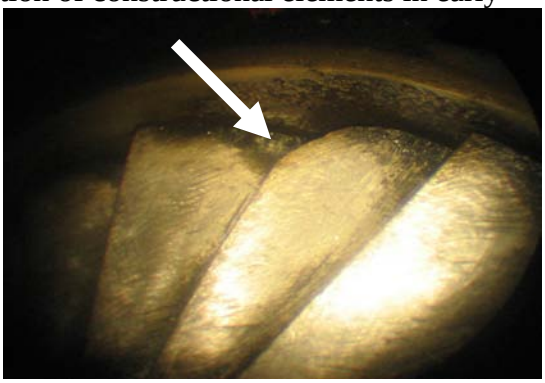
Fig. 8. Defects of marine diesel engines' turbocompressors detected during endoscopic investigations

5. Conclusion

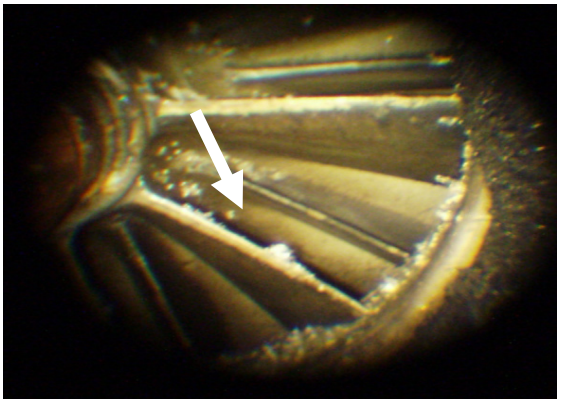
Endoscopic reviews have been led systematically by the author, on the population of 50 marine engines covered with a diagnostic supervision. Gathered results show that numerous material defects was identified in due time, what means that in case of their father development the engine's reliability would be significantly threatened. In many cases the engines did not generate the observed symptoms of the failures' existence, for example the engine's running with mechanical damages of blading within turbocompressor's rotor (fig. 8 and fig. 9). In author's opinion such circumstances unlock the new investigative perspectives, because the usage of endoscopic methods gives the possibility of the primary damages' detection of constructional elements in early

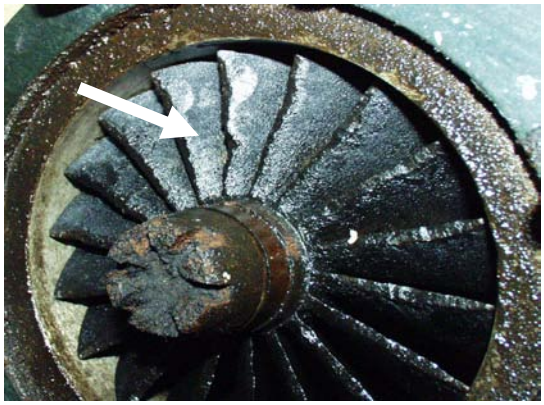


a) Zvezda M401A-1 type 4-stroke engine – oilling up of surfaces of rotor blades of the compressor

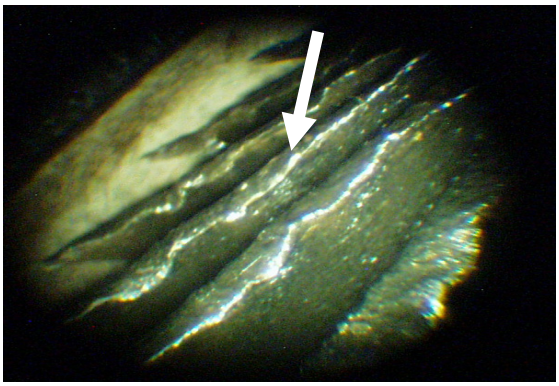


b) Zvezda M401A-1 type 4-stroke engine – curvature of the failured edge of attack of the channel's profile on the external diameter of the compressor's rotor

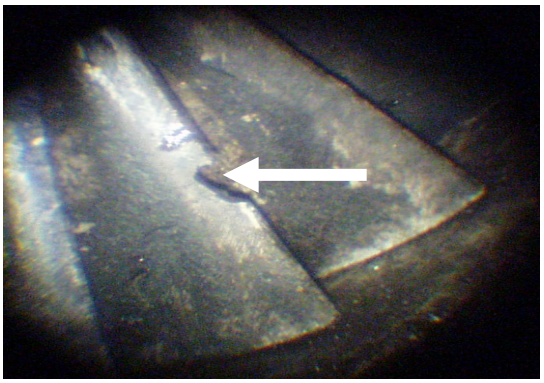




c) Zvezda M401A-2 type 4-stroke engine - dirt deposits in interblade channels of the compressor



d) Zvezda M401A-1 type 4-stroke engine – deformations and mechanical failures of the compressor's rotor



e) Zvezda M401A-1 type 4-stroke engine – deformated profiles of the compressor rotor's blades

f) Zvezda M401A-2 type 4-stroke engine – material decrement on the edge of attack of the compressor rotor's blade

Fig. 9. Defects of marine diesel engines' turbocompressors detected during endoscopic investigations

stages of their development, while measured diagnostic parameters of diagnosing systems are not sufficiently sensitive to the changes in surface layers limiting the engine's working spaces.

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