VIBRO-ACOUSTIC METHODS IN MARINE DIESEL ENGINES DIAGNOSTICS

Tomasz Lus

Polish Naval Academy, Mechanical-Electrical Faculty
Śmidowicza Street 69, 81-103 Gdynia, Poland
tel.: +48 58 6262629, fax: +48 58 6262648
e-mail: t.lus@amw.gdynia.pl

Abstract

Vibro-acoustic diagnostic methods which are used on marine high-speed diesel engines with turbochargers are presented in this paper. Vibration and acoustic signals generated by turbochargers need different signal processing methods to be effective and faultless in turbochargers diagnostics. Diagnostic methods which based on vibration and acoustic signals analysis are sensitive on engine load and speed changes. Methods presented in this paper based on vibration and acoustic signals processing in time and frequency domain. Using this methods checking technical condition of the turbochargers and its rotors and bearings without stopping the engine and dismantling it is possible.

Examples of radial-flow rotor turbine overgrown by carbon soot and axial-flow rotor turbine without turbine blades, sound intensity level of turbocharger and acoustic spectrum of turbocharger in octave mode acoustic spectrum of turbocharger in octave mode for two different technical conditions, acoustic and vibration signal spectrum of the turbocharger, vibration acceleration amplitude of first harmonic for three turbochargers, values of harmonic vibrations of accelerations equivalent of turbine blades number, amplitude of vibrations accelerations in frequency domain for turbocharger in good and bad technical conditions are presented in the paper.

Keywords: *marine diesel engine, turbocharger, diagnostics, vibration*

1. Introduction

Diesel engines technical condition assessment is a very complex process. Most of the malfunctions and troubleshooting in diesel engine installations are generated by the fuel injection system and valve gear mechanism [7]. Most of marine diesel engines are turbocharged. Turbochargers also caused significant number of engine malfunctions especially when engine is fuelled by heavy fuel oil. 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. But how check turbocharger bearings and rotor clearances without stopping the engine and dismantling it ? How to observe technical condition of the turbocharger on working engine? It is known that engine load and speed changes disturb observed turbocharger parameters. 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 Fig. 1.

Typical vibro-acoustic diagnostic methods base on the analysis of acoustic and vibration signals amplitude in time or frequency domain [1, 6]. Acoustic signal analysis methods presented in this paper based on sound intensity level analysis and is rather not convenient for turbocharger diagnostic in real operation conditions because of presence in small engine room compartments other sound sources and sound reflection effects.

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

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

2. Objects of investigations – the WOLA 57H6Aa type diesel engine with the WSK–Holset 4MD turbocharger and SULZER 6AL20/24 type diesel engine with Napier C–045/C turbocharger

The basic aim of investigations were attempt to achieve acoustic and vibration characteristic of the high-speed marine diesel engines and its turbochargers and check which signal (acoustic or vibration) and which signal processing system could be better to use for turbocharger on-line diagnostic systems [2, 4, 5].

There were two objects of investigations. The first object of investigation was high-speed marine diesel engine WOLA type 57HGAa (Engine no 1) with its turbocharging system. The second was SULZER engine type 6AL20/24 (Engine no 2) with turbocharger both installed in Polish Naval Academy laboratory in Gdynia-Oksywie. The main data of the engine are presented in the Tab. 1. Measuring systems configuration and places where acoustic and vibration sensors were installed are shown on Fig. 2 and 2a.

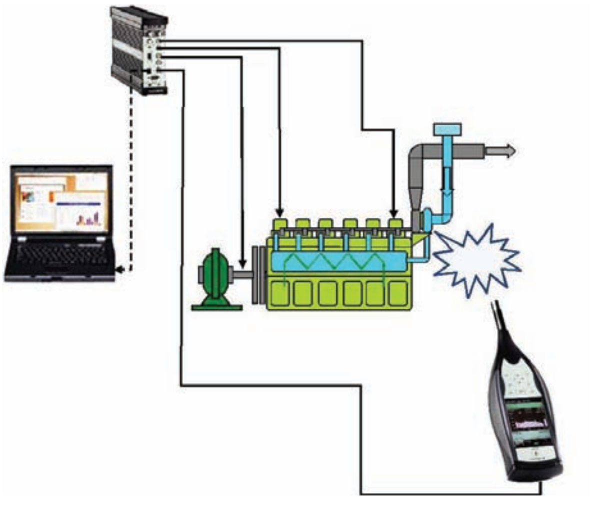

Fig. 2. Acoustic and vibration parameters measuring system configuration on stands of WOLA 57H6Aa and SULZER 6AL20/24 type high-speed diesel engines

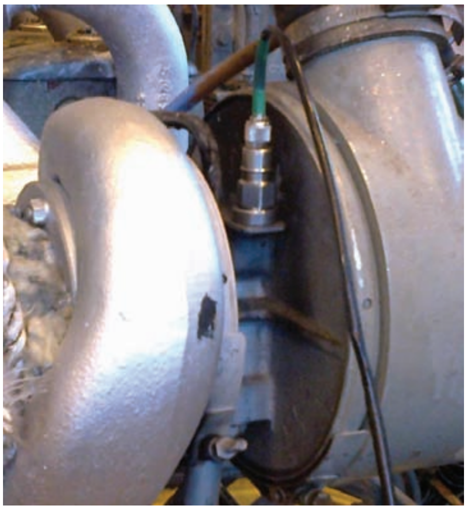

Fig.2a. WSK–Holset 4MD type turbocharger with vibration sensor mounted on the bearing housing

Both tested engines were high-speed marine diesel engine with six-cylinder in line, 4-stroke turbocharged with direct fuel injection. Fresh water in closed circuits is used in engine cooling systems, lubricating oil coolers and air coolers. Engine no 1 is equipped with electric started device and 24V batteries and Engine no 2 has compressed air starting device. WOLA engine could be loaded by two hydraulic brakes HWZ-3 type up to 254 kW at 3000 rpm and SULZER engine could be loaded by one Froude' DPY6D type hydraulic brake up to 420 kW at 750 rpm. During the tests WOLA engine was loaded up to 155 kW at 1500 rpm. SULZER engine was loaded up to 420 kW and 750 rpm.

Tab. 1. Basic data of the high-speed diesel engine type WOLA 57H6Aa and SULZER 6AL20/24

Engine type	WOLA – Henschel 57H6Aa	SULZER 6AL20/24
Turbocharger type	WSK–Holset 4MD	Napier C–045/C
No. of cylinders / Configuration	*i=6 / „ L”*	*i=6 / „ L”*
Nominal output at 1500 rpm	*Pn= 155 kW*	*Pn= 420 kW*
Cylinder bore	*D= 135 mm*	*D= 200 mm*
Piston stroke	*S= 155 mm*	*S= 240 mm*
Compression ratio	ε= 14.0	ε= 12.7
Total displacement volume	$Vss= 13.3\ dm^3$	$Vss= 45.2\ dm^3$
Mean piston speed	*cśr= 8.26 m/s*	*cśr= 6 m/s*
Firing order	1-5-3-6-2-4	1-4-2-6-3-5
Effective specific fuel consumption	*ge= 231 g/kWh*	*ge= 212 g/kWh*
Number of valves per cylinder	*z= 4*	*z= 4*
Fuel injection pressure	*pw= 19.4 MPa*	*pw*= 2.5 MPa

Measuring system and vibro-acoustic apparatuses based on Brüel & Kjǽr PULSE system and 2250 analyser [3]. 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.

3. Results of acoustic investigations – the WOLA 57H6Aa type diesel engine with the WSK–Holset 4MD turbocharger

Brüel & Kjǽr PULSE system with 2250 analyser and microphone type 4189 was used for acoustic measurements. Microphone on tripod was located in 1 meter distance from turbocharger and on the same level as the turbocharger was. Position of the microphone was parallel and perpendicular to turbocharger rotor.

Measurements were made for both engines and with whole engines load and turbochargers speed ranges. Some non-destructive malfunctions were simulated on turbochargers to check if is possible to asses some kinds of malfunctions on the changings in acoustic parameters values.

In the Fig. 3 two sound intensity levels of engine no1 turbocharger versus turbocharger speed in two different technical conditions are shown. Blue (lower) line shows sound intensity level FATeq [dB] for turbocharger in good technical conditions – without any visible malfunctions. Red (upper) line shows sound intensity level measured on turbocharger with removed air filter and silencer. The difference between two curves is not significant even taking into account that it is logarithmic scale.

Acoustic spectrum of these same two signals in octave frequency bands are presented in the Fig. 4. It is seen that higher frequencies are amplified and lover frequencies are a little bit smaller because of taking off the air filter and silencer from the turbocharger. But also even using for acoustic signal processing frequency analysis it is not easy to avoid influence of other sound sources and sound reflection effects in laboratory and in engine room compartment on the ship which could strongly disturb acoustic parameters measuring process.

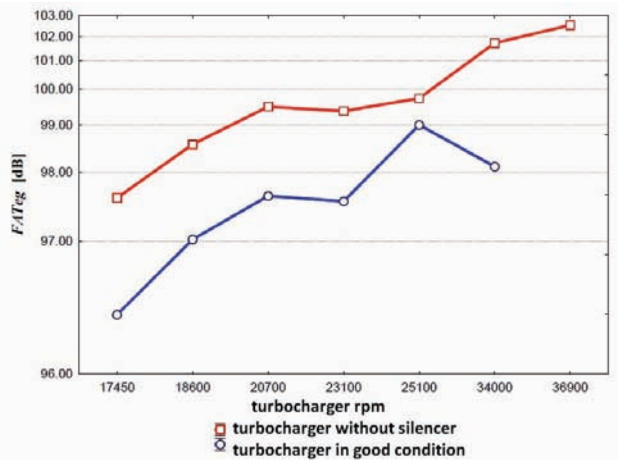

Fig. 3. Sound intensity level of turbocharger in two different technical conditions – blue (lower) – turbocharger in proper technical condition, - red (upper) – air filter and silencer removed from the turbocharger

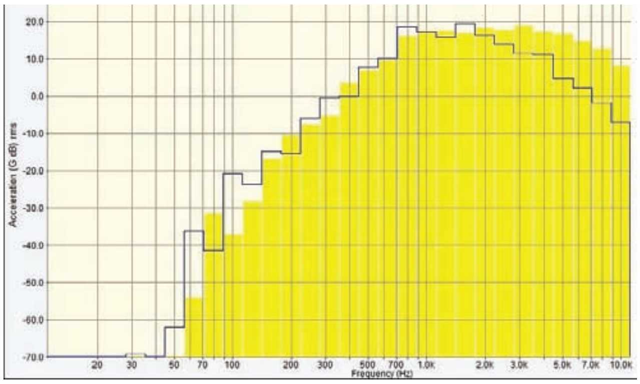

Fig. 4. Acoustic spectrum of turbocharger in octave mode for two different technical conditions – Yellow (grey) – air filter and silencer removed from the turbocharger

From these reasons acoustic methods are not so popular in turbocharger diagnostics but off course they are used by (OEM) manufactures in official certification. Vibrations signals measured on housing of the turbocharger are also 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. 5 the acoustic signal spectrum of the turbocharger and its environment and for the same turbocharger in the Fig. 6 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. 6. 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.

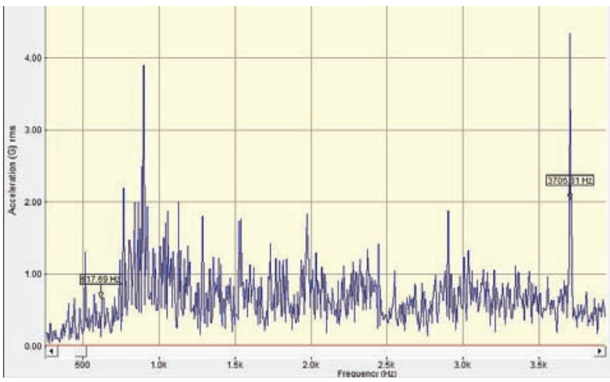

Fig. 5. Acoustic signal spectrum of the turbocharger in frequency range from 0 kHz to 4 kHz

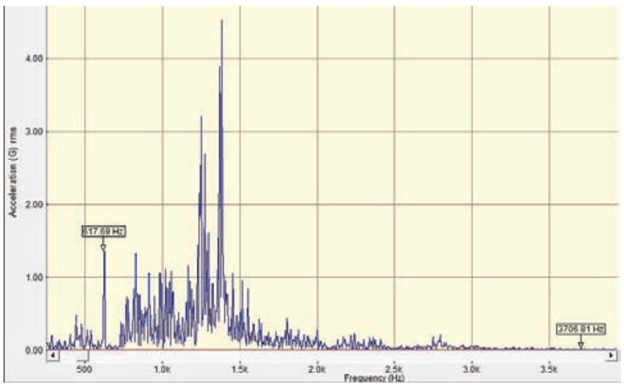

Fig. 6. Vibration signal spectrum of the turbocharger in frequency range from 0 kHz to 4 kHz – magnetic sensor holder

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

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

During tests several 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 Fig. 3. Some chosen results from these tests are presented in this paragraph on Fig. 7-13. In the Fig. 7 tests results of three turbochargers is presented. At the axis of abscissa the turbocharger speed in rpm and at the axis of ordinates the value of vibration acceleration amplitude of first harmonic in [g] scale is presented.

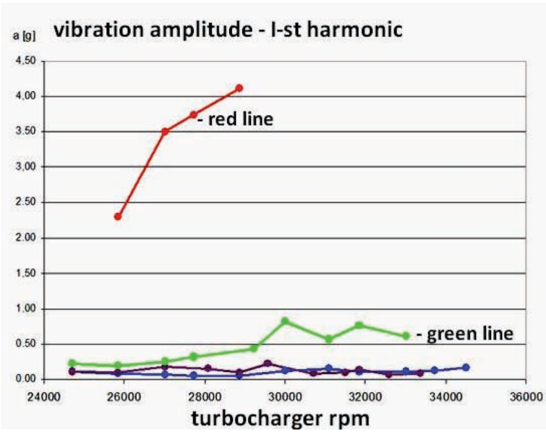

Fig. 7. Vibration acceleration amplitude of first harmonic for three turbochargers. Blue and violet line - turbochargers in good technical condition. Red and green line – turbocharger in bad technical condition (red) and after repair (green)

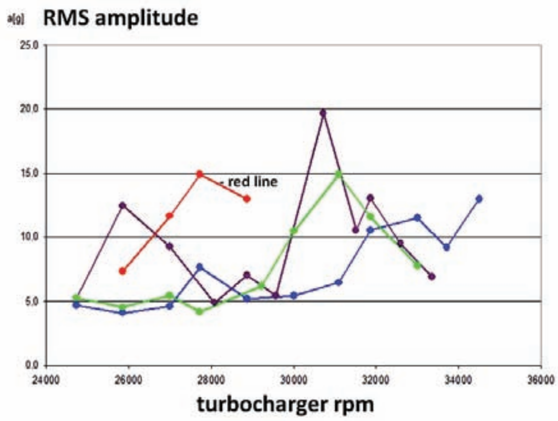

Fig. 8. RMS amplitudes for three turbochargers. Red line – turbocharger in bad technical condition. Blue, violet and green – turbochargers in good technical conditions

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 – (Fig. 8) is not such effective and clear tool for diagnostics as I-st harmonic as it is seen in Fig. 8. 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 Fig. 9 the amplitude of 13-th harmonic vibrations (equivalent of turbine blades number) and in the Fig. 10 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 simulated 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.

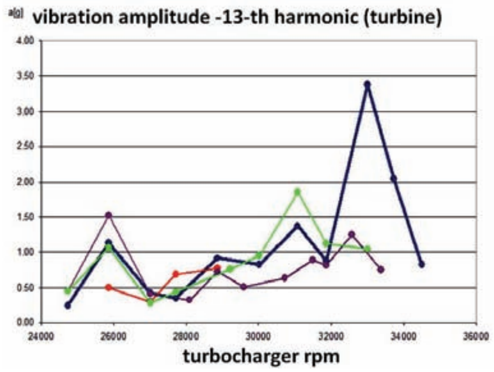

Fig. 9. Value of 13-th harmonic vibrations of accelerations equivalent of turbine blades number

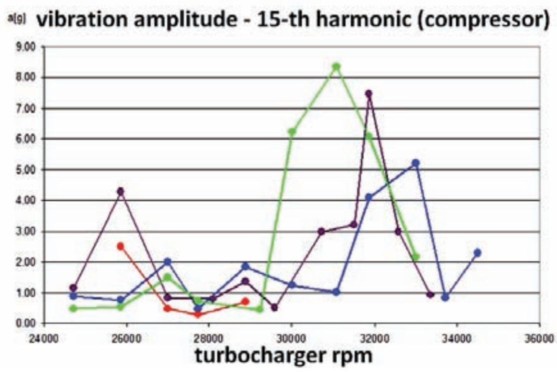

Fig. 10. Value of 15-th harmonic vibrations of accelerations equivalent of compressor blades number

The FFT signal processing is very popular tool in rotary machines diagnostics. In the Fig. 11 and in the Fig. 12 vibrations signals transformed into frequency domain by using FFT technique are presented. In the Fig. 11 the vibration signals in frequency domain for turbocharger in good technical conditions is presented. In the Fig. 12 for this same turbocharger in bad technical conditions

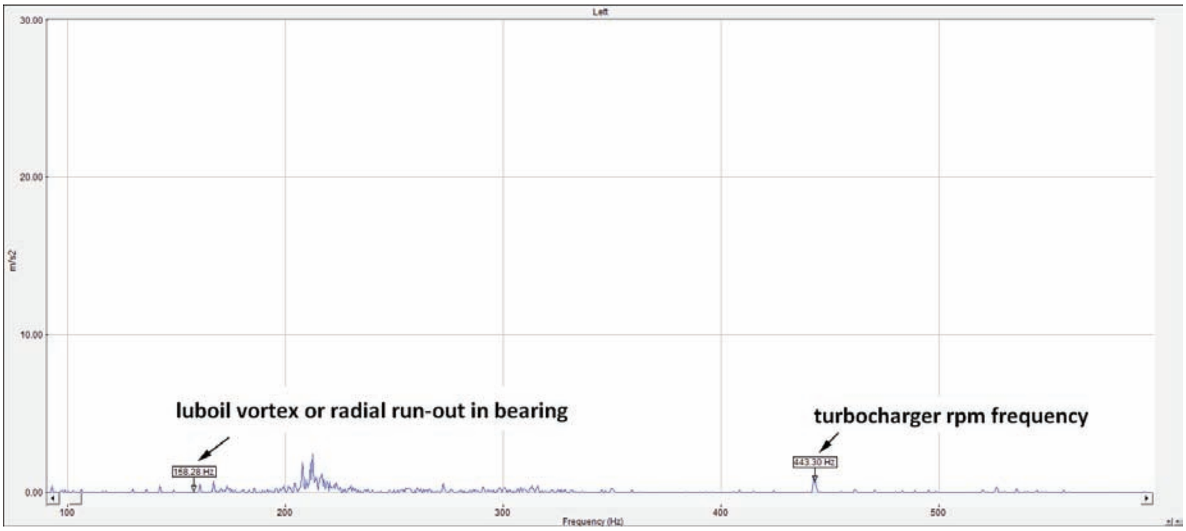

Fig.11. Amplitude of vibrations accelerations in frequency domain for turbocharger in good technical conditions

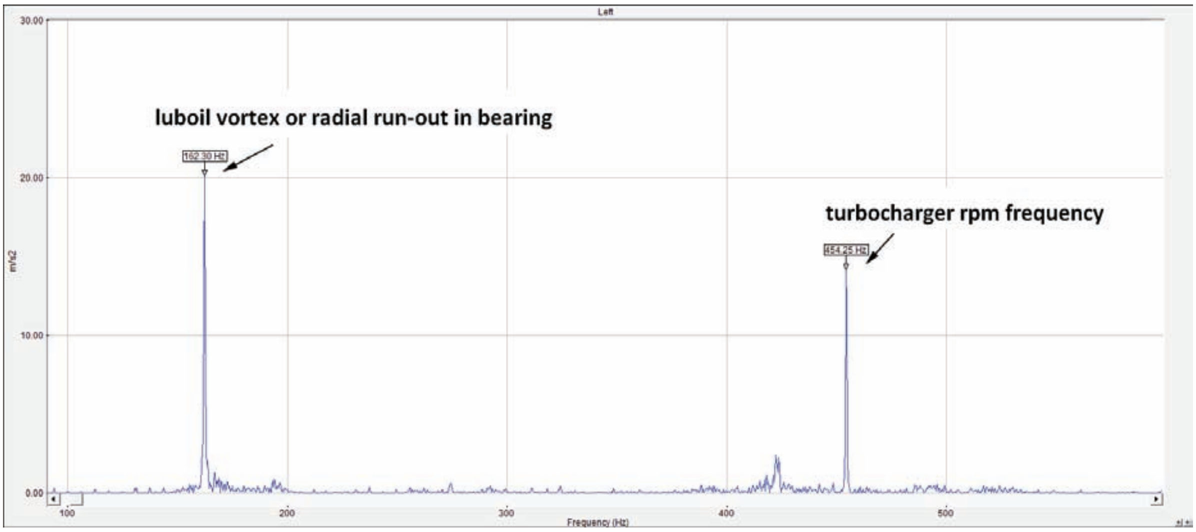

Fig. 12. Amplitude of vibrations accelerations in frequency domain for turbocharger in bad technical conditions

values of vibration signal amplitudes are significantly higher (Fig. 12 versus Fig. 11) which is probably involved by lubricating oil vortex or radial run-out in bearings.

During the research done in PNA connected with turbochargers technical conditions assessment several turbochargers were tested. In the Fig. 13 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 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.

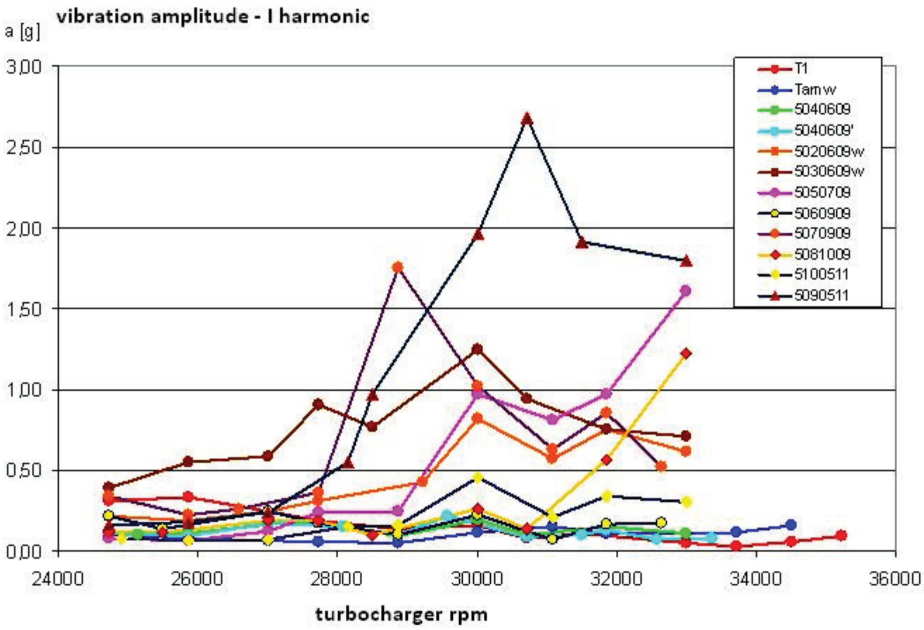

Fig. 13. Vibrations acceleration amplitude – I harmonic measured on turbocharger bearing casing versus turbocharger rpm – twelve turbochargers in different technical conditions tested on the same marine diesel engine stand

5. 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. Acoustic signals processing methods which are attractive by their simplicity are not efficient in real turbocharged engines conditions assessing especially on board the ship in very narrow engine compartments. In this respect vibration signals processing methods seems to be much more effective. But there are still many research works [8] to find out much more convenient diagnostic tools for rotating machinery. Presented vibration methods gives opportunity to change the whole engine maintenance philosophy connected with turbochargers maintenance process. It is possible using on-line vibration monitoring systems to go from scheduled to condition based turbochargers maintenance without fear about real operating engine conditions.

References

[1] Batko, W., Dąbrowski, Z., *Nowoczesne metody badania procesów wibroakustycznych*, Wydawnictwo i Zakład Poligrafii Instytutu Technologii Eksploatacji, PIB, Radom 2006.

[2] Bengtsson, M., *Condition Based Maintenance System Technology – Where is Development Heading*?, Euromaintenance 2004 – Proceedings of the 17th European Maintenance Congress, 11th – 13th of May, 2004, AMS (Spanish Maintenance Society), Barcelona, Spain 2004.
[3] Brüel & Kjǽr., *Machine Diagnostics Toolbox Industrial Solutions*, 2006.
[4] Klockars, T., Eykerman, A., Mayr, I., *Making the most of perfect maintenance timing*, indetail, Wärtsilä Technical Journal, pp. 57-60, Finland 2010.
[5] Krzyworzeka, P., *Wspomaganie synchroniczne w diagnozowaniu maszyn* Biblioteka Problemów Eksploatacyjnych Wydawnictwo Instytutu Technologii Eksploatacji, Radom 2004.
[6] Kurowski, W., *Podstawy diagnostyki systemów technicznych Metodologia i Metodyka* Biblioteka Problemów Eksploatacyjnych Wydawnictwo Instytutu Technologii Eksploatacji Warszawa – Płock 2008.
[7] Madej, H., *Diagnozowanie uszkodzeń mechanicznych w silnikach spalinowych maskowanych przez elektroniczne urządzenia sterujące*, Wydawnictwo Naukowe Instytutu Technologii Eksploatacji – PIB, Radom 2009.
[8] Wang, W., Chen, J., Wu, Z., *The application of a correlation dimension in large rotating machinery fault diagnosis,* Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science IMechE, Shanghai 2000.