

## DIAGNOSING OF SHIP PROPULSION ELEMENTS BY VIBRATION MEASUREMENT

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### Abstract

*In the present time the technical progress, make us use more and more complicated machines in our everyday life. The application of turbine engines as the main propulsion engines of a vessel impels, according to requirements, operation procedures. It alters considerably the usage of gas turbine engines in the navy from the ones in aviation. The relatively low load is characteristic to the operation of the marine engine. In the case of the technology used at sea, the necessity of highly specialized service is especially evident. In the paper, we present the diagnostic systems elaborated to support the exploitation of the vessel power plant with gas turbines. Application of computer simulation for diagnosing a technical state of gas turbines rotor sets should be applied during calculation and project process. During engine assembly, the rotating components are mounted with great care with the main objective of minimizing shaft unbalance. However, even with the best of care, such factors as machining imperfection, differential thermal expansion etc cause a small residual unbalance of gas turbine rotor. The dynamic problems of Marine Gas Turbine Engines are connected with such basic elements: rotors, bearings, struts of bearings, engine body and type of substructure. The proposed diagnostics method makes it possible to determine the limiting value of vibration symptoms .*

**Keywords:** *diagnosing, vibroacoustics, gas turbine engines, ship propulsion plant* Diagnosing, gas turbine engines, ship propulsion plant

### 1. Introduction

The propulsion systems of warship vessels and especially of combat vessels are constructions of great power. The power of the installed propulsion system reaches 100 MW. The necessity of high power production makes the use of gas turbine engines. The contemporary gas turbines used on warships can achieve power up to 30 MW and little unit mass that can reach even 0.2 kg/W.

The marine gas turbine engines work in specific conditions, which to a certain degree influence its exploitation conditions and can be a reason of their increased wear and even a break-down. The marine peculiarity has its influence on the engines of all types but it is especially notorious in the case of gas turbines [1]. It is especially due to:

- great volume intensity of the air flow through the engine, up to 100 m<sup>3</sup>/s,
- high level of the load of the engine,
- complexity and sometimes impossibility of the thorough inspection of the engine,
- requirement of the high level of purity of fuel, oil and air,
- work mostly on partial load.

The engines on the vessels work in the conditions of permanent waving and great stroke loads, etc. These kinds of loads have their influence on the elements of the engine, especially on the labyrinthine seals and bearings. Air passing through the engine brings sea-water and salt, vapours of oils, sucked exhausts of the working engines and, in the coastal regions, the industrial dusts.

## 2. Base diagnostic system of naval gas turbine engines

The usage of naval gas turbines requires a professional technical supervision. Such a requirement cannot be fulfilled by crews of small vessels. Therefore, it was decided to support the crews of such vessels by the „Base Diagnostic System of Naval Gas Turbine Engines” (BDS) [2].

The system is introduced for periodical inspections of engine condition and particularly in case of:

- annual maintenance,
- necessity of the prolongation of mean time between major repairs,
- identification of an abnormal running found during routine maintenance.

The Base Diagnostic System consists of a series of diagnostic positions and provides the possibility of complex examination of engine conditions by EDP (Electronic Data Processing) application. The BDS is capable of working out the prognosis for the engine future operation. An operating decision is worked out on the basis of appropriately prepared measurements of the engine parameters. They are subsequently converted into diagnostic parameters according to the elaborated flow diagrams for computer programs.

From the technical point of view, the BDS is equipped with a special supervising-measuring device capable of carrying out numerous (foregoing) tasks on the grounds of measured values of various parameters of the engine.

In order to work out all tasks securing the proper gas turbine operation the system is equipped with the following special apparatus:

- computer measuring system of start-up and lay-off parameters, and of operational parameters
- for measurements of vibration parameters and their analysis,
- position for oil examinations on metal particle contents and other impurities,
- programmable analyser of high-changeable signals,
- endoscopes,
- automatic test equipment for safety devices and supervising-measuring apparatus of the engines,
- computer data base.

The methods of gathering diagnostic parameters for the condition evaluation of different sub-assemblies of the engine are presented in Fig. 1.

To obtain reliable data on diagnostic parameters, investigations of the gas turbines installed in the presented propulsion system were carried out by means of the multi-symptom diagnostic model whose one of the main features is recording and analysing vibroacoustic signals [3]. The investigations were aimed at determination of permissible in-service unbalance and appropriate assemblage of turbine rotors on the basis of selected vibroacoustic parameters, and - finally – determination of their permissible operation time resources. The investigations were based on the following assumption: if technical state degradation of gas turbine rotor sets is a function of their 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 [4, 5]. Second one important problem is shaft misalignment between engines and reduction boxes and propeller and reduction box. Dynamic reactions, resulting from exceedance of allowable alignment deviations of the torque transmission elements are able to cause failure of the propulsion system and even lead to loss of immovability of the vessel in a relatively short time. Therefore, diagnostic control of the gas turbine power plant in operation became necessary.

Appropriate assembling the main engines and the other torque transmission elements inclusive of propellers is practically determined by a set of tolerated dimension and geometrical location requirements, called geometrical dimension assembling chain. Both typical and modular power plants are prone to coaxiality deviation from its permissible values and in consequence to possible failures one or more elements of the propulsion system. The excessive deviation can lead to the loads on bearings and gear teeth much higher than calculated and in result to their premature failures.

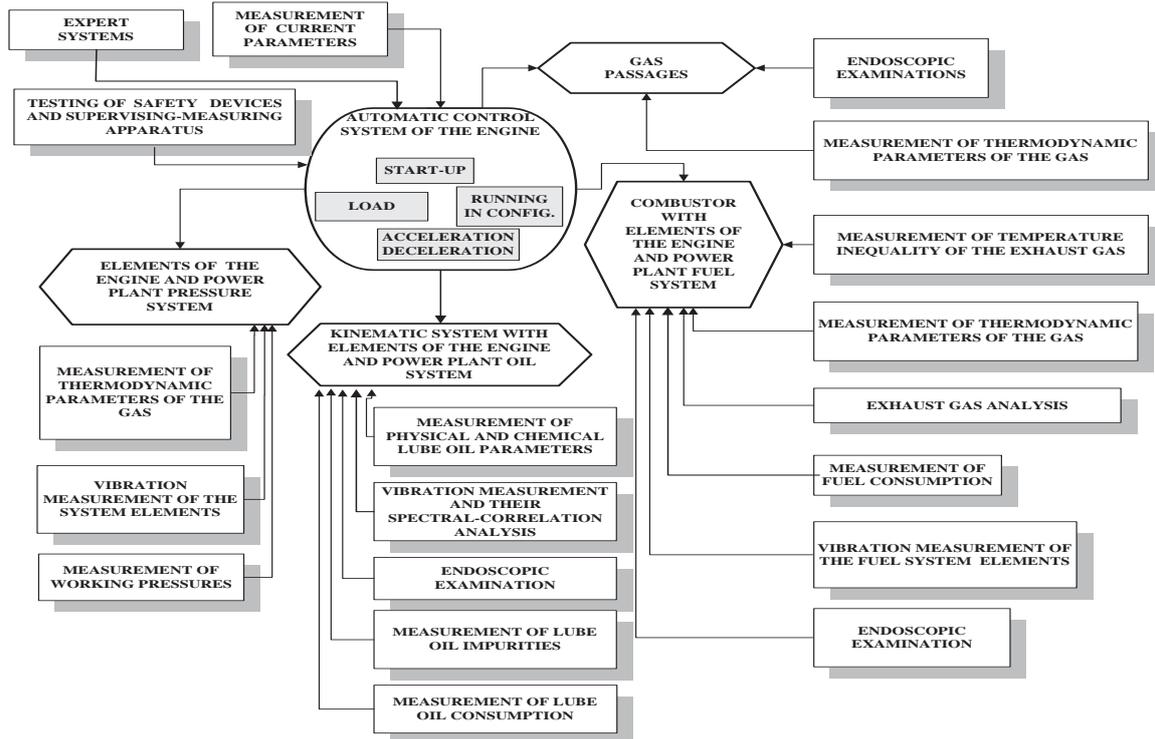


Fig. 1. Methods and means of gathering diagnostic parameters

### 3. Diagnosing the rotors unbalancing

The quality of work process and stability of MGTE are connected with the state of such parameters as well. Dissipation of energy in rotating machines displays as a torque, revolutions, temperature, gas flown and vibration. Vibrations are connected to:

- rotors unbalancing;
- oversize of tolerated axis slope of shafts - misalignment;
- blade tips with the inner roller;
- wear of axis and radial bearings;
- asymmetry of springiness and damping characteristics of rotor and their parts;
- irregularity gas flown forces.

Emission of vibration brings a lot of information including opinion of the technical state. Measurements of vibration, their identification, classification, mathematical analysis, including trends, provide information on the actual technical state and it allows predicting wear process in the future. Vibration analysis of MGTE during sea trials are accomplished by two different procedures: on-line – in real time, and off-line – periodic or single measurements.

For realisation of the investigations the measurement instruments: FFT-2148 analyser and PULSE v 9.0 software of Bruel & Kjaer were used making it possible to collect and process measured data. Measuring transducers (accelerometers) were fixed to steel cantilevers located on the flange of the low-pressure (LP) compressor only. It was decided to carry out the investigations with the use of the transducer fixed to the LP compressor flange for lack of transducers and equipment suitable for measuring signals at the temperature as high as 200o – 300o C occurring on the high-pressure (HP) compressor flange.

The fixing accelerometers' cantilevers are characterised of a vibration natural resonance frequency value, differ enough from harmonic frequencies, due to rotation speed of the turbine rotors and their harmonics. The measurements were taken perpendicularly to the rotation axis of the rotors over main bearings. Such choice was made on the basis of theoretical consideration

of excitations due to unbalanced shaft rotation, and results of preliminary investigations of the object [6]. As signals, usable for the „defect-symptom” relation, the following magnitudes were selected by the turbines’ producer:

- Y - 1st harmonic RMS value of vibration velocity amplitude connected with the LP and HP rotor of compressor;
- Y<sub>rms</sub> – RMS value of vibration velocity amplitude within the range of 35 Hz – 400 Hz.

The choice was justified by the time-between-repair values scheduled by the turbines’ producer. For the purpose of these investigations, a simplification was made consisted in assuming values of the after-repair turbine vibration symptoms as those of the new turbine. The turbines’ producer specified the following limit values of RMS vibration velocity amplitude: Y<sub>rms</sub> = 24 mm/s, Y = 17 mm/s.

In order to obtain uniform diagnostic procedures regarding unbalance assessment of the turbine rotors the dimensionless parameters characterising that states were applied. On the basis of theoretical considerations as well as results of other diagnostic investigations carried out for some years the following parameters were selected as the most sensitive, [8]:

S1 - ratio of the mean vibration velocity amplitude of a given rotor (1st harmonic) and the velocity component relevant to 2nd harmonic excitation frequency of the rotor in question;  $S1 > 1$

S2 - ratio of the mean vibration velocity amplitude of a given rotor (1st harmonic) and the velocity component relevant to 3rd harmonic excitation frequency of the rotor in question.  $S2 > 1,5$ .

One of the most important elements of the off-line system is data base. For further consideration, idle load and full power were taken. Each spectrum were transfered as matrixes MS and copied like fingerprints to the database. Spectras were not synchronized to the revolutions of rotors, at the same loads in different air temperature conditions vary each other, it caused the preparation at the procedure of identification as follows. It appeared as an important point of analysis because of sensitivity of typical spectra – Fig. 3.

#### 4. Diagnosing of shafts misalignment

Usual measurement methods of coaxiality parameters of the propulsion system require disassembling protection covers of shafting between engines and reduction gears. Measurement conditions make it necessary to suspend operation of the COGAG-system for about 8 – 10 days and it is of course intrusive method. A vibroacoustic method presented in this paper allows assessing permissible values of the alignment parameters without stopping exploitation use of the vessel. Moreover, the presented results are intended to form the data base for elaboration of an on-line monitoring system of coaxial of torque transmission elements, applicable to the COGAG propulsion system in question.

Dynamic reactions, resulting from exceedance of allowable alignment deviations of the torque transmission elements are able to cause failure of the propulsion system and even lead to loss of immovability of the vessel in a relatively short time [2]. Therefore, diagnostic control of the gas turbine power plant in operation became necessary.

Appropriate assembling the main engines and the other torque transmission elements inclusive of propellers is practically determined by a set of tolerated dimension and geometrical location requirements, called geometrical dimension assembling chain [3]. Both typical and modular power plants are prone to coaxiality deviation from its permissible values and in consequence to possible failures one or more elements of the propulsion system. The excessive deviation can lead to the loads on bearings and gear teeth much higher than calculated and in result to their premature failures [4].

The usual control methods of the coaxiality deviations do not fulfil user’s expectations in the case of the gas turbine propulsion system. Difficult access to flange connections, long control time, organisational difficulties and lack of qualified personnel create hazards of taking

measurements with errors exceeding allowable values. The proposed vibroacoustic method instead of the usual coaxiality control methods was assumed the aim of this work on result of an analysis of the earlier mentioned operational hazards

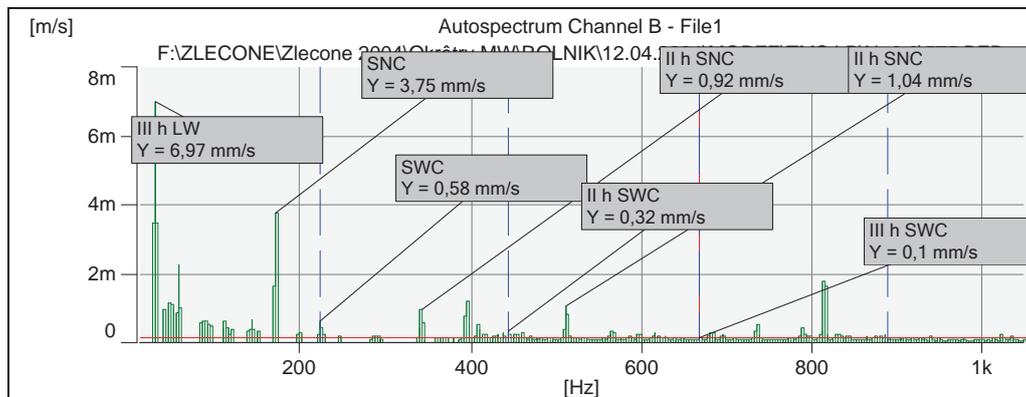


Fig. 3. Typical pattern spectra DR 77 engines, where: SNC – low-pressure compressor rotor, SWC – high-pressure compressor rotor, h – harmonics

Application of the vibroacoustic diagnostics to technical maintenance makes its possible to lower operational cost of the vessel by basing its operational on its actual technical state and predicted failure states [1].

It was assumed that determination of a relationship between the coaxiality parameters and changes of the recorded vibration signals should bring about identification of the proposed diagnostic model consisting in:

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

The research in question was limited to control of the axis slope only. This assumption was made to account for influence of the displacement hull deflection on the element position of the serial multi-shaft system. In this case, the axis displacements are controlled solely during assembling the shafting system in the production and repair stages.

The energy emitted in result of a change of technical state of the flange connection was assumed to be reflected in the recorded vibration signal. By using experiments, position and fitting direction of accelerometers were chosen at the transverse cross-section of the transmission gear just over the main, radial bearing of the input shaft. On the basis of detail identification of the main signal against disturbances, the lateral measurement direction with respect to the rotation axis was determined. The coaxiality measurements were carried out in the conditions of not transmitting the torque to the ship propeller.

In result three conclusions dealing with general measurement principles could be elaborated as far as the investigated vessel is concerned:

1. It is important to determine the limiting values of the selected symptom at different vessel displacements. The proposed method can be applied in the entire range of the vessel's displacement
2. Assessment of axis slope at the flexible coupling on the basis of the symptom in question is of a secondary importance.
3. Selection of the accelerometer fitting position is the most important because of close vicinity of the propulsion (reduction) gear main radial bearing. Accelerometer cantilevers applied during

the measurements did not influence measurement results, as their resonance frequencies were higher than that of the selected vibration symptom.

## 5. Remarks

1. Application of the proposed approach makes managing the engine's operation time much more rational, especially at its end.
2. The proposed approach is non-invasive and does not require taking the ships out of service.
3. Realisation of investigations of the kind makes it possible to collect data for a database of the future monitoring system of ships, which is expected to improve their operational features.
4. Experience gained during the investigations would be utilised for other power plants equipped with gas turbines.
5. Presented method is enough sensitive in operation of propulsion plant that it enables to find primary symptoms of changes technical state of rotordynamics.

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