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DIAGNOSTIC INVESTIGATIONS OF DIESEL ENGINE TURBOCHARGERS AT LABORATORY STANDS

DYZELINIŲ VARIKLIŲ TURBOKOMPRESORIŲ DIAGNOSTINIAI TYRIMAI LABORATORINIAIS STENDAIS

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Turbochargers caused significant number of marine diesel engines malfunctions especially when engine is fueled by heavy fuel oil. Vibro-acoustic diagnostic methods which could be used on marine diesel engines with turbochargers are presented in the paper. Vibration signals generated by turbochargers need different signal processing methods to be effective and faultless in turbochargers diagnostics. Diagnostic methods which based on vibration signals analysis are sensitive on engine load and speed changes. Some results of turbocharger tests which were carried out in the Polish Naval Academy Technical Institute of Ship Maintenance laboratory are presented in the paper with special attention given to the practical aspects in processing the vibration signal and diagnostic effectiveness.

Marine diesel engine, turbocharger, diagnostics, vibration, laboratory tests.

Introduction

Most of marine diesel engines are turbocharged. Turbochargers caused significant number of engine malfunctions especially when engine is fueled by heavy fuel oil. Heavy 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. Chosen examples of turbocharger malfunctions are shown on the figure 1.

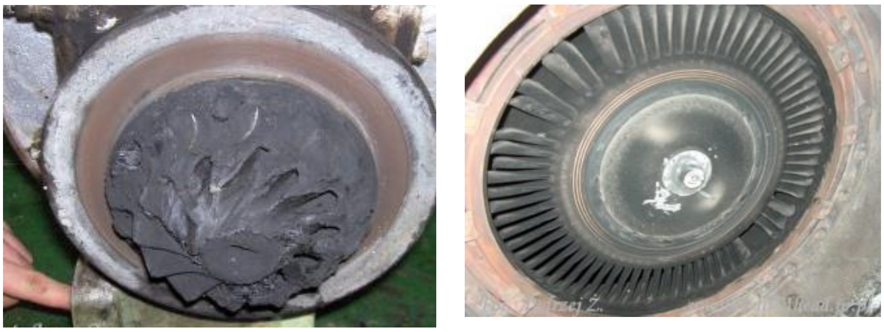

Fig. 1. Examples of radial-flow rotor turbine overgrown by carbon soot (left) and axial-flow rotor turbine without turbine blades (right) [www.full-ahead.net]

1 pav. Pavyzdys kaip užsiteršia anglies suodžiais radialinio srauto rotoriaus turbina (kairėje) ir ašinio srauto rotoriaus turbina be turbinos menčių (dešinėje) [www.full-ahead.net]

According to turbocharger's manuals, intake and exhaust turbocharger sides are cleaned in hours or days intervals during engine operation [3].

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.

Except conventional maintenance and diagnostic methods (for example turbocharger operational parameters assessment) to choose time to clean or repair turbocharger other methods could be used.

The most convenient and popular diagnostic method for turbochargers are methods connected with vibration signals amplitude analysis in time and frequency domain[4,5,7]. Results of about twenty tests carried out on engine stands in Polish Naval Academy laboratory using these methods [6] together with some practical remarks and suggestions are presented in this paper.

Subject of the research

The basic aim of investigations were attempt to achieve vibration characteristic of the delivered by manufacturer turbochargers and check them in real operation on engine stand before sending to the purchasers.

The objects of investigation were SULZER engine type 6AL20/24 with turbochargers installed in Polish Naval Academy laboratory [6] in Gdynia-Oksywie. The main data of the engine and turbocharger are presented in the table no 1. Measuring systems configuration and places where vibration sensors were installed are shown on figures number 2 and number 3.

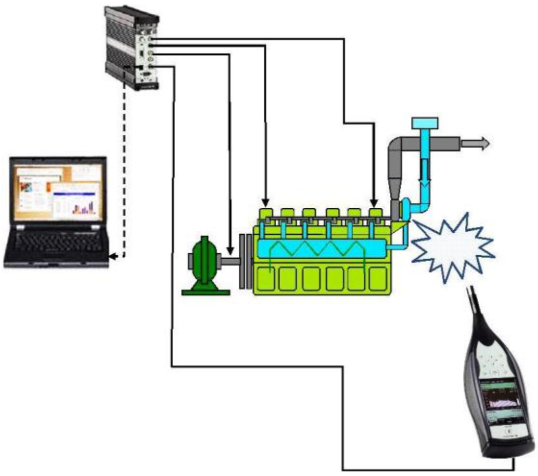

Fig. 2. Acoustic and vibration parameters measuring system configuration on stand of SULZER 6AL20/24type high-speed diesel engines
2 pav. Akustinių ir vibracinių parametrų matavimo sistemos konfigūracija stende SULZER 6AL20/24 tipo greitaeigiuose dyzeliniuose varikliuose

Fig. 3. Napier C–045/C type turbocharger with vibration sensor mounted on the bearing housing
3 pav. Napier C-045/C tipo turbokompresorius su ant guolio korpuso sumontuotu vibracijos jutikliu

Measuring system and vibro-acoustic apparatuses based on Brüel & Kjǽr PULSE system and 2250 analyzer [2]. The ½” B&K microphone type 4189 was used together with 3185D vibration sensor. Parallel to B&K measuring system SVAN 946A vibration analyzer was used as a second set of equipment to verify if such not very expensive system could be also used in every day diesel engine diagnostics.

Tab. 1. Basic data of the high-speed diesel engine type SULZER 6AL20/24
1 lentelė. Pagrindiniai SULZER 6AL20/24 tipo greitaeigio dyzelinio variklio duomenys

Engine type	SULZER 6AL20/24
Turbocharger type	Napier C–045/C
No. of cylinders / Configuration	*i=6 / „ L”*
Nominal output at 1500 rpm	$Pn= 420\ kW$
Cylinder bore	$D= 200\ mm$
Piston stroke	$S= 240\ mm$
Compression ratio	$\varepsilon= 12{,}7$
Total displacement volume	$Vss= 45{,}2\ dm^3$
Mean piston speed	*cśr= 6 m/s*
Firing order	1-4-2-6-3-5
Effective specific fuel consumption	$ge= 212\ g/kWh$
Number of valves per cylinder	$z= 4$
Fuel injection pressure	*pw*= 24,5 MPa

Vibrations signals measured on bearing housing of the turbocharger are disturbed by engine crankshaft and pistons operation but there are reliable methods in vibration signal processing to separate these disturbances. Measuring the vibration signals one should have awareness how important is method of vibration sensor mounting on the tested machine. To present these phenomenon in the fig. 4 the acoustic signal spectrum of the turbocharger and its environment and for the same turbocharger in the fig. 5 vibration signal spectrum in frequency range from 0 kHz to 4 kHz are presented. The vibration sensor was mounted on the turbocharger casing by magnetic holder which was the reason to cut-off higher signal frequencies over 1,5 kHz – fig.5. In examples presented in the next paragraph vibration sensors were mounted on the turbocharger casing using screw holder. Other method which could be used in ship environment without losses in signal spectrum is method with glue mounted holders.

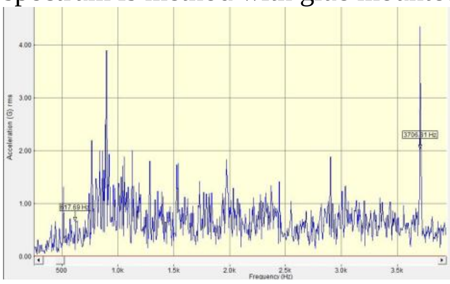

Fig. 4. Acoustic signal spectrum of the turbocharger in frequency range from 0 kHz to 4 kHz
4 pav. Turbokompresoriaus akustinio signalo spektras nuo 0 kHz iki 4 kHz dažnio diapazone

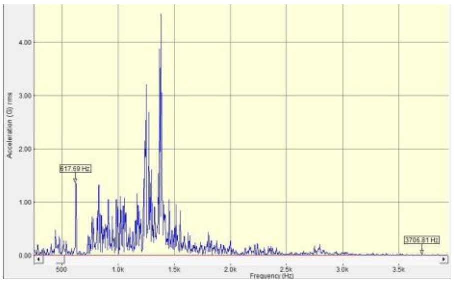

Fig. 5. Vibration signal spectrum of the turbocharger in frequency range from 0 kHz to 4 kHz – magnetic sensor holder
5 pav. Turbokompresoriaus vibracinio signalo spektras nuo 0 kHz iki 4 kHz dažnio diapazone – magnetinio laikiklio apkaba

According to technical specifications of turbocharger manufacturers values of the vibration level on bearing casing are the one of the most important diagnostic parameters.

Results of vibration signals investigations – the SULZER type 6AL20/24 diesel engine with the Napier C–045/C turbochargers

Up to now more than twenty turbochargers type Napier C-045/C were tested on the same stand in Polish Naval Academy laboratory. If it was possible Sulzer engine type 6AL20/24 was loaded up to nominal output at nominal speed 750 rpm. In situations when technical conditions of tested turbochargers were very bad and carrying tests could endanger the engine and turbocharger operation tests were stopped and turbochargers send to workshop for repair. After repairs tests were carried out again. Vibration sensor was mounted on the turbocharger bearing housing using screw bolt as it seen in figure 3. Some chosen results from these tests are presented in this paragraph on figures from 6 to 12. In the figure no 6 tests results of three turbochargers is presented. At the axis of abscissae the turbocharger speed in rpm and at the axis of ordinates the value of vibration acceleration amplitude of first harmonic in [g] scale are presented.

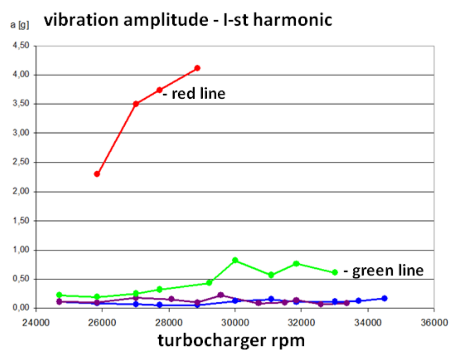

Fig. 6. Vibration acceleration amplitude of first harmonic for three turbochargers. Blue and violet line - turbochargers in good technical condition. Red and green lines – turbocharger in bad technical condition (red) and after repair (green)

6 pav. Pirmosios harmonikos vibracijos įsibėgėjimo amplitudė trims turbo-kompresoriams. Mėlyna ir violetinė linijos – turbokompresorius geros techninės būklės. Raudona ir žalia linijos – turbokompresorius blogos techninės būklės ir po remonto (žalia).

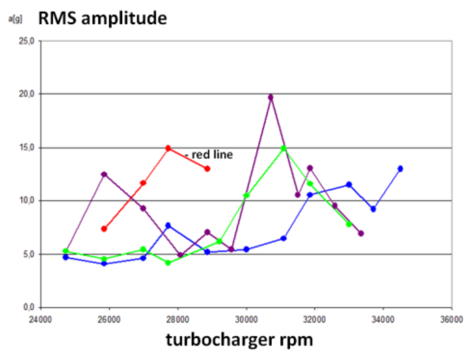

Fig. 7. RMS amplitudes for three turbochargers. Red line – turbocharger in bad technical condition. Blue, violet and green – turbochargers in good technical conditions

7 pav. Trijų turbokompresorių RMS amplitudės. Raudona linija - turbokompresorius blogos techninės būklės. Mėlyna, violetinė ir žalia linijos – turbokompresoriai labai geros techninės būklės

Vibration acceleration amplitudes of I harmonic of two turbochargers (blue and violet line) have such a value that is acceptable. Third turbocharger at first test had very high value of amplitude (red line) which enforced to stopped test and send the turbocharger to workshop to repair. After repair third turbocharger was tested again and this time results (green line) were in acceptable by manufacturer regulations zone. Very popular measuring indicator in vibro-acoustic measurements – RMS – (Figure 7) is not such effective and clear tool for diagnostics as I-st harmonic as it is seen in figure 7. In RMS mode values of vibrations amplitudes are very similar and not such recognizable as it is for I-st harmonic.

In some situations for example when there is probability that compressor or turbine rotor's blades are damaged higher groups of harmonics equivalent numbers of rotors blades could be better indicators. In the figure 8 the amplitude of 13-th harmonic vibrations (equivalent of turbine blades number) and in the figure 9 the 15-th harmonic (equivalent of compressor blades number) are presented. As it is seen for these the same three turbochargers – three in good technical conditions and one in bad technical condition – vibration method which using blades harmonic is not effective for technical condition assessment for malfunctions occurred in this case – unbalanced turbocharger rotor. For such malfunction the best tool for turbocharger test is the I-st harmonic measurement in whole turbocharger speed range or at list in whole engine output range.

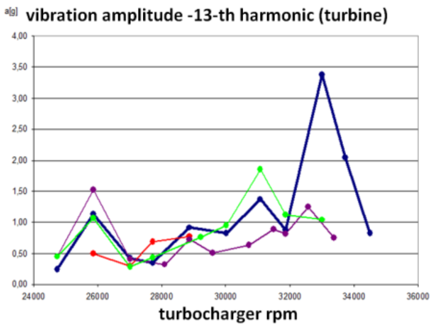

Fig. 8. Value of 13-th harmonic vibrations of accellerations equivalent of turbine blades number

8 pav. 13-tosios harmonikos vibracijų įsibėgėjimo reikšmė ekvivalentinė turbinos menčių skaičiui

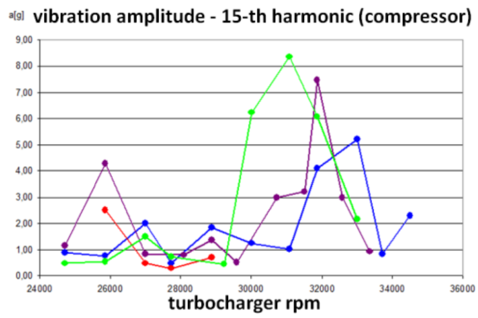

Fig. 9. Value of 15-th harmonic vibrations of accellerations equivalent of compressor blades number

9 pav. 15-tosios harmonikos vibracijų įsibėgėjimo reikšmė ekvivalentinė kompresoriaus menčių skaičiui

The FFT signal processing is very popular tool in rotary machines diagnostics. In the fig. 10 and in the fig. 11 vibrations signals transformed into frequency domain by using FFT technique are presented. In the fig. 10 the vibration signals in frequency domain for turbocharger in good technical conditions is presented. In the fig. 11 for this same turbocharger in bad technical conditions

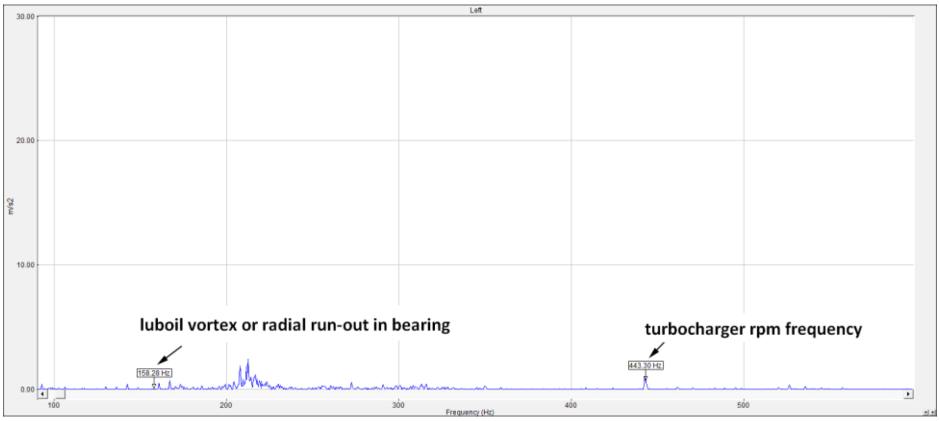

Fig. 10. Amplitude of vibrations accelerations in frequency domain for turbocharger in good technical conditions

10 pav. Vibracijų įsibėgėjimų amplitudė dažnių srityje esant gerai turbokompresoriaus techninei būklei

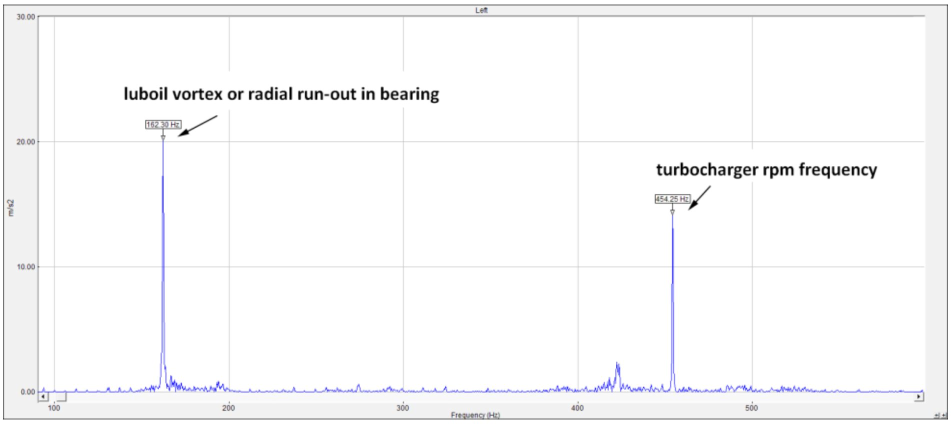

Fig. 11. Amplitude of vibrations accelerations in frequency domain for turbocharger in bad technical conditions

11 pav. Vibracijų įsibėgėjimų amplitudė dažnių srityje esant blogai turbokompresoriaus techninei būklei

values of vibration signal amplitudes are signifficantly higher (fig. 11 versus fig. 10) which was propably involved by lubricating oil vortex or/and radial run-out in bearings.

During the research done in PNA connected with turbochargers technical conditions assessment several turbochargers were tested. In the figure no 12 one of chosen results of these tests are presented. The I-st harmonic for twelve turbochargers tested on the same diesel engine stand varies from less than 0,50 [g] to more than 2,5 [g] in one cases. Only turbochargers with this parameter value below 1[g] were accepted by classification societies to use on ships and stationary power plants. Much more reliable in operation are off course these turbochargers which are in lower region of acceptable vibrations amplitude zone.

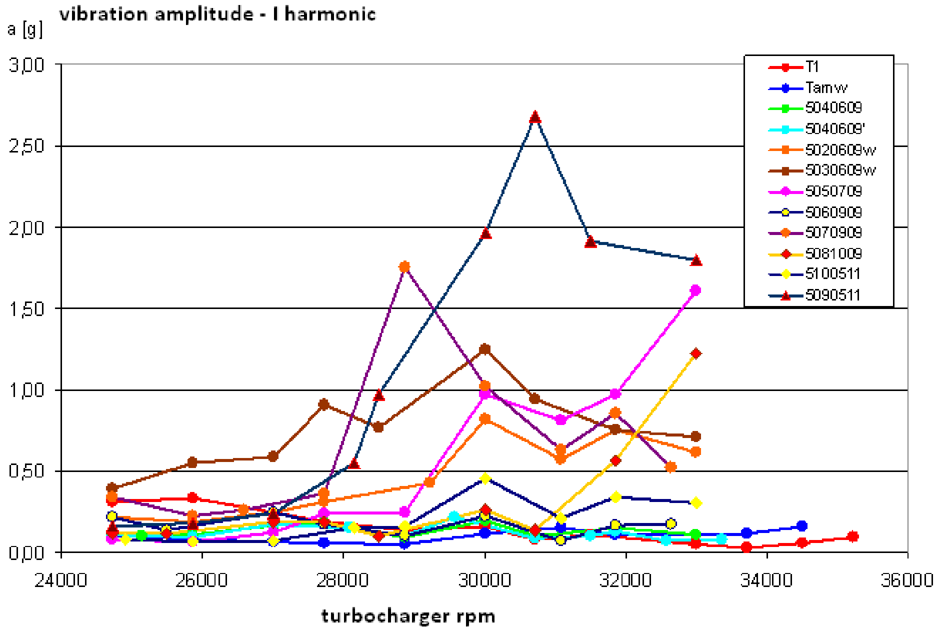

Fig. 12. Vibrations acceleration amplitude – I harmonic measured on turbocharger bearing casing versus turbocharger rpm – twelve turbochargers in different technical conditions tested on the same marine diesel engine stand

12 pav. Vibracijų įsibėgėjimų amplitudė – I amplitudės, išmatuota ant turbokompresoriaus guolio korpuso, kitimas priklausomai nuo turbokompresoriaus sukimosi dažnio – dvylika skirtingos techninės būklės turbokompresorių, išbandytų ant to paties laivų dyzelinio variklio stendo

Conclusions

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 tools available in signal analysis which gives opportunity to trace changes in signal patterns in real time online monitoring systems. Presented in the paper vibration methods are reliable enough to asses technical condition of the turbocharger in operation and give opportunity to change the whole engine maintenance philosophy connected with turbochargers maintenance process. Values of vibration acceleration amplitudes of I-st harmonic are especially valuable to asses malfunctions connected with turbochargers rotors unbalance. It is possible using on-line vibration monitoring systems to go from scheduled to condition based [1] turbochargers maintenance without fear about real operating engine conditions.

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Reziumė

Turbokompresoriai sudaro didelį skaičių laivų dyzelinių variklių gedimų, ypač kai varikliai yra maitinami sunkiomis degalų frakcijomis (mazutu). Straipsnyje pateikiamas vibroakustinis diagnostikos metodas, kurį galima panaudoti laivų turbokompresoriniams dyzeliniams varikliams tirti. Turbokompresorių generuojami vibraciniai signalai reikalauja skirtingų signalo apdorojimo metodų siekiant kad jie būtų efektingi ir veiktų nepriekaištingai diagnozuojant turbokompresorius. Diagnostiniai metodai, kurie paremti vibracinių signalų analize, yra jautrūs variklio apkrovos ir sukimosi dažnio pokyčiams. Kai kurie turbokompresorių tyrimo rezultatai, gauti Lenkijos Karo Jūrų Laivyno Akademijos Laivų Techninės Priežiūros Instituto laboratorijoje yra pateikiami straipsnyje, kuriame ypatingas dėmesys praktiniams vibracinių signalų apdorojimo ir diagnostikos efektyvumo aspektams.

Laivų dyzelinis variklis, turbokompresorius, diagnostika, vibracija, laboratoriniai bandymai.

Томас Лус, Марек Лутович, Ярослав Литковски

ДИАГНОСТИЧЕСКИЕ ИССЛЕДОВАНИЯ ТУРБОКОМПРЕССОРОВ ДИЗЕЛЬНЫХ ДВИГАТЕЛЕЙ НА ЛАБОРАТОРНЫХ СТЕНДАХ

Аннотация

Турбокомпрессоры составляют большое число отказов судовых дизельных двигателей, особенно когда двигатели работают на тяжелых фракциях топлива (мазуте). В статье приведен метод вибрационной акустической диагностики, который может быть использован для исследования судовых турбокомпрессорных дизельных двигателей. Вибрационные акустические сигналы, генерируемые турбокомпрессорами, требуют различных методов обработки сигналов, чтобы они были эффективными и безупречными при диагностировании турбокомпрессоров. Диагностические методы, которые обоснованы анализом вибрационных сигналов, являются чувствительными к изменениям нагрузки и частоты вращения двигателя. Некоторые результаты исследования турбокомпрессоров, полученные в лаборатории Института Технического Ухода Судов, Польской Академии Военного Морского Флота представлены в статье при особенном внимании уделенном практическим аспектам обработки вибрационных сигналов и эффективности диагностирования.

Судовой дизельный двигатель, турбокомпрессор, диагностирование, вибрация, лабораторные исследования.