MARINE AUXILIARY DIESEL ENGINE TURBOCHARGER DAMAGE (EXPLOSION) CAUSE ANALYSIS

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Abstract

In the paper causes of a container ship auxiliary engine turbocharger self damage during its service at sea have been analyzed. The damaged turbocharger working elements have been presented. The direct reason of the turbocharger damage was its explosion. The damage cause analysis takes into consideration the possibility of stimuli accumulation leading to the damage as well as damage causes overlapping and the influence of quality of fuel feeding the auxiliary engine. Eventually the turbocharger damage has been attributed to fuel quality. Probability of fuel seeping into exhaust manifold and scavenge air receiver due to injector needle suspension as well as ignition and combustible properties of fuel feeding the auxiliary engine have been focused on. Injector testing results achieved on trial stand and fuel quality analysis carried out by means of FIA-100/3 analyzer have been presented.

Keywords*: marine engine turbocharger, fuel oil quality, combustion properties, stress accumulation, damage*

1. Introduction

A turbocharger damage cause of a container vessel combustible auxiliary engine during the regular engine room service at sea has become the subject of the following analysis. Before the damage occurred growing whistle denoting the turbocharger revolutionary speed increase significantly exceeding the range of normal revolutionary speeds achieved during its service (28 000-34 000 rpm), which was followed by explosion. The turbocharger suffered total destruction which made the auxiliary engine further exploitation impossible .There were no casualties among the crew members. The engine was stopped and the place protected against possible fire.

In Fig.1. basic turbocharger working components after the explosion have been presented (rest of the compressor rotor, turbine rotor and the broken shaft) by means of marking their location in the broken turbocharger. The turbocharger shaft got divided into two parts as a result of twisting. Its crack occurred near the labyrinthine sealing on the exhaust gas side.

In Fig. 2. main components condition seen from the turbine side and the compressor side have been presented (A - closing cover of exhaust gas side, B - parts of the turbine rotor wheel, C - the gas inlet casing with rest of the nozzle ring of turbine side, D - parts of the compressor casing, parts of the compressor wheel, F - the nozzle ring of compressor side).

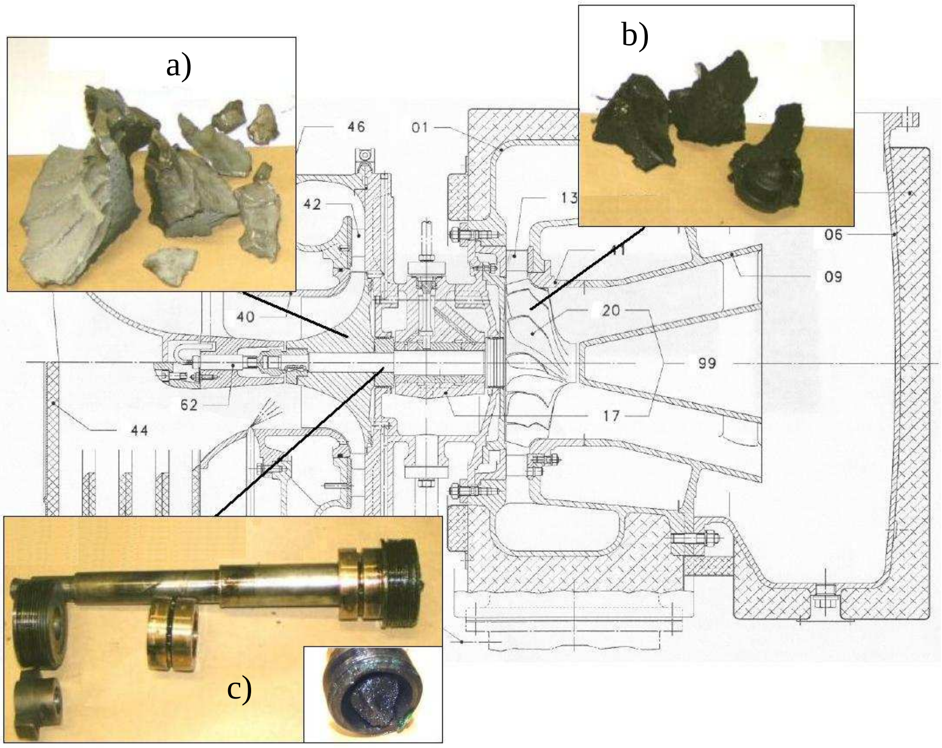

Fig. 1.Rest of the turbocharger working elements after the failure: a) – compressor rotor, b) – turbine rotor, c) – propeller shaft, bearings, and labyrinth sealing

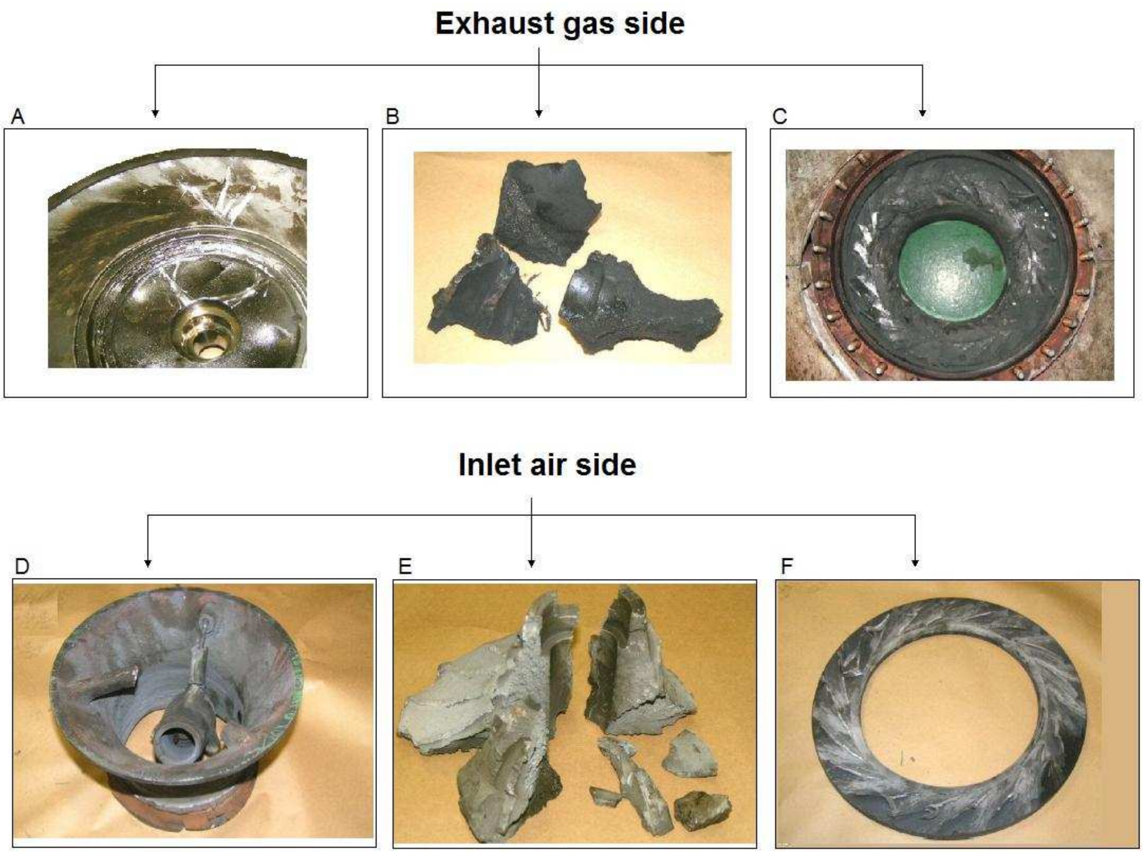

Fig. 2.Damage of working components on both sides of the turbocharger

The components inspection pointed out fuel accumulation in the outlet installation. The turbine casing was covered with a significant amount of carbon deposit and asphalt (Fig. 3.).

Fig. 3. Carbon deposits / asphalts taken from the exhaust gas outlet casing

When analyzing the turbocharger failure causes two cases were taken into consideration:

- -possibility of stimuli accumulation resulting in the damage [5, 6, 7, 18, 21] as well as damage
  causes overlapping [9, 10, 12, 13, 16, 17];
- -influence of the quality of fuel feeding the auxiliary engine.

2.Fuel oil quality and the damaged components of the engine

Physical-chemical fuel oil properties certainly influence correct and failure free working of combustible engines [19, 20, 22]. Fuel oil composition may influence faster wear of fuel injection systems precise pairs as well as forming of sediment and carbon deposits on the components of load exchange system and the engine combustible spaces. Most important characteristics of fuel oils and its effects for diesel engine components are given in Tab. 1.

Combustion quality is an essential indicator for engine fuel oils, however, so far there is no common, standard method of combustion evaluation. One of the calculated indexes defining the property may be *Calculated Carbon Aromaticity Index* (*CCAI*). In the case analyzed above value of *CCAI* was high. It is generally assumed that if *CCAI* value does not exceed 860 during regular service the fuel possesses acceptable combustible quality, there may occur problems with right engine exploitation for fuel oils of *CCAI* between 860-880, exploitation problems including engine damage within a short time shall be caused by fuel oils of *CCAI* beyond 880. Apart from *CCAI* sometimes *Calculated Ignition Index* (*CII*) is used. *CII* gives values for residual fuels in the same order as the cetane index for distillate fuels. However, it should be pointed out that *CCAI* as well as *CII* as indicators are calculated on the basis of fuel viscosity and density according to formulas:

$$CCAI = \cdot \rho_{15} - 141 \cdot \log\log(\nu_{50} + 0{,}85) - 81, \quad (1)$$

$$CII = (270{,}795 + 0{,}1038 \cdot T_r) - 254{,}565 \cdot \rho_{15} + 23{,}708 \cdot \log\log(\nu + 0{,}7), \quad (2)$$

where:

ρ_{15} – density at 15ºC [kg/m^3]
υ_{50} – viscosity at 50 ºC [cSt]
υ – viscosity at temperature T_r [cSt]

Tab. 1. Characteristics of engine fuel oils influencing engine work and fuel systems

Quality criteria	Fuel oil characteristics	Main effects
Combustion quality	Conradson Carbon Asphalteness	Ignition ability. Combustion condition. Fouling of gas ways.
Impurity content	Sulphur	Corrosive wear.
	Vanadium Sodium	Formation of deposits on exhaust valves and turbochargers. High temperature corrosion.
	Water	Disturbance of combustion process. Increased heat load of combustion chamber components. Fouling of gas ways. Mechanical wear and cavitation of fuel injection system components.
	Ash Catalyst fines	Mechanical and corrosive wear of combustion chamber components. Formation of deposits. Mechanical wear of fuel injection system, cylinder lines and piston rings.
Handling properties	Viscosity Density Pour point	Temperatures, pressures and capacities of fuel oil systems for storage, pumping and pre-treatment.
	Flash point	Safety requirements.

These measures may be applied only for initial fuel combustible quality evaluation because the indexes do not take into account the influence of fuel chemical composition on the combustion process. In the case above *CCAI* was 850 which means that it ranged within the recommended limits. Combustion process may be defined with the use of combustion analyzers. *DNV Petrolium Services* offers combustion quality tests carried out with the use of *FIA-100/3* analyzer [11]. *FIA – 100/3* establishes the ignition quality of diesel engine fuel oils based on an ignition delay measured on an actually measured ignition delay. A fuel oil sample that is injected into the combustion chamber of *FIA-100/3*, self ignites and burns as in real engine. Start of Main Combustion process is used in order to establish the ignition quality of a fuel oil tested as a *FIA CN* (Cetane Number). For heavy fuel oils the ignition properties are typically ranging from *CN*=18.7 to above *CN*=40. Fuel ignition quality depends on *FIA CN* for different fuel oils is given in Tab. 2.

Tab. 2. Ignition quality of the fuel oil tested as a FIA Cetane Number (FIA CN)
(Depends on engine type, engine condition and load) [11]

FIA Cetane Number	Heavy Fuel Oil	Marine Diesel Oil
< 20 to 25	Very bad ignition properties	Unfit for use
25 ≤ FIA CN <28	Bad ignition properties	Very bad ignition properties
28 ≤ FIA CN <35	Acceptable ignition properties	Bad ignition properties
35 ≤ FIA CN <40	Good ignition properties	Acceptable ignition properties
40 ≤ FIA CN <45	Very good ignition properties	Good ignition properties
FIA CN ≥ 45	Very good ignition properties	Very good ignition properties

The basis for *FIA CN* is a reference curve for the instrument in question, showing the ignition properties for mixtures between the reference fuels *U15* and *T22* from *Phillips Petroleum International*. On the basis of these data the mean value for ignition delay, start of main combustion, pressure trace, *FIA CN* and *Rate of Heat Release* (*ROHR*) are established

After the turbocharger had broken down fuel combustible properties were tested by *DNV Petroleum Services*. For the case in question the fuel analysis results obtained with the use of *FIA–100/3* analyzer have been presented in Fig.4.

6.1 Analysis Results

Tests		Results	Method
Density @15 °C	kg/m^3	986.4	ISO 12185
Viscosity @50 °C	mm^2/s	285	ISO 3104
CCAI		850	

6.2 Fuel Ignition & Combustion Results

6.2.1 Ignition Delay	9.95	ms (dp = 0.2 bar above initial chamber pressure
6.2.2 Start of main combustion	14.8	ms (dp =3.0 bar above initial chamber pressure
6.2.3 Max. ROHR position	15.0	ms (Position relative to start of injection)
6.2.4 Max. ROHR level	1.4	Bar /ms(Max. rate of combustion pressure increase)
6.2.5 Combustion Period	15.1	ms(ROHR positive area)
6.2.6 FIA Cetane Number	<<18.7	

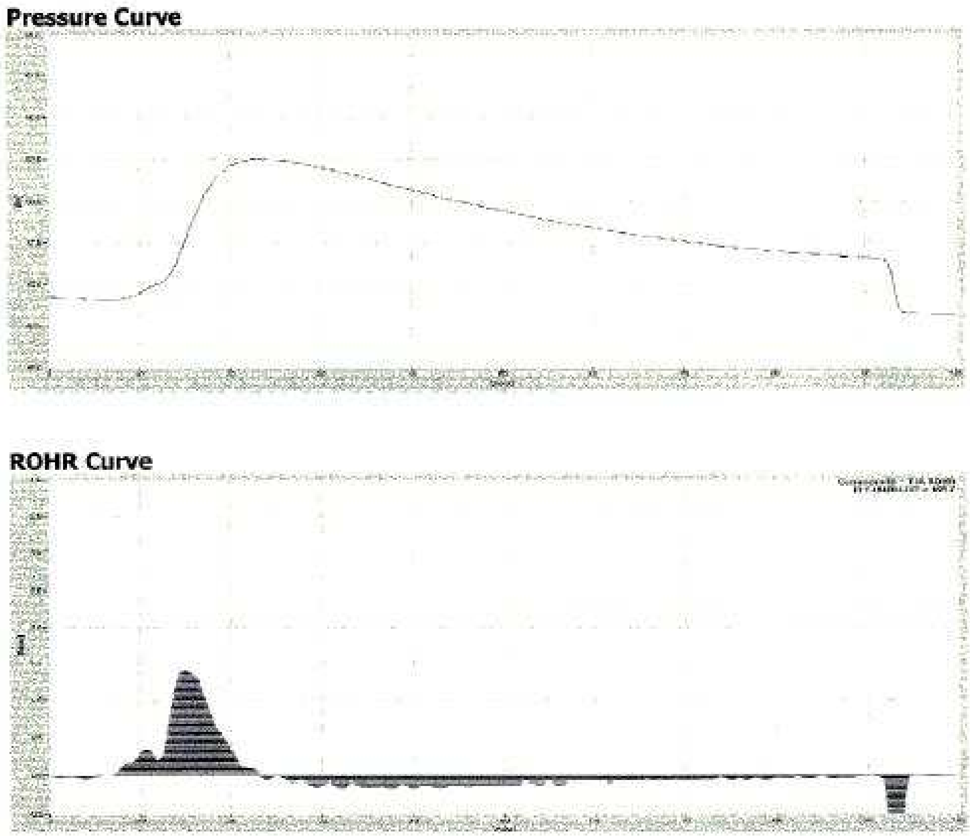

Fig. 4. Combustion tests results carried out by FIA

Value of the *CCAI* being 850, the *Fuel Ignition Analyzer test* results indicate a fuel with very bad ignition quality, *FIA CN*<<18.7. Combustion properties of this fuel are very poor, being below the values of an average intermediate fuel oil. Fuel oils with poor combustion and ignition properties are likely to contribute to high pressure peaks and thermal overload of combustion chamber.

3.Consolidation

The analysis of the described turbocharger damage points out that the main cause of its explosion was leak and not burnt fuel oil accumulated in exhaust manifold and/or scavenge air receiver. The fuel may have leaked into the mentioned spaces due to injection needle suspension, which may have been caused by the adverse effect of sodium contained in the fuel. Then the fuel ignition took place which caused blow-by of vast amount of exhaust gases into the turbine and eventually led to its damage. This cause, however, seems to be unlikely and it has not been explicitly confirmed.

Another cause may have been poor ignition properties and poor combustion quality of the applied fuel. Generally fuel with high *CCAI* ignites very late after injecting it into the combustion chamber and in extreme cases self ignition may not take place at all. Then the not burnt fuel leaks into the charging air spaces and exhaust manifold, and after some time it burns leaving a thick layer of coke. The coke as well as the fuel may cause jamming of valve stems in guides which helps fuel to enter the described spaces.

After testing the injectors of the engine in question performed on the trial stand the first cause was eliminated. Exhaust valves were jammed on two cylinder systems of the engine in question and left in open position during the whole cycle of the engine work. This fact confirms the latter mentioned causes. Presumably the series of events leading to serious damage [1,2,3,4] of auxiliary engine components most probably took place due to very poor combustible property of fuel which was later confirmed by combustion quality tests.

In the discussed above case an engine room fire did not take place, which often happens in such situations (e.g. 13.09.1999 on a Singapore container vessel *X-Press Jaya* the fire broke out as a result of main engine turbocharger explosion [15].

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