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A diagnostic system for marine gas turbine engines

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ABSTRACT: In this article, the author presents the application of methods of vibroacoustic analysis in naval technology. The element of a Base Diagnosing System (BDS) is incorporated and utilised in those ships that are powered by the COGAG power plant. The permissible in-service imbalance and the appropriate assemblage of turbine rotors on the basis of selected vibroacoustic parameters, and finally the determination of their permissible operation time resources, are considered and examined in this article. Another element of BDS, which is analysed in this article, is the vibration control of the misalignment of propulsion shafts. An important component in the training of future maritime engineering personnel involves current diagnostic techniques and it thus contributes significantly to maritime engineering education. These issues of special importance to engineering education, as they relate to the application of methods of vibroacoustic analysis in maritime technology, are presented and discussed by the author in this article.

INTRODUCTION

Contemporary ships are complex constructions with enormous power that can reach 100 MW. Due to reasons of navigation safety and the protection of human lives and property, as well as environmental concerns, such ships require highly qualified crews for their operation. Hence, the requirements for proper educational methods in the teaching processes of future ships' captains, as well as engine room officers, who are responsible for operating shipboard equipment, are constantly increased.

The requirements set forth by the International Maritime Organization (IMO) indicate the great importance of practical classes and laboratory training, as well as training performed on simulators in the educational process. For these reasons, the didactic process, particularly with respect to engine room operations, apart from a certain number of hours of classes performed on the simulators, entails that trainees be required to participate in laboratories, where real diagnostic methods are applied, which are used onboard ships. In this paper, the author details an example of the application of a basic diagnostic method in the didactic process of training related to ships' gas turbines.

BASE DIAGNOSING SYSTEM

The application of periodical or online diagnostic procedures makes it possible to operate ship propulsion systems in accordance with their current technical state [1]. This especially takes into consideration the criteria for determining the maintenance time of a ships' gas turbines, which is presently hourly. Such an exploitation strategy facilitates the early scheduling of maintenance operations and their logistic assurance. However, it can also simultaneously contribute to an increase of costs because of the system of replacing elements (technically often still serviceable components), as well as it makes it impossible to detect early symptoms of failure occurring before the end of a maintenance period. Students need to acquire knowledge with respect to a diagnostic system, its goals and application methods, as well as the principles of exploitation while using the diagnostic system. These are important considerations in the training of future maritime engineering personnel and should be considered in maritime engineering education.

OBJECT OF INVESTIGATION

In order to obtain reliable data on diagnostic parameters, an examination of the gas turbines installed in the presented propulsion system was carried out by means of a multi-symptom diagnostic model. One of the main features of this model is that it consists of recording and analysing vibro-acoustic signals. The investigations were aimed at determining permissible in-service imbalance and the appropriate assemblage of turbine rotors on the basis of selected vibroacoustic parameters. Finally, it also targeted the determination of their permissible operation time resources [2].

The students ought to possess the knowledge of the relations between the degree of usage of engine's and other elements of the power transmission and the symptoms observed during the measurements, including the vibroacoustic signals. By personally effectuated measurements and the spectrum vibration analysis, the students have to be able to determine which engine element influences the change in the vibration characteristics. This presents an excellent opportunity to engage maritime engineering education students in these vital procedures.

The analysis was based on the following assumption: if the degradation of the technical state of a gas turbine rotor set is a function of its operation time (at a load spectrum assumed constant), then it is possible to select from the recorded vibration signal spectrum such parameters whose changes can be unambiguously assigned to the operation time [3][4]. A second important problem is shaft misalignment between engines and reduction boxes, as well as between propeller and reduction box. Dynamic reactions, resulting from exceeding allowable alignment deviations of torque transmission elements, can cause failure of the propulsion system and even lead to loss of movability of the vessel in a relatively short period of time [4]. Therefore, the diagnostic control of the gas turbine power plant while in operation is necessary.

DIAGNOSIS OF ROTOR IMBALANCE

The dynamic problems of marine gas turbine engines (MGTEs) are connected with such basic elements as: rotors, bearings, struts of bearings, engine body, type of substructure, hydro- and meteorological conditions during sea trials, and gas flown parameters inside the engine. The quality of the work process and the stability of MGTEs are also related with the state of such parameters, thus being an important component of the education of future maritime engineers.

For the purposes of performing vibration analysis, the student has to possess the knowledge regarding the engine's construction and its principles of exploitation, as well as the operating conditions and the exploitation parameters.

The dissipation of energy in rotating machines displays as a torque, revolutions, temperature, gas flow and vibration [5]. Vibrations are related to the following factors:

- Rotor imbalance;
- Oversize of the tolerated axis slope of the MGTE shafts' misalignment;
- Blade tips with the inner roller;
- Wear of the axis and radial bearings;
- Asymmetry of the springiness and damping characteristics of the rotor and its parts;
- Irregularity in the forces of gas flow.

Vibration emissions generate much information, including a determination of the technical state of the devices. The measurement of vibrations, their identification, classification and mathematical analysis, including trends, provide information on the current technical state. This permits maritime engineering students to predict the wear process in the future. The vibration analysis of MGTEs during sea trials is accomplished by way of two different procedures, namely:

- Online in real time;
- Offline from periodic or single measurements.

Both procedures have advantages and disadvantages that maritime engineering students need to understand. The online system enables the permanent control of vibration parameters in real time. This allows for the monitoring of vibration parameters, holding memory and shutting down the engine when in a critical state. The data preview of memory can activate the trend functions and can reveal changes of frequency or time parameters of vibration as a function of operational time. The disadvantages of this system are linked with costs, primarily because software and hardware are stationary and sometimes individual. The objects of this research did not possess online monitoring systems and there were only four propulsion plants. For this reason, a periodical offline diagnostic system was applied.

In order to perform the investigations, the following measurement instruments were utilised:

- FFT-2148 analyser;
- *PULSE* v 9.0 software of Bruel & Kjaer.

Such instruments make it possible to collect and process the quantified data by students. The measuring transducers (accelerometers) were fixed to steel cantilevers located on the flange of the low-pressure (LP) compressor only. The decision to carry out the investigations with the use of the transducer fixed to the LP compressor flange resulted from the lack of transducers and equipment suitable for measuring signals at temperatures as high as 200º-300º C, occurring at the high-pressure (HP) compressor flange.

The fixing accelerometers' cantilevers are characteristic of a natural resonance of vibration, whose frequency value differs enough from harmonic frequencies due to the rotation speed of the turbine rotors and their harmonics. The measurements were taken perpendicularly to the rotation axis of the rotors over the main bearings. Such a choice was made on the basis of the theoretical consideration of excitations due to unbalanced shaft rotation, and the results of preliminary investigations of the object [6]. To obtain signals that were usable for the *defect-symptom* relation, the following magnitudes were selected by the turbines' producer:

- Y_{LPC}: 1st harmonic RMS value of vibration velocity amplitude connected with the LP rotor of compressor;
- Y_{HPC}: the same but connected with the HP rotor of the compressor;
- Y_{RMS}: the RMS value of vibration velocity amplitude within the range of 35-400 Hz.

The choice was supported by the time-between-repair values scheduled by the turbines' producer; maritime engineering students need to be aware of such factors. For the purposes of these investigations, a simplification was made, which consisted of assuming that the values of the after-repair turbine vibration symptoms were equal to those of a new turbine. It was necessary to make such an assumption because of a rather low number of investigated objects (only eight turbines of each type). The turbines' producer specified certain limit values of RMS vibration velocity amplitude, as shown in Table 1.

Table 1: Limit values of the RMS vibration velocity amplitude.

	Permissible Value of Yrms	Permissible Value of Harmonics Y
DR 76 engines	24 [mm/s]	17 [mm/s]

One of the most important elements of the offline system is the database. Idle load and full power (nominal load) were taken for further consideration. Each spectrum was transferred as matrices M_S and copied like fingerprints to the database. Spectra were not synchronised to the revolutions of the rotors, at the same loads, at various air temperature conditions. This set-up provides an excellent opportunity to engage students' learning in this field.

DIAGNOSIS OF SHAFT MISALIGNMENT

The usual measurement methods of coaxiality parameters of the propulsion system utilised by maritime engineering graduates require the disassembly of protection covers of shafting between engines and reduction gears. Measurement conditions make it necessary to suspend the operation of the COGAG-system for approximately 8-10 days and it is obviously an intrusive method that maritime engineering students need to come to grips with.

Students have to become familiar with traditional methods for assessing shaft misalignment and, in laboratory conditions, analyse the consequences of influence of the alignment parameters' changes on vibrational characteristics.

The vibroacoustic method presented in this paper lets maritime engineering students assess the permissible values of alignment parameters without stopping the vessel's exploitation. Moreover, the presented results are intended to form the database for the elaboration of an online monitoring system of coaxial torque transmission elements that are applicable to the propulsion system in question and thus present pertinent information for maritime engineering educators.

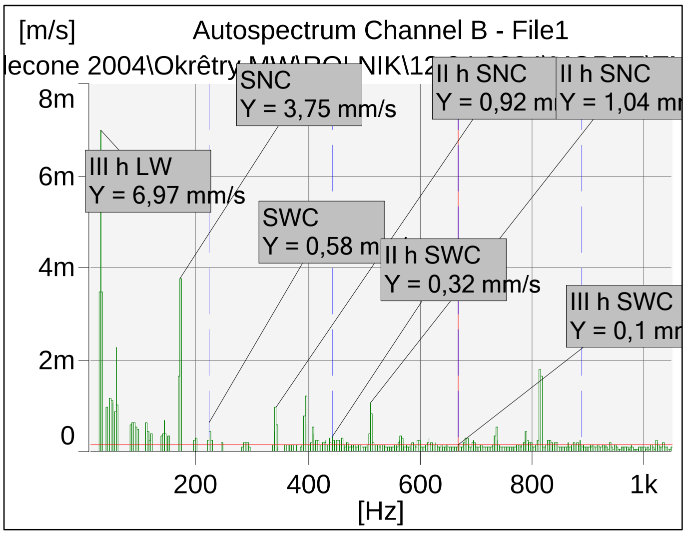

Figure 1: Typical pattern spectra DR 77 engines, where: SNC = low-pressure compressor rotor, SWC = high-pressure compressor rotor, and h = harmonics.

Dynamic reactions, which result from exceeding allowable alignment deviations of the torque transmission elements, are able to cause the failure of the propulsion system – even leading to a loss of movability of the vessel in a relatively short space of time [4]. Therefore, the diagnostic control of the gas turbine power plant in operation has become quite necessary and students need to be trained in this function.

The appropriate assembly of elements of the main engines and other torque transmission elements (including propellers) are practically determined by a set of tolerated dimension and geometrical location requirements. These are the so-called geometrical dimension assembling chain [1]. Both typical and modular power plants are prone to coaxiality deviation from its permissible values as a consequence of the possible failure of one or more elements of the propulsion system. Excessive deviation can lead to loads on bearings and gear teeth that are much higher than calculated, and may result in their premature failures [7]. Again, maritime engineering students need to become more aware of this.

The application of vibroacoustic diagnostics for technical maintenance allows for the lower operational cost of the vessel by basing its operation on its current technical state and predicted failure states [3].

It was assumed that determining the relationship between the coaxiality parameters and changes of the recorded vibration signals should bring about an identification of the proposed diagnostic model, consisting of the following factors:

- Choice of geometrical parameters that describe the position deviations, ie axis slope and displacement;
- Choice of adequate parameters of the vibroacoustic signal;
- Determination of the mutual relationships between the sets of the coaxiality deviations and vibration diagnostic parameter values;
- Sensitivity assessment of the symptoms in question;
- Establishment of the database for statistical analysis and operational decision making.

In exploitation conditions, ships never achieve the same displacement values. This is due to the constant change in the level of reserves. This is specifically important for small ships, which have low displacement, where changes in the amount of reserves cause a change in the draught level and, as a result, a change in the position of the engine and the shafts. The person responsible for the exploitation of an engine in the future must be aware of the fact that a change in vibration characteristics does not result uniquely from a change in the technical state of an engine, but may also be related to external conditions and the level of storage. Trainees should be acquainted with these factors during laboratories and while performing measurements on real machinery.

Examples of investigation results are presented in the form of symptom change regression functions at different displacement values of the vessel and different axis slope values. The results were approximated with the use of the least square method. The results were analysed by assigning the mean value of the vibration signal, ie the harmonic connected with the excitation frequency of vibration velocity amplitudes to the measured axis slope value. Archive charts of the investigation results are shown in Figure 2. This also presents an excellent research activity for maritime engineering students.

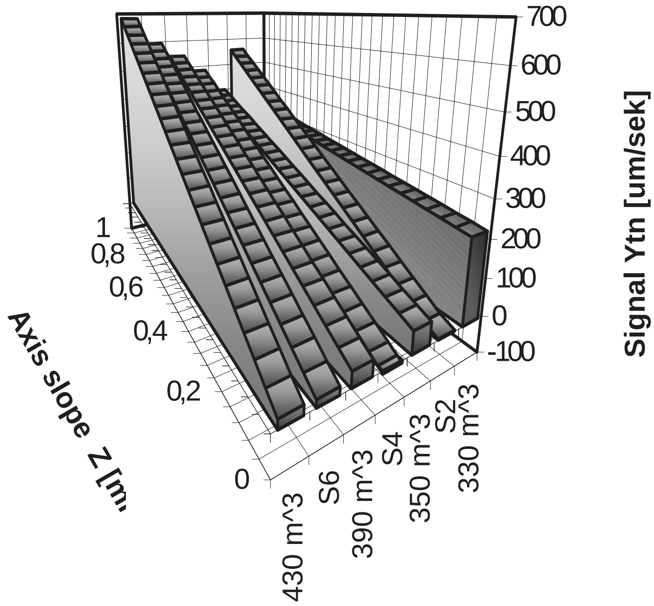

Figure 2: Examples of archive charts of the investigation's results.

During the investigation, no limit state of the axis slope of Z = 1 mm/m was found in the propulsion system in question. A regression function of the symptom changes at different vessel displacement was calculated so as to determine the limiting (tolerated) values of the symptom. It was also stated, on the basis of analysis of the investigation results, that the mean signal value, Ytn, increased as the vessel's displacement increased, at the axis slope Z = const. This is shown in Figures 3 and 4.

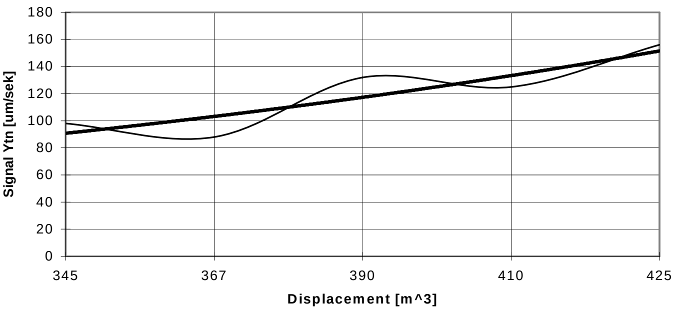

Figure 3: Symptom change regression functions at the different displacement values of the vessel and different axis slope values.

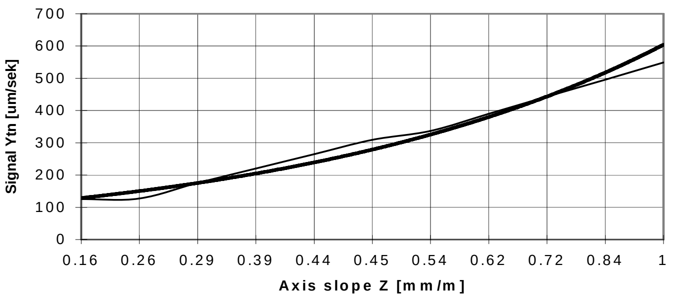

Figure 4: Symptom change regression functions at different slope values of the vessel's displacement of D = 410 m^3.

FINAL REMARKS

- In order to adequately prepare maritime personnel to take up their first positions onboard ships, the didactic process requires the broad application of laboratory exercises, simulators and real diagnostic methods;
- The application of the proposed approach makes managing the engine's operation time significantly more rational, especially at its end, which is important for maritime engineering students to understand, as it will impact in their working careers;
- The proposed approach is non-invasive and does not require taking the ships out of service, thus being an important and timely aspect in the training of maritime engineer;
- The realisation of this kind of investigations makes it possible for students and engineers to collect data for a database for the future monitoring system of ships, which is expected to improve their operational features;
- Experience gained during these investigations could be utilised for other power plants equipped with gas turbines;
- The proposed exploitation method leads to important economical profits, especially with regard to reliability improvements, a high-priority problem, especially for engineering students with management aspirations;
- The presented method is sensitive enough in the operation of a propulsion plant, so much so that it enables students to find the primary symptoms of change in the technical state of rotor dynamics;
- The regression equation of the trend is a satisfactory rule for students to verify the sensitivity of symptoms;
- Cross-coherent procedures are useful tools that students can utilise in order to recognise quickly the differences between spectra in databases.

CONCLUSIONS

The conclusions from this study are as follows:

- The application of real diagnostic systems in the training process of future engine room officers enables more effective knowledge acquisition with the operation of an engine room and allows trainees to assess the influence of other factors than usage with respect to the features and intensity of the vibration signal;
- By participating in classes where real diagnostic systems are being applied, students can obtain the necessary information on existing systems, and they can also become acquainted with their operating principles and the methodology for utilising diagnostic data;
- The proposed measurement method makes it possible to determine the limiting value of Ytn symptom that, if exceeded, indicates the inadmissible axis slope value and, moreover, provides an unambiguous relationship between the axis slope and the vessel displacement values;
- Implementation of the method to routine operation of the ship power plant could lead to the important reduction of the maintenance scope on the condition of extending the diagnostic control to all propulsion connections;
- The online monitoring system for the early detection of symptoms that exceed the coaxiality allowances of selected components of a ship's gas turbine propulsion systems is an important component to be considered when training modern ship-bound engineers;

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