MARINE DIESEL ENGINE DIAGNOSTICS IN OPERATING CONDITIONS

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Summary

Most of marine diesel engines are turbocharged. Conventional maintenance methods for engine turbochargers depend on bearings clearances checks between rotor shaft and bearing housing. Some parts of the turbocharger have to be checked on the special stands or by using endoscopic methods. Fuel oil not burnt to the end and severe engine working conditions (long time idling) led to several typical turbocharger malfunctions and damages of it in some cases. Always it is easier to prevent malfunctions than take repair works on any assets. In the paper results of main and auxiliary ship's diesel engines turbochargers diagnostic investigations are presented. Methods presented in the paper based on vibration signals processing in time and frequency domain. Using these methods for checking technical condition of the turbochargers and its rotors and bearings without stopping the engine and dismantling it is possible.

Key words: marine diesel engine, diagnostics, turbocharger.

DIAGNOSTYKA OKRĘTOWYCH SILNIKÓW TŁOKOWYCH W WARUNKACH EKSPLOATACJI

Streszczenie

Większość silników okrętowych jest budowana, jako silniki doładowane turbosprężarką. Konwencjonalne metody diagnozowania turbosprężarek polegają na sprawdzaniu luzów łożyskowych pomiędzy wałem a tulejami łożysk. Niektóre części turbosprężarki muszą być sprawdzane na specjalnych stanowiska lub z wykorzystaniem metod endoskopowych. Niespalone do końca paliwo i ciężkie warunki pracy silnika (długotrwała praca na biegu luzem) prowadzą do występowania kilku typowych niesprawności a w niektórych okolicznościach uszkodzeń turbosprężarek. Zawsze jest łatwiej zapobiegać uszkodzeniom niż dokonywać napraw urządzeń. W artykule przedstawiono wyniki badań diagnostycznych turbosprężarek silników głównych i pomocniczych na okręcie. Metody prezentowane w referacie bazują na przetwarzaniu sygnałów drganiowych w dziedzinie czasu i częstotliwości. Stosowanie tych metod umożliwia ocenę stanu technicznego turbosprężarek wraz z ich wirnikami i łożyskami bez ich demontażu i zatrzymywania silnika.

Słowa kluczowe: silnik okrętowy wysokoprężny, diagnostyka, turbosprężarka.

INTRODUCTION

For many years technical condition assessment of ship diesel engines and its turbocharger has been done by engine compartment crew. At present, ship-owners most frequent outsources it in specialized companies. It is due to lack of proper qualification among crewmembers, sometimes due to ship-owner strategy focused on ship maintenance costs cutting [1, 2]. In some newest types of engines and turbochargers it is impossible to repair them on board the ship as it was in the past. In this paper complex engine and turbocharger diagnostic method which is used in Polish Navy is presented. The method based on wide range of different type diagnostic technics which are not always common especially in turbochargers diagnosing.

Since the technical condition of the turbocharger is strictly dependent on the engine condition, one should first make sure of the correct operation of engine as whole system and each engine cylinder systems separately. The best diagnostic method in this field is combustion processes evaluation under inside-cylinder pressure waveforms [4]. Turbocharger rotor and bearing system technical condition assessment based on vibration signal parameters analysis and finally verified by turbocharger flow channels endoscopic examination. The paper presents the chosen technical diagnostic results of two turbochargers type *PDH-35* installed on main propulsion engines and two turbochargers type *C–045/C* installed on auxiliary engines onboard navy vessel during sea trials.

1. THE OBJECTS AND METHODS OF RESEARCH

The tests involved the PBS Turbo type PDH-35 turbochargers installed on SULZER 8AL25/30 type main engines and NAPIER C-045/C type turbochargers installed on SULZER auxiliary engines type 6AL20/24. Engines basic technical data are shown in Table No. 1. The test apparatus used in the study consisted of an engine analyzer built in Polish Naval Academy. Turbochargers vibration parameters were acquired using SVAN 946A vibration analyzer. Endoscopic examinations of turbochargers were made by using a set of OLYMPUS fiberscopes and bore scopes.

Table 1. Basic data of SULZER diesel engines type 8AL25/30 and type 6AL20/24

Engine type	SULZER 8AL25/30	SULZER 6AL20/24
Turbocharger license/type	PBS turbo/ PDH-35 type	Napier / C–045/C type
No. of cylinders / Configuration	i=8 / „ L”	i=6 / „ L”
Cylinder nominal output at 750 rpm	Pcn= 140 kW	Pcn= 70 kW
Cylinder bore	D= 250 mm	D= 200 mm
Piston stroke	S= 300 mm	S= 240 mm
Compression ratio	ε= 12,7	ε= 12,7
Total displacement volume	Vss= 117,7 dm^3	Vss= 45,2 dm^3
Mean piston speed	cśr= 6 m/s	cśr= 6 m/s
Effective specific fuel consumption	ge= 212 g/kWh	ge= 212 g/kWh
Number of valves per cylinder	z= 4	z= 4
Fuel injection pressure	pw= 24,5 MPa	pw= 24,5 MPa

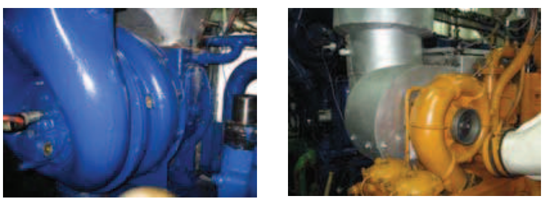

Fig. 1. PBS Turbo PDH-35 type axial-flow turbocharger on SULZER main engine type 8AL25/30 (left) and NAPIER C-045/C radial-flow turbocharger on SULZER auxiliary engine type 6AL20/24 (right)

Both tested engines types were high-speed marine diesel engine in line form, 4-stroke turbocharged with direct fuel injection. Fresh water in closed circuits is used in engines cooling systems, lubricating oil coolers and air coolers. PDH-35 type turbochargers are water-cooled units and C-045/C type turbochargers are air-cooled units.

2. THE TESTS RESULTS

In order to assess the technical condition of turbochargers on the basis of engine performance parameters the engines were introduced in a specific state of the load which were involved by vessel and weather external conditions. Close to the rated load the turbocharger rotor speeds, charging pressures, charge air temperatures and other parameters were read-out and recorded. The values obtained were compared with the values of parameters set from engines acceptance tests. To determine the engines load indicated power was measured using electronic engine analyzer which measuring capabilities are presented in paper [4]. Selected indicator diagrams recorded during the tests are shown in figure number 2.

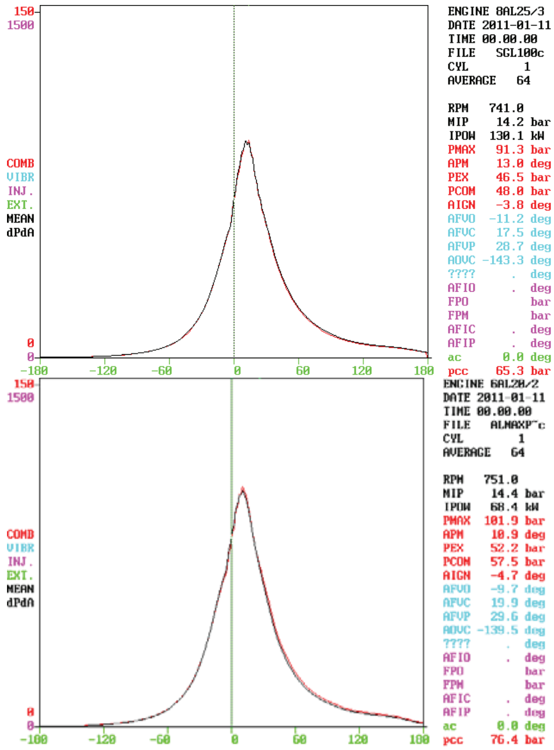

Fig. 2. Chosen engine cylinder pressure diagrams with other parameters for close to rated power load – main engine 8AL25/30 type (up), - auxiliary engine 6AL20/24 type (down)

2.1. Results of vibration signals investigations – the SULZER type 8AL25/30 main diesel engines with the PBS Turbo PDH-35 type turbocharger

Measurements were made for both main engines and with engines load and turbochargers speed ranges dependent on vessel operation mode.

Engines crankshaft speed has changed from 400 rpm to 750 rpm and engines load from idling (engine load index = 1,2) to engine load index = 6,3/6,8. Turbochargers speed varies from about 3300 rpm to about 19600 rpm (Tables No. 2 and No. 3).

Table 2. Values of chosen vibration parameters – Main Engine – port side

Date	11.01.2011	Main Engine LB			
Ambient temperature	18 °C				
Atmospheric pressure	1009 hPa				
Engine speed	[rpm]	400	550	750	750
Engine load index	%	1.2	1.5	4.8	6.3
Basic frequency	[Hz]	63	91	236	315
Turbocharger speed	[rpm]	3780	5460	14160	18900
Vibration acceleration [I harmonic] compressor side	a [m/s²]	0.10	0.10	1.22	6.53
	a [g]	0.01	0.01	0.12	0.67
Vibration acceleration [I harmonic] turbine side	a [m/s²]	0.11	0.12	1.33	6.38
	a [g]	0.01	0.01	0.14	0.65
Vibration acceleration [RMS]	a [m/s²]	4.5	12.3	27.9	34.7
	a [g]	0.46	1.25	2.84	3.54

Table 3. Values of chosen vibration parameters – Main Engine – starboard side

Date	11.01.2011	Main Engine PB			
Ambient temperature	18 °C				
Atmospheric pressure	1009 hPa				
Engine speed	[rpm]	400	550	750	750
Engine load index	%	1.7	1.9	5.2	6.8
Basic frequency	[Hz]	56	92	273	327
Turbocharger speed	[rpm]	3360	5520	16380	19620
Vibration acceleration [I harmonic] compressor side	a [m/s²]	0.32	0.20	0.24	2.69
	a [g]	0.03	0.02	0.02	0.27
Vibration acceleration [I harmonic] turbine side	a [m/s²]	0.10	0.16	0.49	6.17
	a [g]	0.01	0.02	0.05	0.63
Vibration acceleration [RMS]	a [m/s²]	3.4	10.0	24.8	24.3
	a [g]	0.34	1.02	2.53	2.48

Vibration parameters were measured on both compressor and turbine sides of turbochargers. According to technical specifications of turbocharger manufacturers values of the vibration level on bearing casing are the one of the most important diagnostic parameters. Values of vibration acceleration of I-th harmonic on both sides of tested turbochargers are lower than 10 m/s^2 which mean that turbochargers rotors and bearing systems are in good technical conditions.

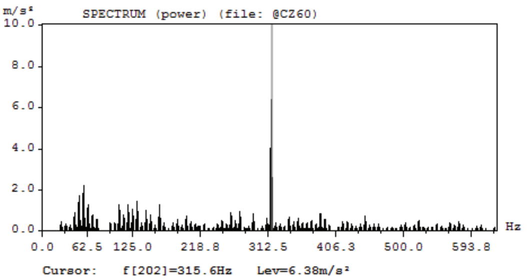

Fig. 3. Turbocharger amplitude of vibrations accelerations in frequency domain Main Engine – port side

Power spectra (fig. No 3 and fig. No 4) for both turbochargers shows the maximum values of the vibration signals (between 6,0 and 8,0 m/s^2) for the basic frequency 315 Hz and 326 Hz respectively.

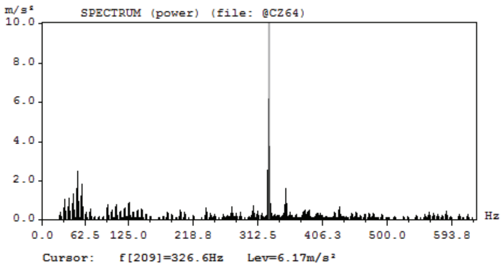

Fig. 4. Turbocharger amplitude of vibrations accelerations in frequency domain Main Engine – starboard side

Technical conditions of turbochargers were verified by endoscopic examinations which results are shown in the fig. No. 5 and No. 6.

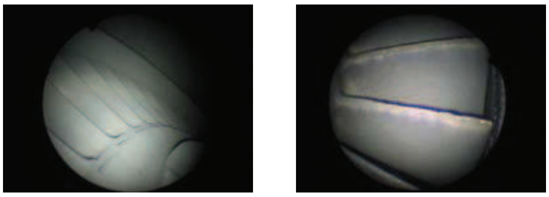

Fig. 5. Turbine (left) and compressor (right) wheels - Main Engine – port side

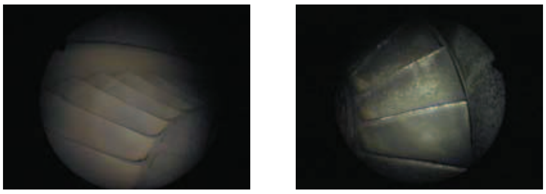

Fig. 6. Turbine (left) and compressor (right) wheels - Main Engine – starboard side

2.2. Results of vibration signals investigations – the SULZER type 6AL20/24 auxiliary diesel engines with the napier C–045/C type turbocharger

Measurements were made for both auxiliary engines and with engines load and turbochargers speed ranges dependent on vessel electric installation mode. In the paper chosen parameters mainly for engine load closed to rated load are presented.

Table 4. Values of chosen vibration parameters – Auxiliary Engine – Diesel Generator No. 1

Date	11.01.2011	Diesel Generator No 1		
Ambient temperature	18 °C			
Atmospheric pressure	1009 hPa			
Engine speed	[rpm]	400	750	750
Engine load index	%	2.7	4.3	6.0
Basic frequency	[Hz]	173	358	536
Turbocharger speed	[rpm]	10380	21480	32160
Vibration acceleration [I harmonic]	a [m/s²]	0.13	0.67	0.76
	a [g]	0.01	0.07	0.08
Vibration acceleration [RMS]	a [m/s²]	2.0	21.9	20.9
	a [g]	0.21	2.23	2.13

Vibration parameters were measured in one point on turbocharger bearing casing between compressor and turbine casing. Values of vibration acceleration of I-th harmonic on both tested turbochargers are lower than 10 m/s^2 which mean that turbochargers rotors and bearing systems are in good technical conditions.

Table 5. Values of chosen vibration parameters – Auxiliary Engine – Diesel Generator No. 2

Date	11.01.2011	Diesel Generator No 2		
Ambient temperature	18 °C			
Atmospheric pressure	1009 hPa			
Engine speed	[rpm]	400	750	750
Engine load index	%	2.8	4.6	6.3
Basic frequency	[Hz]	169	365	565
Turbocharger speed	[rpm]	10140	21900	33900
Vibration acceleration [I harmonic]	a [m/s^2]	0.16	0.72	2.43
	a [g]	0.02	0.07	0.25
Vibration acceleration [RMS]	a [m/s^2]	2.7	20.2	31.6
	a [g]	0.28	2.06	3.22

Power spectra (fig. No. 7 and fig. No. 8) for both turbochargers shows the local maximum values of the vibration signals - less than 1,0 m/s ^{2} for DG No1 at the basic frequency 536 Hz and about 2,5 m/s^2 for DG No 2 at the basic frequency 565 Hz respectively.

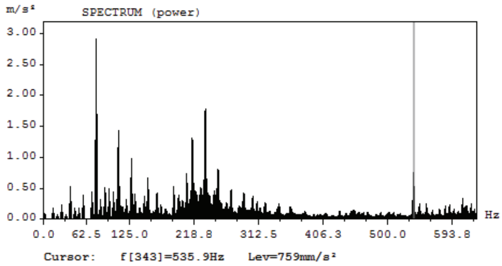

Fig. 7. Turbocharger amplitude of vibrations accelerations in frequency domain Diesel Generator No. 1

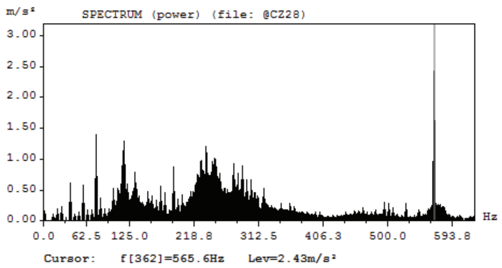

Fig. 8. Turbocharger amplitude of vibrations accelerations in frequency domain Diesel Generator No. 2

Technical conditions of turbochargers were verified by endoscopic examinations which results are shown in the fig. No. 9 and No. 10.

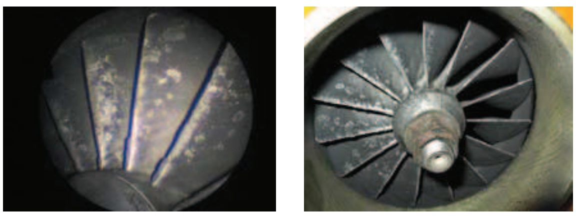

Fig. 9. Turbine (left) and compressor (right) wheels - Diesel Generator No. 1

Fig. 10. Turbine (left) and compressor (right) wheels - Diesel Generator No. 2

3. SUMMARY

Diesel engines technical condition assessment is a very complex process. Some of the malfunctions and troubleshooting in diesel engine installations are generated by turbochargers. There are some diagnostic tools available to trace changes in technical condition such important assets as marine diesel engines turbochargers are. In fig. No. 11 some chosen results obtained during sea trials are presented. As it is seen tested turbochargers are in relatively good technical condition and values of I-th harmonic vibration acceleration amplitudes are much lower than acceptable in service.

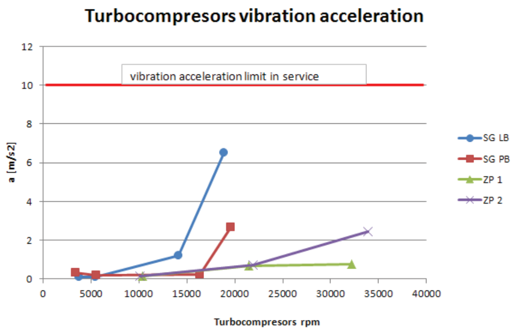

Fig. 11. I-th harmonic vibrations acceleration amplitude measured on turbochargers bearing casing versus turbocharger rpm
SG LB (blue line) – main engine port side,
SG PB (red line) main engine starboard,
ZP 1 (green line) - Diesel Generator No. 1,
ZP 2 (violet line) - Diesel Generator No. 2

Vibration signals processing methods seems to be effective in marine diesel engines turbocharger diagnostics [3] and could be used in onboard monitoring or diagnostic systems. Presented vibration methods gives opportunity to change the engine maintenance philosophy connected with turbochargers maintenance process. It is possible using on-line or off-line vibration monitoring systems to go from scheduled to condition based turbochargers maintenance without fear about real operating engine conditions.

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