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Dynamika maszyn
Pomiary drgań,
Śledzenie rzędów

Andrzej GRZĄDZIELA

VIBRATION DIAGNOSTICS OF MARINE GAS TURBINE ENGINES IN NON – STEADY STATES

Vibration tests of marine gas turbine engines are performed as researches on-line and off-line types. Systems on-line type generally monitored one or two vibration symptoms, which asses the limited and/or the critical values of parameters and they potentially can warn and/or shutdown engines. Systems off-line types are usually used for vibration analyzing during non-steady state of work. The paper presents comparison of different methods of analyzing vibration symptoms measured under run-up and shut-down processes of marine gas turbine engines. Results of tests were received on two gas turbine engines types of the COGAG type propulsion system simultaneously. Both types of engines were not fitted with vibration monitoring system. Main goal of researches was qualified of helpfulness and unequivocally results received by methods of synchronous measurement, order tracking and auto tracking.

DIAGNOSTYKA DRGANIOWA OKRĘTOWYCH TURBINOWYCH SILNIKÓW SPALINOWYCH W STANACH NIEUSTALONYCH

Badania drganiowe silników turbinowych realizowane są w według procedur on-line i off-line. Systemy typu on –line zwykle nadzorują jeden lub dwa symptomy drganiowe, których przekroczenie tolerowanych wartości wyzwala alarm lub zatrzymuje maszynę. Systemy off- lne są zwykle stosowane przy analizie w stanach nieustalonych. Referat przedstawi a porównanie dwóch metod diagnostycznych stosowanych w trakcie procesów rozruchu i zatrzymania silników turbinowych tj. pomiaru synchronicznego i śledzenia rzędów. Rezultaty badań przedstawiają wyniki uzyskane w badaniach realizowanych równocześnie na silnikach typu DR w układzie napędowym typu COGAG. Badane silniki nie posiadały własnego systemu monitoringu drgań. Głównym celem badań było uzyskanie odpowiedzi na pytanie, która z prezentowanych metod badawczych jest bardziej wrażliwa na zmiany stanu technicznego układu wirnikowego.

1. INTRODUCTION

Operation of naval ships propulsion systems is a complex task due to specific features of marine environment as well as demand of maintaining high level of serviceability and reliability of the ships. Application of periodical or on-line diagnostic procedures makes it possible to operate ship propulsion systems in accordance with their current technical state. Especially, in the case when gas turbines engine maintenance schedule is a criteria for maintenance time determination. Though such exploitation strategy makes early scheduling of maintenance operations and their logistic assurance possible, but it simultaneously contributes to increase of costs because of its replacement system of elements (technically often still serviceable ones) as well as it makes impossible to early detect primary symptoms of failures occurring before the end of maintenance time.

Application of the vibration diagnosing makes managing the engine's operation times much more rational, especially at its end and does not require taking the ships out of service. It is possible to divide vibrations measurements of marine gas turbine engines on:

- *off-line* type (measurements made as a free run or synchronous sampling);
- *on-line* type (real time monitoring).

Both methods have their own advantages and disadvantages. *Off-line* type systems are usually offered as very simple analyzers – data collectors. Defined measuring path allows in a vessels power plant, with programmed setups of registration, use of average technical personnel, whose the main task is precision in measuring procedure. Analysis of measured data proceeds beyond the shipping power plant, on the properly equipped laboratory stand. There are not wide population of data collectors *off-line* types enable to analyze vibration in real time and sign the outrun of limited values of diagnosing symptoms. The main advantage of this kind of devices is the prize, but it is necessary to underline that data collectors are mainly useful only for assessing the vibro-activity of gas turbine engines.

The vibration, diagnostics systems *on-line* type ensure permanent supervision of the technical state of gas turbine engines, including recording, analyzing, alarming and predicting. It allows to recognize primary symptoms of the permanent, technical state changing with possibility of the trend remarks. Vibration systems *on-line* type usually work as an element of the complex, multisymptoms, diagnosing system of vessels power plant.

Diagnosing such machines like gas turbine engines depends on measurement and processing of vibration signals. It is an important fact that marine gas turbine engines do not work with a constant rotational speed of compressors and power turbines rotors. That is the reason to synchronize processing method with selected reference magnitude, that is rotational frequency of one of rotors. It allows to recognize most of the typical multifunction of rotors systems. Basic, operational inefficiency of gas turbine engines include following question:

- in result of damage or crushing of the compressors' blade(s) or power turbines blade(s) – more rarely;
- in result emerged unbalancing coming from the carbon deposit or the salinity;
- in result of seizing of rotors sealing system and leaking the lubrication oil inside the rotor;
- in result of aero-dynamical misalignment between gas generator and power turbine;
- in result of thermal damages of combustion chambers – torsional vibration of the power turbine;
- in result of damage auxiliary mechanisms of the engine.

Some of inefficiency can be recognized in the vibration spectra as a change of natural frequency of rotated elements of engine, so it is a reason to introduced the synchronous sampling under variable engine condition, e.g run-up or shut-down processes. The occurrence of non-stationary effects, typical in the case of small unbalancing, can also be the result of progressive forming of damages, even though their intensity is slight in the early stages. Results presented in the paper compare different synchronous methods of vibrations analyzing and discuss on obtained results.

2. OBJECT OF INVESTIGATION

Monitoring vibration signals coming from rotated machines is a common diagnostics procedure, well known all over the world. Most of rotated machines like marine gas turbine engines are constructed as supercritical machines so analyzing of vibration parameters in the steady state are technically limited. Therefore it was decided to analyze rotors dynamics of marine gas turbine engines in non-steady states using *off-line* method. It was expected to take information on the following areas: rotor unbalancing, rotors misalignment, natural frequencies, critical speeds etc.

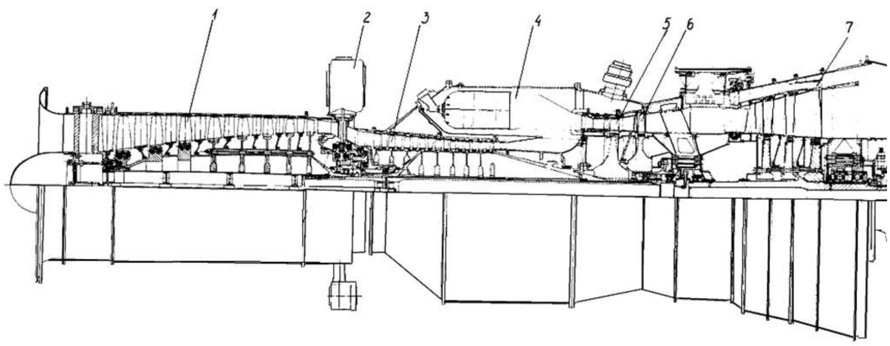

Fig. 1 Longitudinal section of rotor system gas turbine engine DR76 type, where: 1 – low pressure compressor (LPC), 2 – auxiliary drives, 3 – high pressure compressor (HPC), 4 – burning chambers, 5 –high pressure turbine (HPT), 6 – low pressure turbine (LPT), 7 – power turbine (PT)

The object of researches was a marine gas turbine engine DR76 type mounted in the COGAG type propulsion plant of Polish Navy Tarantula class corvette. The scheme of longitudinal section of rotors system presents Figure 1. The investigation covered analyzes of vibration parameters during run-up and shut-down processes in the turning of engine process.

2. NON – STEADY STATES VIBRATION SIGNALS ANALYSING

For realization of the first type of measurements the analyzer of Brüel & Kjær 3560B was used, while collecting and processing of measured data were made possible by using the program PULSE Version 12. Two measuring transducers (accelerometers ICP type) were fixed to steel cantilevers located on the flange over the front strut of the LPC. The fixing cantilevers characterized of a vibration resonance frequency value different enough from harmonic frequencies due to rotation speed of the given rotors. The measurements were taken perpendicularly to the rotation axis of the rotors. 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.

2.1 Vibration analyzing of the run-up process

First test was analyzing the run-up process in the turning of engine process. Characteristic of acceleration of the LPC rotor presents Figure 2.

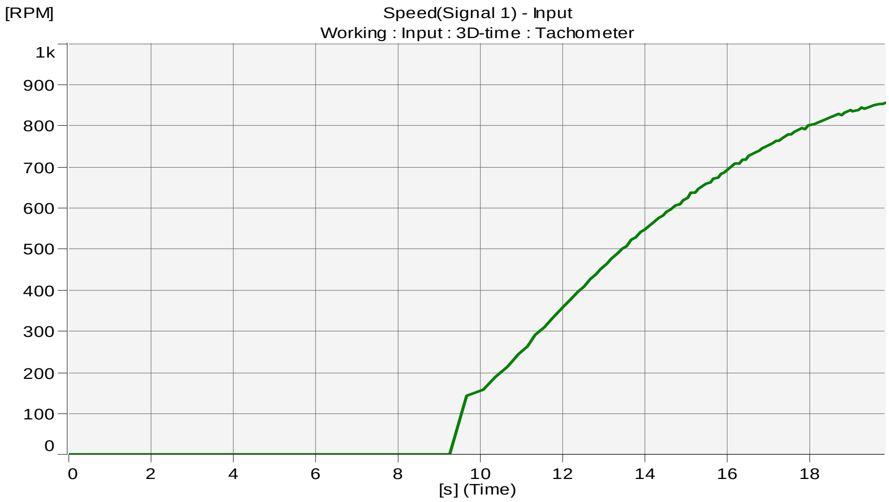

Fig. 2 Rotors LPC rotational speed characteristics during run-up process

Synchronous signal was collected from the tachometer coupled with the auxiliary drive gear box where the transmission ratio average *i*=0,125, so the LPC rotor had 8 times higher rotational speed than presented in the Figure 2. The main goal of the synchronous analyzing vibration signals during the run-up process was the identification of dynamics disturbances. The influence of "other" signals is presented in the Figure 3.

The run-up process was started in point t = 7 second (see Figure 3) so all vibration signals recorded before start point contain "other" signals coming from dynamics of another rotated machines in the power plant, natural frequencies of engine or their combinations. It allows to identify main "other" signals like: f_1 = 305 Hz, f_2 = 600 Hz, f_3 = 1,6 kHz i f_4 = 2 kHz. The most energetic signal during rotors acceleration process is the I harmonic of velocity of vibration.

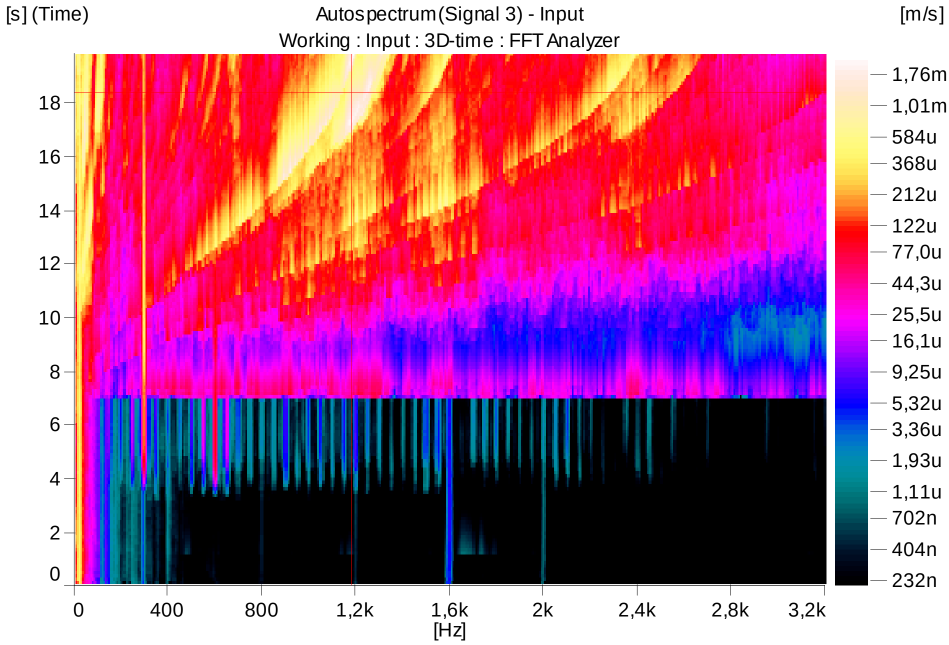

Fig. 3 Synchronous spectra of the velocity of vibration during run-up process with using the band – pass filter of 0,1Hz – 3,2 kHz range

3.2 Vibration analyzing of the shut-down process

Next test, connected with analyzes of vibration parameters, was the shut-down processes in the turning of engine process. The Figure 4 presents autospectrum of signal 3 of velocity of vibration with the use of Order Tracking procedure. Changes of parameters are presented in the domain of time function. In contrary to run-up process the main vibration signal in the shut-down process of rotor is subharmonic (1/2 of harmonic) – presented as a 4 Order. Slope of pressure of the lubrication oil in the radial bearing brought the upgrowth the misalignment between of HPC and LPC rotors (HPC shaft rotated inside the LPC shaft – see Figure 1) and typical in the technical diagnostics domination of subharmonic.

Upgrowth of stiffness of bearing system confirm the “right-hand branches” of harmonics appeared from the time point equal 4 second from 4, 8 and 12 orders when the pressure of lubrication oil fall down.

Analyses of gas turbine rotors dynamics in the non-steady states with the use of PULSE system should be made in both processes. The start-up process allows to recognize “other” signals but the identification of dynamics features is very difficult regard to the high rotors acceleration. Identification of dynamics features of rotors system is well recognized in deceleration as a main orders characteristics – Figure 5 and 6.

Analyze of the I harmonic (8 order) enables to observe changes of dynamics features as a trends. Application of the domain of rotors rotational speed function is the most important thing in basic orders analyze during shut-down process. It allows to identify changes of natural frequencies without any disturbances signals coming from thermo-dynamics processes typical for “hot work” of gas turbine engine – Figure 5.

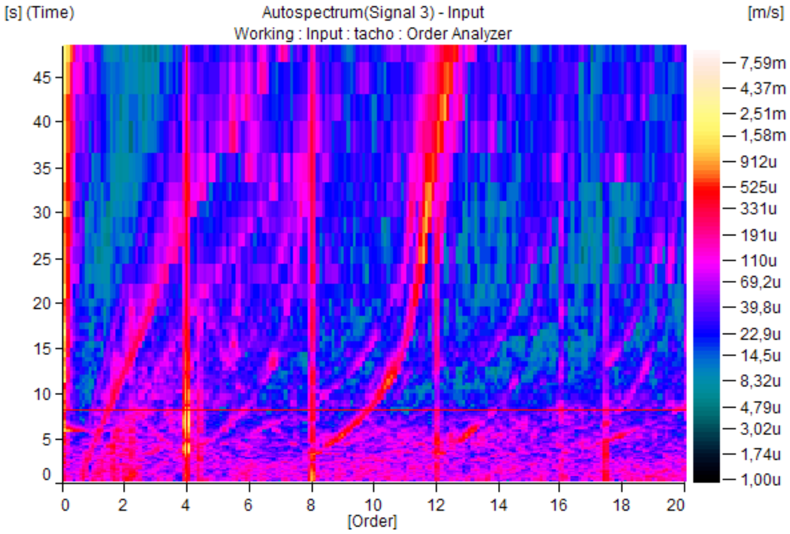

Fig. 4 Autospectrum of velocity of vibration in the shut-down process with the use of order tracking procedure, in the domain of time function

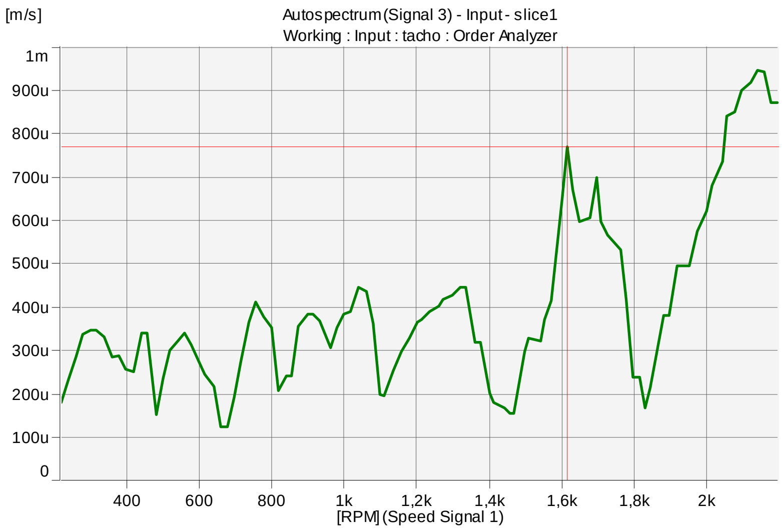

Fig. 5 Autospectrum of 8 order (I harmonic) of velocity of vibration in the shut-down process of LPC rotor stoppage.

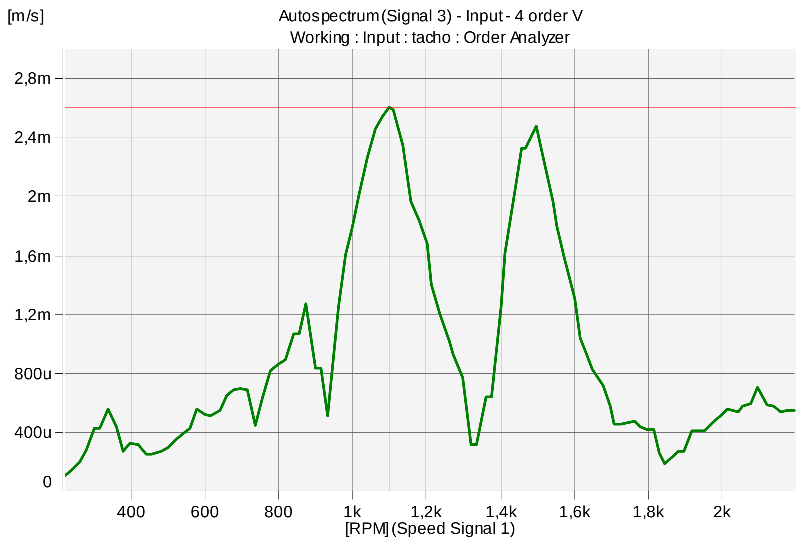

Fig. 6 Autospectrum of 4 order (subharmonic) of velocity of vibration in the shut-down process of LPC rotor stoppage.

Analyzes of subharmonics signals are very useful as well. The autospectrum of 4 order (subharmonic) of velocity of vibration in the shut-down process of LPC rotor shows individual features of analyzed rotor system. Increase of subharmonic value in the domain of rotors rotational speed is like a fingerprints of rotor system. Every changes of technical state like changes of stiffness and damping, unbalancing or misalignment caused changes in the characteristic of subharmonic – Figure 6.

4. CONCLUSIONS

Two-way realization of the investigations made reliable verification of the investigation results possible. The following detail conclusions were drawn for further diagnostic inference of compared method:

- Both methods have their own advantages and disadvantages but they can fulfill all technical requirements for diagnosing rotors systems of marine gas turbine engines.
- The synchronized measurement of vibration signals allows to recognize specified symptoms of resonance and changes of natural frequencies during processes of run-up and stoppage of rotor systems.
- Application autotracking and order tracking procedures for monitoring system of gas turbine engines enables recognize wide spectrum of typical faults recognized by vibroacoustics diagnosing.

5. REFERENCES

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