Analysis of vibration parameters of ship gas turbine engines

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ABSTRACT

This paper presents a method of vibroacoustic control of ship gas turbine engines. Analysis of recorded parameters makes it possible to identify unbalance of rotors, as well as sources of the unbalance. The presented software ANALIZA makes measured data storing and processing for engine diagnosing purposes possible.

Key words : gas turbine engine, technical diagnostics, vibrations, database

INTRODUCTION

Diagnosing the ship gas turbine engines covers a wide range of service parameters and maintenance operations [1]. One of them is the control of allowable unbalance of rotors. Identification of various unbalance forms, its values and fitting places of correction masses, is commonly known. Such tests have been carried out on Polish Navy ships for more than 20 years. The Diagnostic Unit for Gas Turbine Engines has realized the tests on the engines of four types. In the case of combat ship's power plants the diagnostic procedures are limited for a few reasons. The most important is the necessity of being still ready to start the engine, connected with tactical technical demands. The other ones are associated with a lack of information on structural parameters, guarantee limitations, incomplete amount of spare units etc.

OBJECTS AND CONDITIONS OF TESTS

The frigates of *Oliver Hazard Perry* type a.o. belong to the Polish Navy ships which are subjected to diagnostic control. They are equipped with the COGAG combined propulsion systems fitted with two LM 2500 General Electric gas turbine engines.

The LM 2500 engines are gas turbines adjusted to sea conditions, widely used on contemporary naval ships. They are composed of :

- ★ 16 – stage axial compressor of 18 : 1 maximum compression, whose first 7 stages are fitted with inlet guide vanes
- ★ ring-type combustion chamber fitted with injectors making it possible to burn fuels of various purity classes
- ★ 2 – stage high pressure turbine of cooled blades, being the main drive of the compressor and auxiliary devices coupled with the engine
- ★ 6 – stage low pressure turbine being the propelling one.

The main element of the axial compressor is its rotor. It consists of 3 rotor discs of the stages marked I through XVI (see Fig.1).

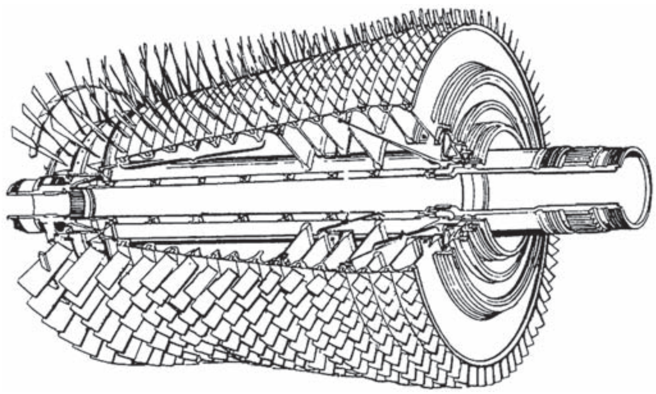

Fig. 1. *Cross-section of LM 2500 engine's compressor rotor .*

The vibration monitoring system which LM 2500 engines are equipped with, synchronously measures vibrations being the information source on rotor unbalance, which are generated over the middle bearing of the gas generator (GG) and over the fore bearing of the propulsion turbine (PT). The fixing place of the vibration gauge over the compressor bearing is shown in Fig.2.

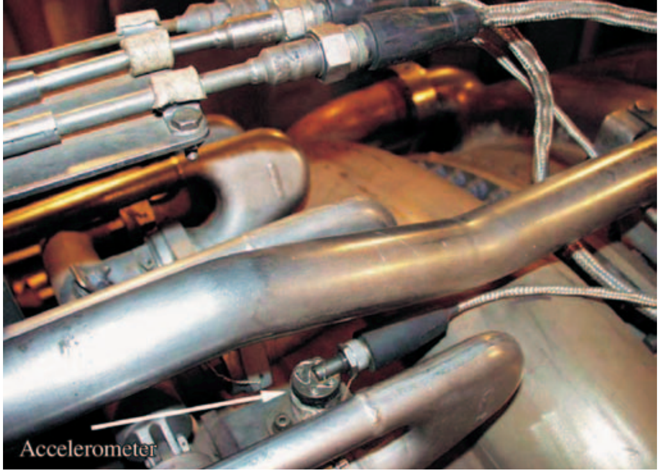

Fig. 2. *The fixing place of the accelerometer over the gas generator .*

The maximum (*peak – to – peak)* value of vibration displacement amplitude within the range of the middle-pass filter controlled by synchronizing signal taken from rotational speed of both rotors, is a diagnostic parameter. The set values of *warning* signals and *shutdown* ones react only to a surpass of tolerated values. The system does not analyze trends of fundamental harmonics and relations of successive harmonics of rotors, characteristic for particular rotor stages.

The preliminary trend analysis of vibration parameters, for purposes of the mentioned diagnostic system, was based on the parameters provided by the engine producer. On the basis of available documents, an analysis of history of changes of the parameters was performed by accounting for trends of changes of symptoms respective to their limiting levels. According to the engine producer guidelines, the vibration tests contain the rms displacement amplitude analysis, given in [mils] (which stands for 1/1000 inch). The analysis covered the frequency band corresponding with the 1st harmonic of rotational speed of the gas generator – for (GG/GG) and (GG/PT) signals and the propulsion turbine – for (PT/PT) and (PT/GG) signals, measured simultaneously over the middle bearing of the gas generator and the rear bearing of the propulsion turbine. The used symbols were adapted from the ship monitoring system of operational parameters and they stand for, respectively :

- ❖ GG/GG – GG 1st harmonic signal measured on GG (gas generator), [mils]
- ❖ PT/GG – PT 1st harmonic signal measured on GG (gas generator), [mils]
- ❖ GG/PT – GG 1st harmonic signal measured on PT (propulsion turbine), [mils]
- ❖ PT/PT – PT 1st harmonic signal measured on PT (propulsion turbine), [mils].

To obtain reliable diagnostic parameters, the gas turbine engine tests realized by the team of Polish Naval University (PNU) since 1987, have been based on a multi-symptom diagnostic model whose one of the basic tasks is the recording and analyzing of vibration and acoustic signals.

Identification of diagnostic symptoms and assessment of their sensitivity was carried out in compliance with the standard diagnostic procedure. A schematic diagram of decision--making process used for identifying the unbalance of rotors is presented in Fig.3.

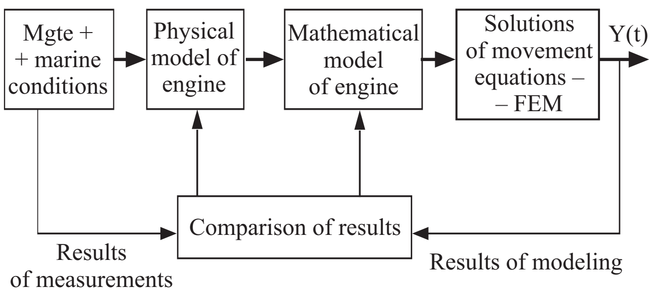

Fig. 3. Schematic diagram of the used decision-making process.

REALIZATION OF MEASUREMENTS

The tests were performed by fixing the accelerometers of charge type close to the measuring transducers of the ship monitoring system. The fixing place was so chosen as to eliminate disturbance of signals. In the case of load-carrying bearings of rotors one should choose a bearing body console free of ducts of other media. Only the strut no. 5 („EMPTY") fulfilled the requirement (Fig.4). The accelerometer fixture was so designed as its resonant frequency at the measurement axis was not superimposed on the fundamental harmonics associated with rotational speeds of both rotors. The chosen measurement direction was perpendicular to the rotation axis of rotors [3, 4].

For realization of the tests, the measurement instrumentation capable of data recording, collecting and processing, was used, namely the FFT Bruel &Kjær analyzer of 2148 type together with the software PULSE v 9.0.

On the basis of usefulness analysis of vibration parameters the following were chosen as useful signals for the relation „defect - symptom" :

- ➢ value of the 1st harmonic of vibration velocity amplitude associated with the gas generator compressor – Y_{GG} [mm/s]
- ➢ value of the 1st harmonic of vibration velocity amplitude associated with the propulsion turbine – Y_{PT} [mm/s]
- ➢ as well as the rms values of vibration acceleration amplitudes, characteristic for vibration frequencies of particular stages of rotors.

To elaborate uniform procedures for unbalance assessment of rotors of gas turbine engines having service wear of various degrees, a concept of finding dimensionless parameters characterizing that state, was applied. With the use of a theoretical analysis of excitations as well as diagnostic test results, the following symptoms were selected as the most sensitive [2] :

- ➔ S 1 – ratio of the average value of vibration velocity amplitude of the relevant rotor (1st harmonic) and the component which corresponds with 2^{nd} harmonic of excitation frequency of the relevant rotor, and
- ➔ S 2 – ratio of the average value of vibration velocity amplitude of the relevant rotor (1st harmonic) and the component which corresponds with 3^{rd} harmonic of excitation frequency of the relevant rotor.

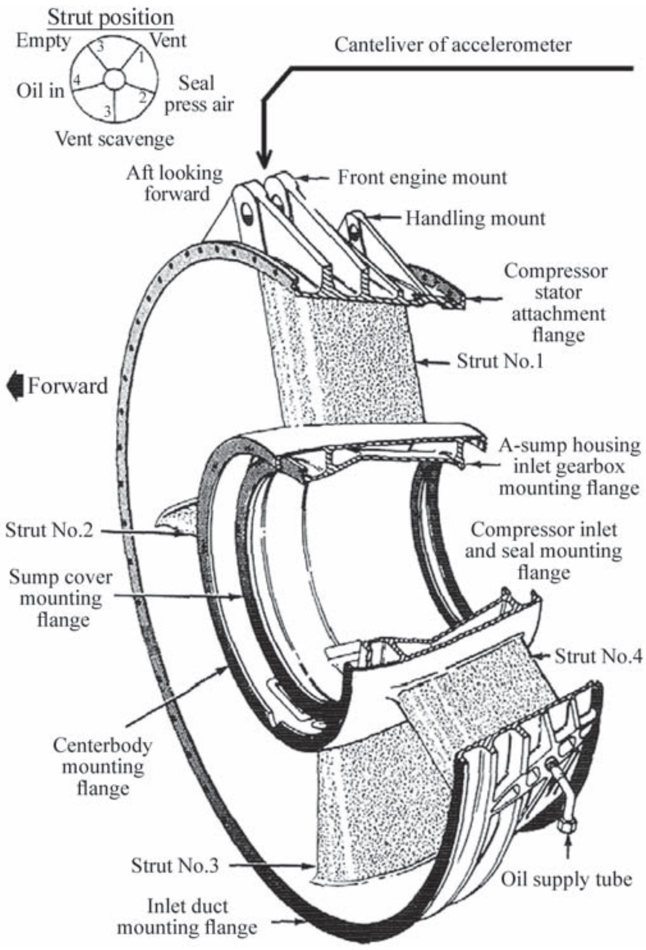

Fig. 4. The fixing place of the vibration gauge .

For diagnosing purposes the vibration symptoms was divided into 3 groups, Tab.1.

***Tab.1.** Groups of symptoms*

Group	Vibration parameters
1	1st harmonic of GG/GG signal [mm/s] 1st harmonic of GG/PT signal [mm/s] 1st harmonic of PT/GG signal [mm/s] 1st harmonic of PT/PT signal [mm/s]
2	S1 GG [-], S2 GG [-], S1 PT [-], S2 PT [-]
3	rms values of vibration acceleration amplitudes of frequencies characteristic for particular stages of gas generator rotor .

An example spectrum of vibrations recorded over the middle load-carrying bearing of the gas generator is given in Fig. 5.

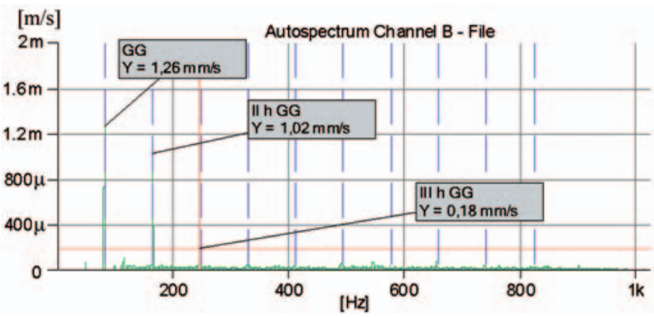

***Fig. 5.** An example spectrum of vibrations over the middle load-carrying bearing of the gas generator .*

TREND ANALYSIS

Changes of vibration symptoms were subjected to analysis of their trends in function of service time of the engines. At first an analysis of service documentation was performed to take results of so far made tests into account in diagnosing process. For the tests realized by these authors a simplification was introduced which consisted in relating the after-repair technical state of the engine (strictly – values of its symptoms) to that of a newly produced engine. Such simplification was made because of a small number of tested engines.

Results of the author tests showed that the symptoms S1 and S2 are most sensitive to changes of technical state of the rotor system. The analysis of S1 and S2 symptoms dealt with relations of the harmonic components of rotational frequencies of both the rotors. For LM 2500 engines the minimum values of the symptoms were the following :

- ☆ The minimum value of S1 taken from GG (gas generator) – 1.2
- ☆ The minimum value of S2 taken from GG – 1.5
- ☆ The minimum value of S1 taken from PT (propulsion turbine) – 1.2
- ☆ The minimum value of S2 taken from PT – 1.5

The minimum value of S symptoms should be considered as a limiting level below which a detail unbalance assessment analysis should be performed.The presented values relate to the engine load state corresponding with the gas generator rotational speed $n_{GG} > 7000$ rpm.

The recorded results were at first analyzed separately and then successively for each of the engines. In each case the measurement results were analyzed together with simultaneous checking and assessing the results of the preceding tests. This procedure, though logically correct, was very time-consuming. In order to shorten the decision making time and to start an active data base of the considered vibration parameters, the ANALIZA software was elaborated, aimed at storing and processing the measurement data for identification of technical state of rotor systems of the engines in question. The data flow chart was shown in Fig.6.

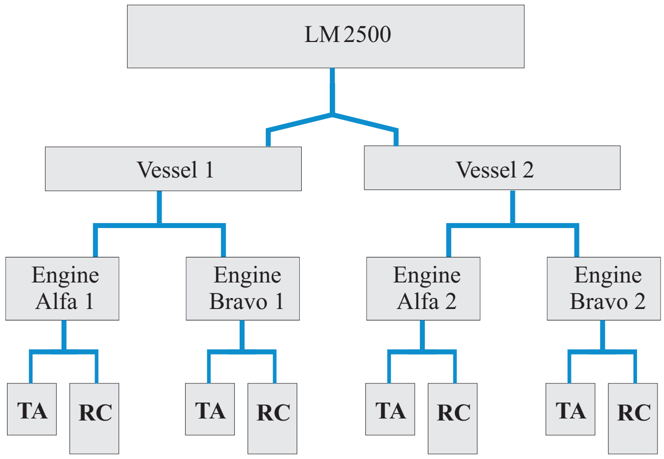

***Fig. 6.** Data arrangement in ANALIZA software.*
***TA** - trend analisis; **RC** - rating curves .*

The elaborated software processes the files recorded by the Bruel & Kjær PULSE system in the spectral form to the level of column matrix whose 1st column means the middle frequency value, the 2nd and next columns – values of a considered vibration symptom (rms value either of vibration velocity or acceleration depending on a group of symptoms). Each of the files has its own specific name recognizable for the software, which contains information on a ship, engine and its load, on which the vibration has been registered. The remaining information concerning a way of recording, is contained in the file's heading and recognized in the course of data processing. The analyzed spectra are considered at two sampling frequencies: $f_1 = 800$ Hz – for assessing the rotor unbalance and S1 and S2 parameters, and $f_2 = 12800$ Hz – for assessing the blade frequencies of particular rotor stages, Fig.7.

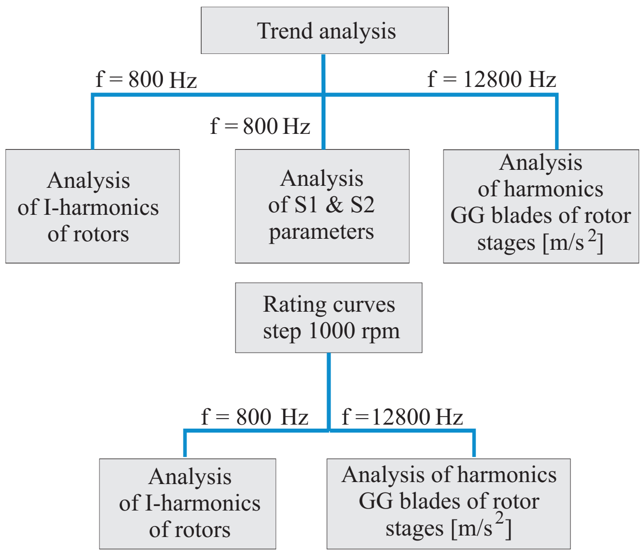

***Fig. 7.** Structure of the analyzed characteristics .*

The trend assessment of changes of the tested parameters of all the groups of considered symptoms was performed in function of service time with taking the measurement date as its variable, Fig. 8. Obviously, there is a possibility of changing

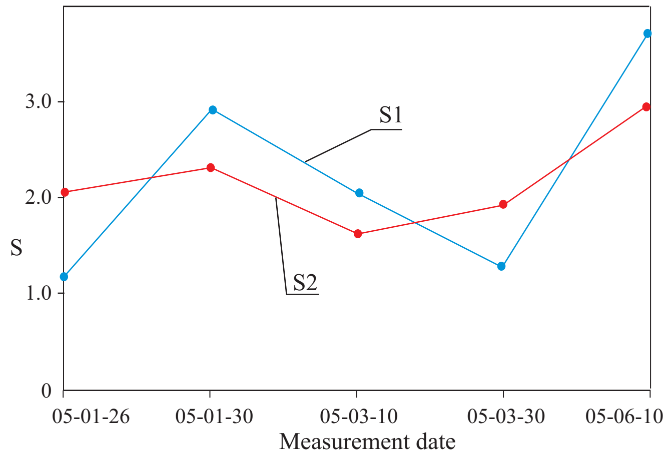

Fig. 8. *Trend analysis of S1 and S2 symptoms for the gas generator .*

a declared argument and in such case the same diagram can be appropriately presented in function of the engine's working time. Such approach makes it possible to fast derive information concerning changes in values of diagnostic symptoms and to compare them with those obtained from the other engines.

The next procedure amounts to elaboration of velocity characteristics of the considered parameters. The tests are carried out in steady states at the following constant values of the rotational speed of gas generator rotor, n_{GG} = 5000, 6000, 7000, 8000 and 9000 rpm.

To assess technical state of the rotor system, were analyzed changes of values of 1st harmonic velocity amplitude of vibrations characteristic for both rotors, i.e. of the gas generator (GG) and propulsion turbine (PT), as well as changes of S1 and S2 parameters. The achieved characteristics were compared with those taken from the preceding tests, and in the case of surpassing any symptom values by more than 20%, a detail spectrum analysis was performed.

The characteristics of changes of S1 and S2 parameters for the gas generator, presented in Fig.8 in function of measurement date, unambiguously shows that the considered symptoms are not independent on each other and that their dispersion during successive measurements is small. Such multiple tests and expected trend analysis of changes may serve as a basis for predicting the technical state changes.

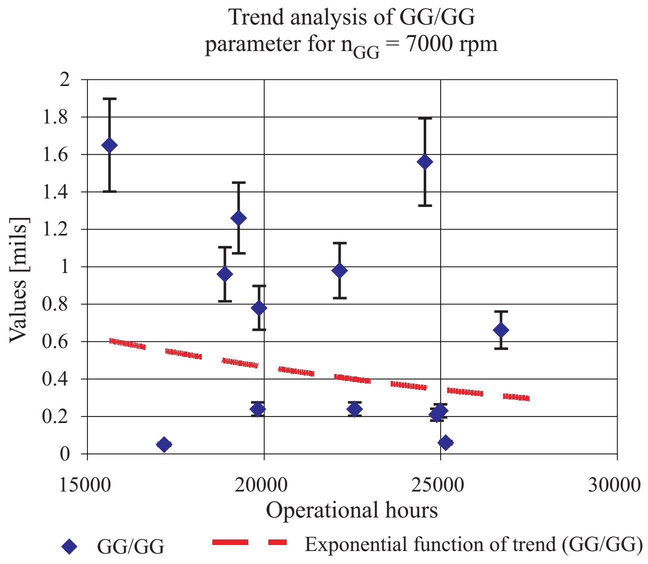

Fig. 9. *An example trend of changes of GG/GG parameter of the ship monitoring system for the tested population of engines .*

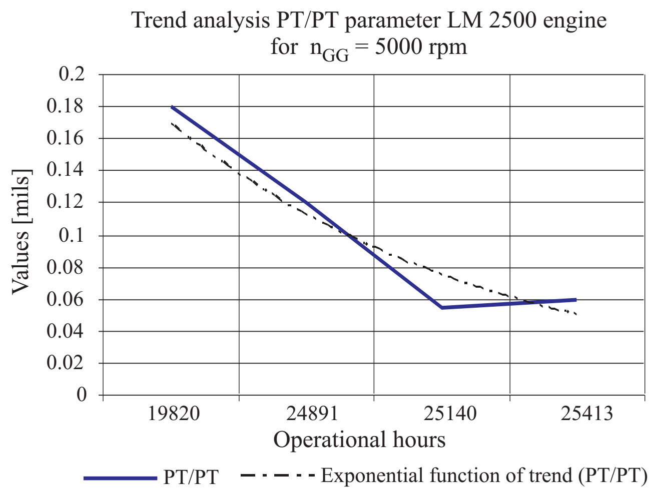

Fig. 10. *An example trend of changes of PT/PT parameter of the ship monitoring system for one of the engines .*

FINAL REMARKS AND CONCLUSIONS

- As the ship monitoring system is not capable of analyzing the trend of changes of measured parameters it has been so far not possible to assign any parameter changes to service time for the population of only 4 engines, Fig.9. It means that tests of the parameters specified by the engine producer should be realized for each of the engines individually.
- The individual statistical analysis of particular engines unambiguously indicates the relations which form the basis for predicting the changes of selected vibration parameters. It is exemplified by the trend of changes of GG/GG parameter of one of the LM 2500 engines, shown in Fig.10. Similar relations were observed for S symptoms.
- Application of the proposed method of analysis makes it possible to rationally manage engine's life-time in the case of developed wear processes. Results of the previous tests, confirmed by engine overhaul results, indicate that the symptoms specified for assessing the allowable unbalance of rotors, are very sensitive.
- The performed tests made it possible to collect the database necessary for realization of the diagnostic procedures which could greatly increase effectiveness of predicting the technical state of ship propulsion systems.
- From the analysis of the achieved results the following conclusions can be drawn:
  - The proposed concept of assessing the rotor systems by using the non-invasive vibration method does not require to take ships out of operation during control periods [5].
  - Implementation of the concept of technical state assessment of ship gas turbine engines by using the trend analysis of selected vibration parameters makes it possible to early detect an unbalance of rotors and collect a rich database for future diagnostic tests.
  - Periodical tests of trend development of selected parameters make it possible to reliably reveal changes in values of the parameters during ship operation and to assess further serviceability of the engine.

NOMENCLATURE

COGAG	–	Combined Gas turbine And Gas turbine propulsion
FEM	–	Final Element Method
FFT	–	Fast Fourier Transform
GG	–	gas generator
II h, III h	–	2nd, 3rd harmonic, respectively
Mgte	–	Marine gas turbine engine
PT	–	propulsion turbine
RMS (rms)	–	root-mean-square (average)
S	–	vibration symptom
Y	–	vibration amplitude

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Conference

Scientific seminar of regional group

On 24 November 2005 was held a successive scientific seminar of the Regional Group of the Section on Exploitation Foundations, Machine Building Committee, Polish Academy of Sciences (PAS). It was held in The State Higher Professional School in Elbląg.

For this reason Prof. Z. Walczyk, the School's Rector, presented widely recognized results of 7-year activity of the School in the area of investment, organization and education.

During the Seminar 2 papers prepared by the School's scientific workers were presented, namely :

- ***Dynamics of power turbine units – reconstruction of foundations*** – by M. Kahsin, H. Olszewski and Z. Walczyk
- ***Possible use of biomass for energy production in Elbląg County*** – by A. Rychter and J. Terlikowski.

The Seminar was ended by a very interesting visit to the casting workshop of ALSTOM Power Co.

Conference

HYDRONAV'05 and MANOEUVRING'05

On 7-10 September 2005 Faculty of Ocean Engineering and Ship Technology, Gdańsk University of Technology, and Foundation for Safety of Navigation and Environment Protection, Iława organized :

★ 16^{th} **International Conference on Hydrodynamics in Ship Design**

and

★ 3^{rd} **International Symposium on Ship Manoeuvring**

The interesting scientific meeting took place in Ostróda, the well known touristic resort located in the lake region 130 km distant south – east from Gdańsk.

The whole program contained 57 papers, and the first of them titled :

The challenge of technology innovation

was given by Mr. J.C. Card representing American Bureau of Shipping. The remaining papers were presented during 5 technical sessions :

- ☆ **Manoeuvrability** (19 papers)
- ☆ **Stability** (11 papers)
- ☆ **Seakeeping** (9 papers)
- ☆ **Resistance and propulsion** (10 papers)
- ☆ **Miscellaneous** (7 papers)

The organizers were very satisfied of that 31 papers were prepared by 10 Polish universities and scientific research centres, whereas 25 papers by foreign scientific workers from 8 European countries as well as Brazil, India and Iran.

Among Polish authors the most active were those of Gdańsk University of Technology and Gdynia Maritime University (7 and 5 papers, respectively) and among foreign authors – from Russia and Iran (6 and 5 papers, respectively).

The broad interest paid to the topics of the Conference and Symposium and to the presented base of training floating models of ships of common types augur well to the successive scientific meetings of the kind.