ANDRZEJ GRZĄDZIELA, D.Sc.,M.E.
Polish Naval Academy, Gdynia
Institute of Construction
and Propulsion of Vessels

Diagnosing of naval gas turbine rotors with the use of vibroacoustic parameters

SUMMARY

In the paper results are presented of vibroacoustic research on balance control of gas turbine rotors and assessment of their permissible operation times. The work is a part of implementation of an integrated diagnostic control system of gas turbines installed on Polish Navy ships fitted with COGAG propulsion systems.

INTRODUCTION

Exploitation of naval ship 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 [1]. From the side of operators, doubts are often expressed concerning maintenance times or making decision on further exploitation of an object.

The vibroacoustic monitoring systems of ship propulsion systems were first applied in the middle of 1980s [5,7]. Application of periodical diagnostic procedures or on-line monitoring systems makes it possible to operate ship propulsion systems in accordance with their current technical state. In the case of ship gas turbines the hourly period of scheduled maintenance or repair surveys is presently the criterion for maintenance time determination. Though such exploitation strategy makes early scheduling of maintenance operations and their logistic assurance possible, 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 [2,3,4].

Application of vibroacoustic techniques to the gas turbine propulsion systems, as an element of multi-symptom diagnostics, is justified not only regards the turbines themselves but also for investigations of mutual geometrical position of elements of torque transmission system as well as of control of electric energy generating sets.

OBJECT OF INVESTIGATIONS

1241 RE missile corvettes, among other Polish Navy ships, are also subject to a permanent basic diagnostic system. They are fitted with COGAG gas turbine propulsion systems. Their configuration scheme is 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 analyzing vibroacoustic signals. 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 degradation of the technical state 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.

If critical values of the vibroacoustic parameters are known then it is possible to estimate a permissible operation time period on the basis of changes with time of the investigated parameters. During realization of the investigations in question the use was made of producer's guidelines for permissible values of vibration parameters, as a initial comparative and verifying element. Because DR 76, DM 76 and DR 77 turbines are similar to each other, a uniform measurement method was applied to all the considered engines (at observing individual values of symptoms).

REALIZATION OF THE INVESTIGATIONS

For realization of the investigations the measurement instruments: GC-89 analyzer and FFT-2148 analyzer, of Bruel & Kjaer, were used making it possible to collect and process measured data.

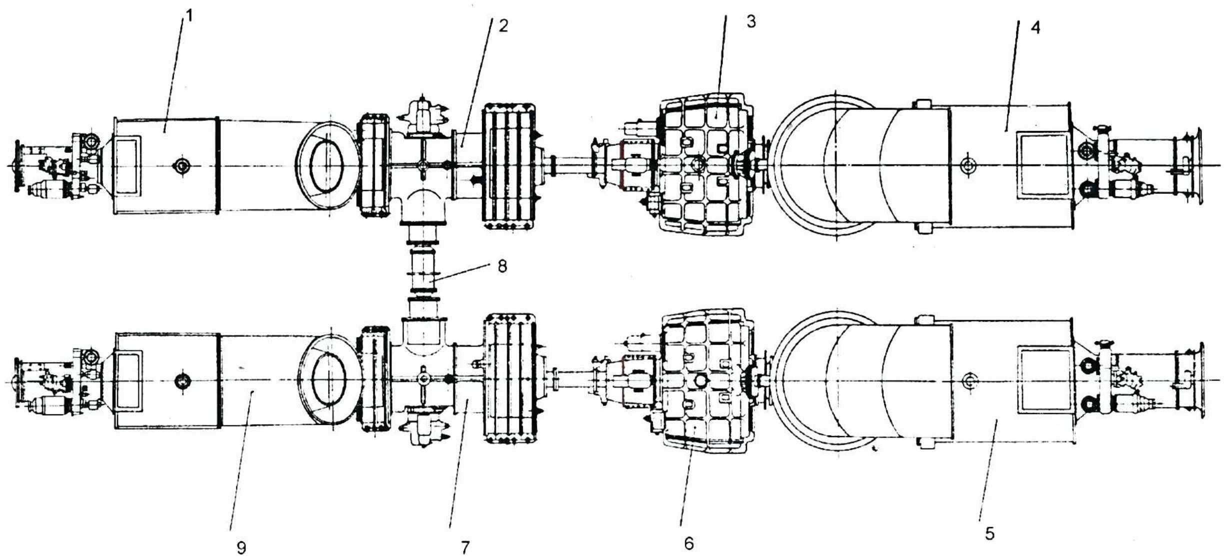

Fig.1. A scheme of the propulsion system of 1241 RE missile corvette

1 – Starboard service turbine unit of abt. 3000 kW output
2 – Starboard service reduction gear
3 – Starboard peak-power reduction gear
4 – Starboard peak-power turbine unit of abt. 9000 kW output
5 – Port side peak-power turbine unit of abt. 9000 kW output
6 – Port side peak-power reduction gear
7 – Port side service reduction gear
8 – Intermediate shaft
9 – Port side service turbine unit of abt. 3000 kW output

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 200 ÷ 300° C occuring on the high pressure (HP) compressor flange.

The fixing cantilevers had a vibration resonance frequency value sufficiently different from harmonic frequencies due to rotation speed of the turbine 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 [6].

The following magnitudes were selected by the turbines' producer as signals usable for the „defect-symptom" relation :

- Y_{LPC} - 1st harmonic value of vibration velocity amplitude connecected with the LP compressor
- Y_{HPC} - the same but connected with HP compressor
- Y_{rms} - root-mean-square value of vibration velocity amplitude within the range of 35 ÷ 400 Hz.

The changes of the vibroacoustic symptoms were analyzed in function of service time within the ranges :

for DR 76 and DM 76 engines : from 0 to 2000 hours
for DR 77 engines : from 0 to 1000 hours.

The choice was justified by the time-between-repair values scheduled by the turbines' producer.

For purpose of these investigations a simplifcation was made consisting in assuming values of the after-repair turbine vibroacoustic symptoms as those of the new turbine.

It was necessary to make such assumption due to rather low number of the investigated objects (only eight turbines of each type).

Location of the accelerometers on the engines is shown in Fig.2.

The following limit values of rms vibration velocity amplitude were specified by the turbines' producer :

for DR 76 and DM 76 engines :
- permissible value of Y_{rms} equal to 24 mm/s
- permissible value of harmonics Y equal to 17 mm/s.

for DR 77 engines :
- permissible value of Y_{rms} equal to 30 mm/s
- permissible value of harmonics Y equal to 20 mm/s.

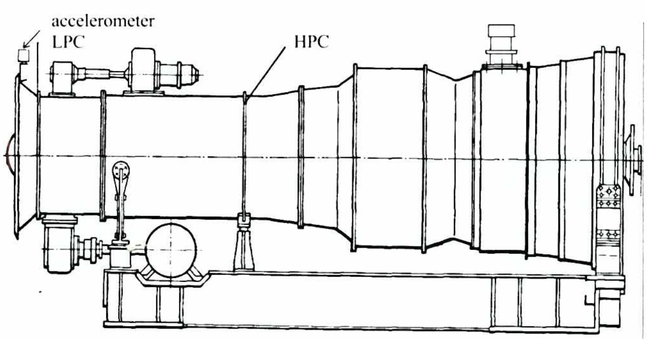

Fig.2. Location of the accelerometer on the DR 76 and DR 77 engines
***Notation :** LPC – low-pressure compressor*
HPC – high-pressure compressor

For further diagnostic inference the criterial 1st harmonic values of HP compressor was rejected for the reason of an important influence of damping decrement on recorded values of Y_{HPC} signals. Determination of the maintenance time on the basis of a Y_{HPC} signal value is possible only indirectly - by analyzing Y_{rms} and Y_{LPC} signals.

Results shown in Fig.3 and 4 of the investigations of changes of the considered values of symptoms during ship operation indicate that the maintenance time is a function of not only turbine design features, but also of a selected exploitation policy. At the considered service load spectrum the expected maintenance time for both types of turbines was twice as long as that specified by the turbines' producer.

As it was necessary to adjust operation procedures to warranty terms it was decided to establish two-way control of cleanness of the gas flow part of the turbines : 1st - by means of the endoscopic method and 2nd - assessment of changes of the vibroacoustic parameters. The control is carried out at least two times a year for all gas turbine engines in service. Its scope also contains recording the values of the operational parameters whose changes could be an initial symptom of failures of the coupled devices as well as elements of the fuel supply system. All information is recorded and stored in the database of the system in operation.

Results of the maintenance time assessment on the basis of Y_{LPC} parameters for DR 77, DR 76 and DM 76 engines are presented in Fig.3 and 4.

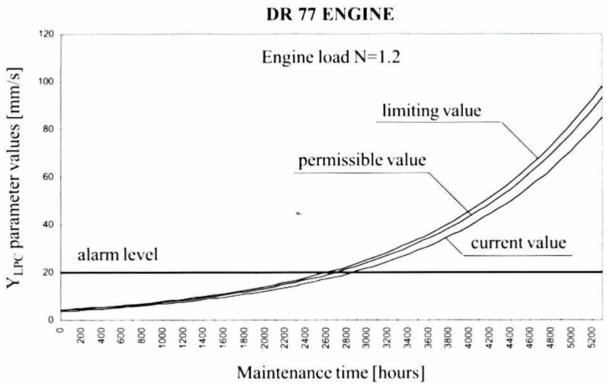

***Fig.3.** Maintenance time assessed by means of Y_{LPC} parameter*

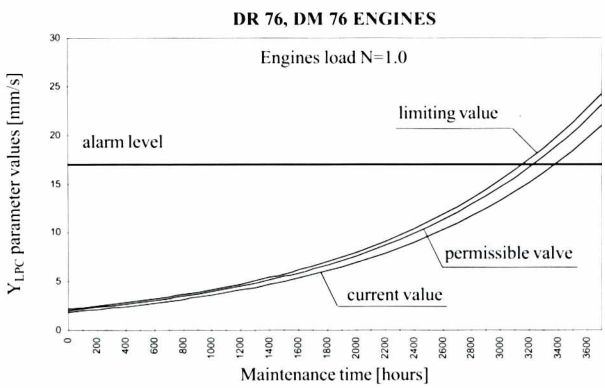

***Fig.4.** Maintenance time assessed by means of Y_{LPC} parameter*

In order to obtain uniform diagnostic procedures regarding unbalance assessment of the turbine rotors the dimensionless parameters characterizing that state 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 those most sensitive :

- 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.
- 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.

From an analysis of the results the following minimum values of S1 and S2 parameters were determined :

for DR 76 and DM 76 engines :

$S1_{LPC}$ = min 1.5
$S2_{LPC}$ = min 2.5
$S1_{HPC}$ = min 1.5
$S2_{HPC}$ = min 2.5

for DR 77 engine :

$S1_{LPC}$ = min 1.5
$S2_{LPC}$ = min 2.8
$S1_{HPC}$ = min 1.7
$S2_{HPC}$ = min 2.9

where : LPC stands for LP compressor,
HPC – for HP compressor.

By analyzing the kinematic system, the front internal bearing of the HP compressor rotor was selected as the most dynamically and thermally loaded one. By means of harmonic analysis of the vibration excitations connected with the bearing's work regarding the internal shaft unbalance it was possible to determine permissible values of the velocity amplitude of the vibrations characteristic for frequency of the difference V_R of the rotor velocities of HP and LP compressors. They are as follows :

1st harm V_R = 8.0 mm/s
2nd harm V_R = 1.6 mm/s

The presented method was verified by investigating also other parameters characterizing technical state of the engine in function of operation time, such as skid, endoscopic control, starting parameters, lubricating oil contamination etc. Moreover, the permissible diagnostic parameter values specified by the producer were taken as those verifying the assumed vibration symptoms. The accelerometers were fixed in the same way as that assumed in the turbine producer's model of vibration energy propagation. Changes of values of S1 and S2 parameters are presented in Fig.5 and 6.

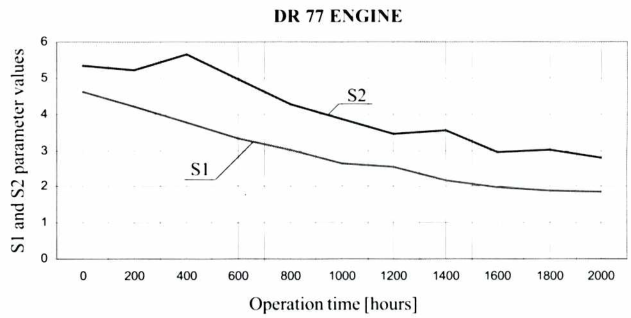

***Fig.5.** Changes of values of S1 and S2 parameters in function of operation time for DR 77 engine*

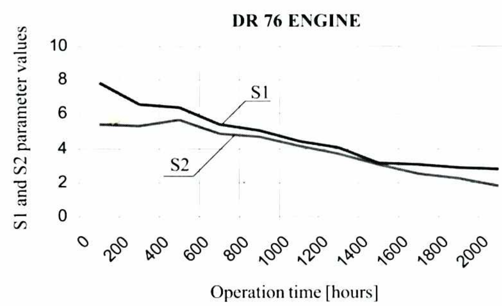

***Fig.6.** Changes of values of S1 and S2 parameters in function of operation time for DR 76 engine*

COMMENTS TO RESULTS OF THE INVESTIGATIONS

Two-way realization of the investigations made reliable verification of the investigation results possible.

The following detail conclusions were drawn for further diagnostic inference :

- For DR 76 engines: Y_{LPC} vibroacoustic parameters are diagnostically susceptible at the dimensionless engine load N = 1.0 (i.e. at the nominal power output) and for DR 77 engines : Y_{rms} and Y_{LPC} parameters at the engine load N = 1.2.
- Changes of 1st harmonic values connected with the HP compressor rotors (Y_{HPC}) and the LP ones (Y_{LPC}) at the work of DR 76 and DR 77 engines at idle load are hardly noticeable in function of operation time therefore their operational applicability is too low.
- Changes of Y_{rms} parameter with operation time are not unambiguous hence it is of a low diagnostic merit.

On this basis „symptom value – operation time" relationships were determined, and the time to next maintenance finally assessed. The expected maintenance time for DR 76 and DM 76 engines, evolving from exceedance of permissible symptom values during normal operation of the engine, was assumed the criterion for estimation of the compulsory maintenance time of the engines. For the calculation of Y(t) values the factor k = 1.1 (covering 10% measurement error) and the user confidence factor m = 1.05 was applied as follows :

$$Y(t) = k \cdot m \cdot Y_r(t)$$

where :

$Y_r(t)$ – vibration parameter function of operation time

For DR 77 engine the Y_{LPC} parameter is diagnostically susceptible because it leads to a shorter maintenance time at the considered maximum load. By taking into account the between-repair-time period for DR 77 engines amounting to 1000 hours the expected maintenance time of 2600 hours was assessed in accordance with its technical state on the basis of Y_{LPC} parameter values (Fig.3).

DR 76 turbine engines are installed in the considered service propulsion system. The load N = 1.0 of them was assumed the criterion for determining their maintenance time basing on exceedance of permissible values of the considered symptoms at normal engine operation.

For estimation of the engine's maintenance time according to its technical state such parameter was selected whose normal service changes determine the maintenance time shortest at a higher load.

This was based on the following two assumptions :

* Forces connected with various unbalance forms, manifested in recorded vibration signal changes, increase along with rotational speed increase (hence also with engine's load).
* Results of the investigations at the load N = 0.6 of DR 76 service engines and N = 0.8 of DR 77 peak-output engines have been rejected as the least credible ones. At these loads the engines operate within resonance speed ranges therefore the results could not be the basis for technical state assessment of the engines.

Hence for estimation of their maintenance time, Y_{LPC} parameter was selected and its value of 3150 hours was determined from exceedance of the permissible value (Fig.4).

FINAL REMARKS AND CONCLUSIONS

- Application of the proposed approach makes managing the engine's operation time much more rational, especially at its end.
- The proposed approach is non-invasive and does not require taking the ships out of service.
- Realization of investigations of the kind makes it possible to collect data for a database of the future monitoring system of ships, expected to improve their operational features.
- Experience gained during the investigations would be utilized for other power plants equipped with gas turbines.
- The proposed diagnostic method is a coherent element of Basic Diagnostic System used by the Polish Navy for many years.
- The proposed exploitation method leads to important economical profits and especially to reliability improvement, a first-rate problem.

From analysis of the presented results the following detail conclusions dealing with vibroacoustic investigations can be offered :

- For further research the following target operation times of rotor systems (at the assumed load spectrum), required for their maintenance should be assumed :
  - 3150 hours - for DR 76 and DM 76 turbines
  - 2600 hours - for DR 77 turbines.
- Assessment of the engine technical state by means of S1 and S2 vibration parameters makes it possible to flexibly utilize engine operation time in the case of not performing repair operations.
- Periodical control of Y_{LPC} parameter trend development enables to credibly represent changes of a given parameter in function of operation time.
- The Y_{LPC} parameter was selected the same for both considered engines due to its unambiguous dependence on operation time and similar character of its changes.
- The proposed maintenance time resources concern only the rotor sets. Assessment (in the proposed time instant) of serviceabilty of the coupled devices, fuel supply and lubricating systems was not included into the scope of the present investigations.

Appraised by Adam Charchalis, Prof.,D.Sc.,M.E.

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Conference

WSM

Composite materials

PTMK

The West Pomeranian Division of the Polish Society of Composite Materials (PTMK), based at Maritime University of Szczecin, has been active since January 2000. It gathers scientists and industrial specialists and is orientated to polymer as well as metallic composites, the modern structural materials.

On 12 June this year the Division organized a scientific seminar during which, apart from organizational matters, the following topics were presented and discussed :

* *Reinforced thermoplastics – their kinds and technologies* by Prof. Wacław Królikowski
* *Role of boundary layer in polymer composite materials* by Prof. Andrzej Błędzki
* *Composites manufactured by means of powder metallurgy* by Prof. Jerzy Nowacki
* *Comparison of abrasion resistance of grey cast iron and AK9-SiC composite* – by Prof. Wojciech Przetakiewicz

The four seminar papers together with another seven ones are contained in the first publication of the West Pomeranian PTMK Division. It presents scientific accomplishments of that scientific circle in the area of modern structural materials wider and wider applied in the industry.