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Coupled non-linear vibrations in multi-supported rotors founded on slide bearings

SUMMARY

A study is presented of mutual coupling of the lateral, torsional and axial vibrations in multi-supported rotors operating in the non-linear range. The object of investigations is a 200 MW turbogenerator founded on seven slide bearings.

Presented are the methods of modelling of rotor cracks. These defects were regarded as the reasons of generating the coupled forms of vibrations. The work contains trajectories and vibration spectra of the real objects, as well as the results of tuning the model to the operational data of the objects.

INTRODUCTORY REMARKS

Coupled forms of lateral, axial and torsional vibrations of the object are observed in large-power rotating machinery such as for example power station turbogenerators. The issue of lateral vibrations of the line of rotors is a subject of many investigations and articles [1÷7]. In the literature significantly less attention is devoted to axial and torsional vibrations, and especially their mutual interaction. However, in some cases axial vibrations of the turbogenerator reach, for no apparent reason, such values that tripping the object is necessary.

The present work is a preliminary study of this very difficult and complex phenomenon. It is an attempt to answer the question what such coupling can result from and what consequences can result to the assumed object.

OBJECT OF INVESTIGATIONS AND RESEARCH TOOLS

The subject of the analysis is 13K215 turboset of 200 MW power, which operates at one of the power stations in Poland. Fig.1 presents a scheme of the object's rotor line. In the course of experimental investigations on the real object series of data were obtained such as trajectories and vibration spectra which could serve as a basis for tuning and verification of the models and the computer software developed by Institute of Fluid - Flow Machinery, Polish Academy of Sciences, Gdańsk, for the analysis of dynamics of the line of rotors and slide bearings. This is relevant to the computer software of the NLDW-70 series [8], which makes it possible to analyze coupled bending-torsional and axial vibrations in the non-linear range as well as to consider structural or technological imperfections such as a rotor crack or coupling misalignment. In order to use such advanced tools in investigations of coupled forms of vibrations on the real object experimental verification of the model and software must be obviously performed and subsequently it must be tuned to acquired operational data. This time consuming and expensive procedure was undertaken and in effect „diagnostic cards" for the reference case were obtained, an example of which is presented in Fig.2. Calculated trajectories and vibration spectra correspond quite well to the operational data acquired from the real object.

COMPUTER SIMULATION

A series of computer calculations were conducted by using an adequately tuned NLDW-70 software. It was assumed that the object is influenced only by the external excitations in the form of residual imbalance and electric field of the generator. No existence of coupled forms of vibrations (i.e. axial and torsional vibrations) was detected despite the presence in the system of strongly non-linear terms such as slide bearings.

In this light a question emerged which mechanisms are responsible for such coupling. It was then postulated that the rotor cracks are responsible for the phenomena.

It was further assumed that in the system in question some cracks were present in the medium pressure part of the rotor and in the generator, extending up to 10% and 30% of the shaft diameter D. In Fig.3 and 4 calculation results are presented in the form of coupled spectra of vibrations. It turned out that the rotor cracks of the order of 30% D were capable of inducing the system into axial vibrations of the same order as the lateral vibrations despite the fact that the system was not influenced by any other axial excitations. This is an interesting and surprising conclusion. It ought to be also noted that torsional vibrations in the medium pressure part of the rotor are significantly greater than those in the generator (Fig.4), which can be explained by the smaller mass of rotating elements of the latter.

Interesting information is gained from the comparison of Fig.5 and 6. The rotor crack of the order of 10% D (Fig.6) qualitatively changes the course of trajectories, but the vibration spectra in both cases (of the undamaged rotor and the cracked one) are practically the same. This means that the crack diagnostics based on the vibration spectra analysis can be misleading. The reason for that are phase shifts of the vibration components in the direction of x- and y-axis. Phase spectra of vibrations would undoubtedly reveal differences between the undamaged and the cracked rotor.

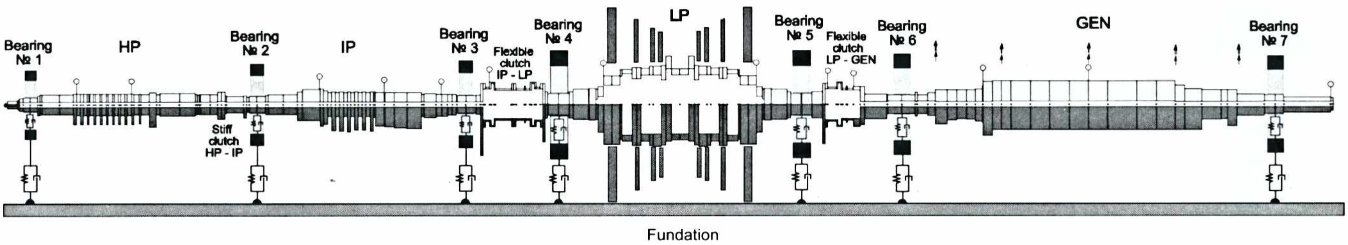

Fig.1. FEM discretization of 13K215 turboset rotor line

Card code :	SBA 5060	Object :	T - 13K215	Date :	24.09.1998
Defect description :	Test for instability threshold at support displacement				
Variable data :	No displacement				

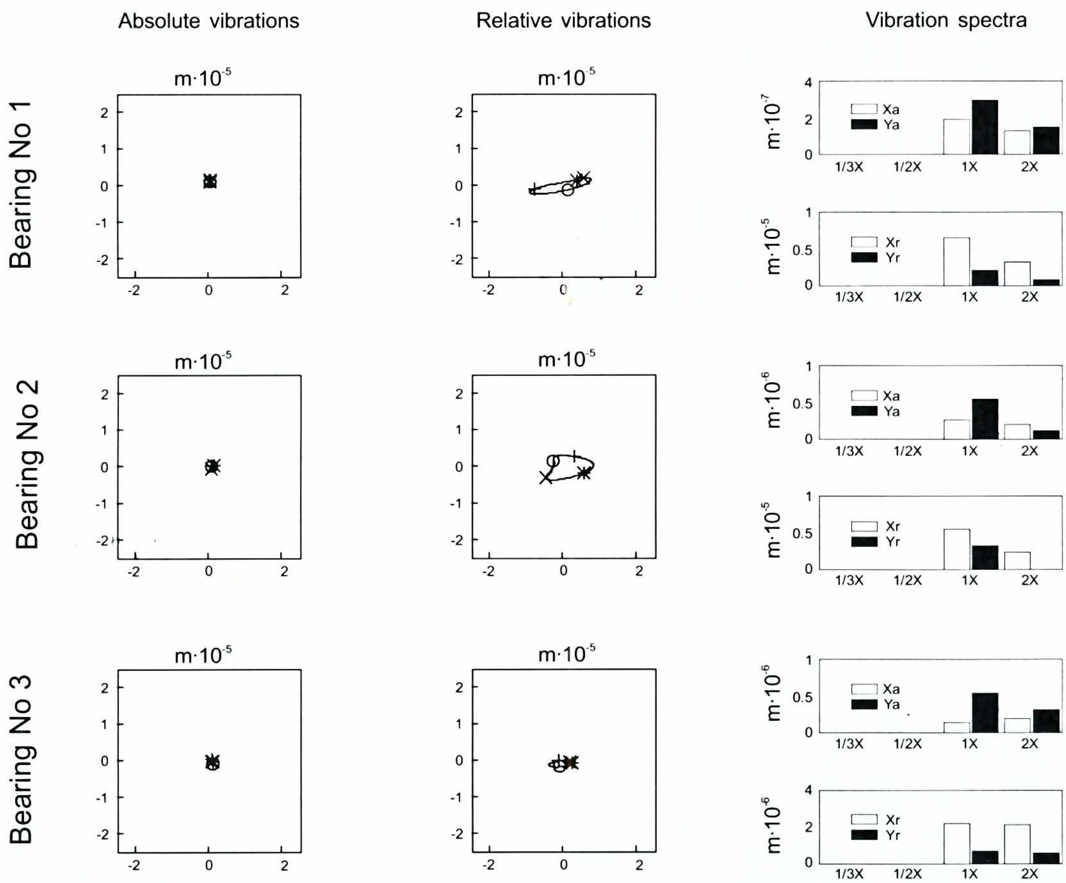

Fig.2. Effect of tuning the simulation model to the real object

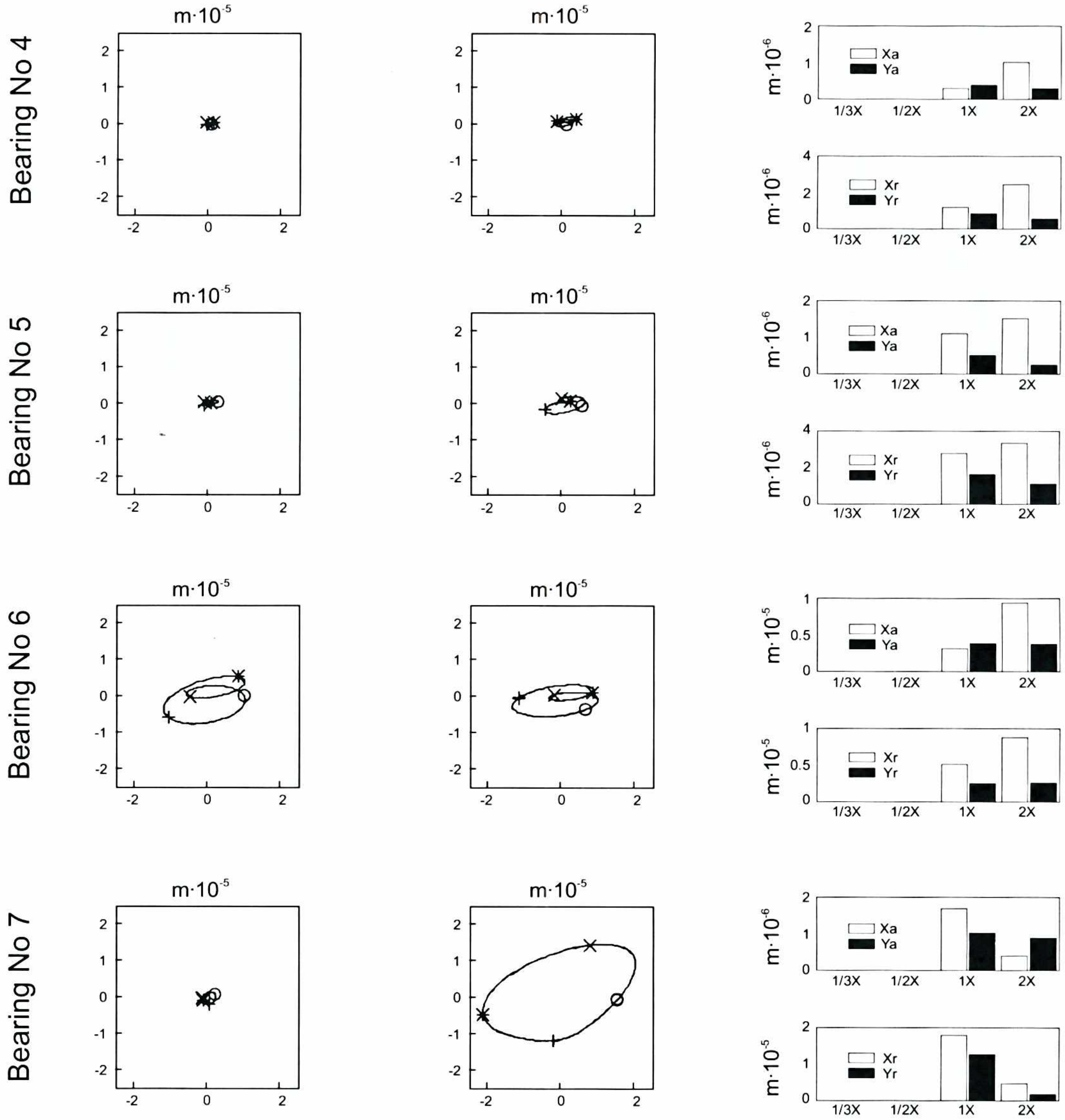

Fig.2. Effect of tuning the simulation model to the real object

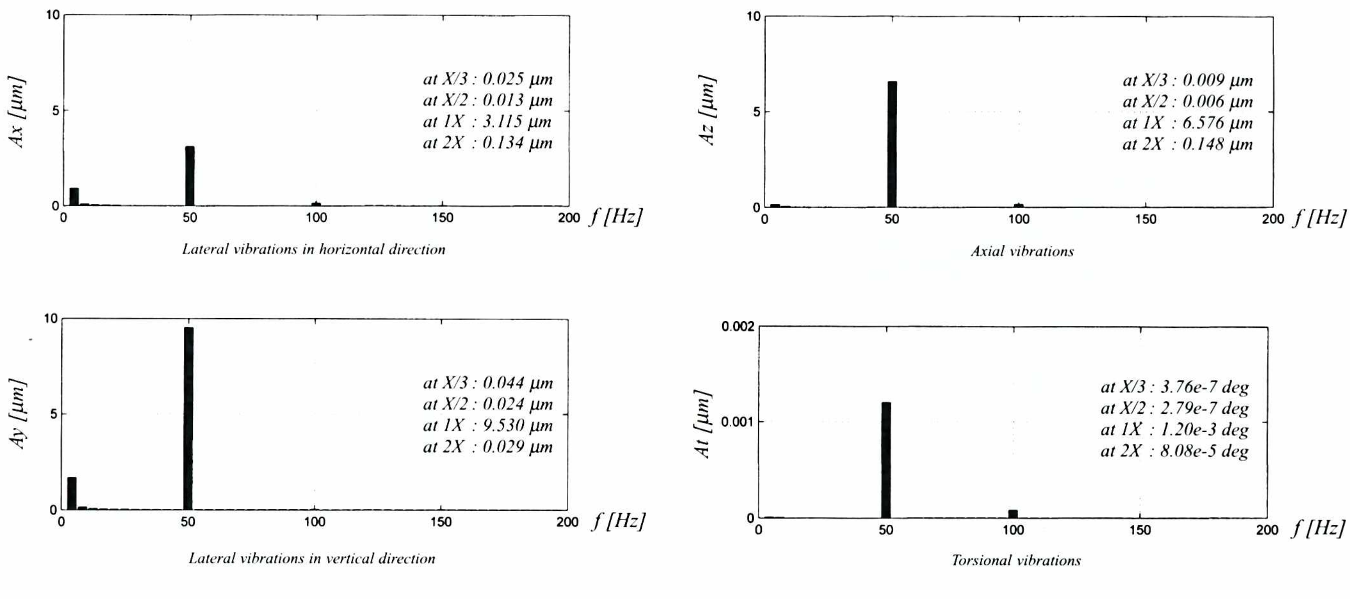

Fig.3. Coupled spectra of lateral, axial and torsional vibrations in the middle of IP rotor. Cracked rotor ($P_1 = P_2 = 30$ %) (n=3000 rev/min, df=4.17 Hz)

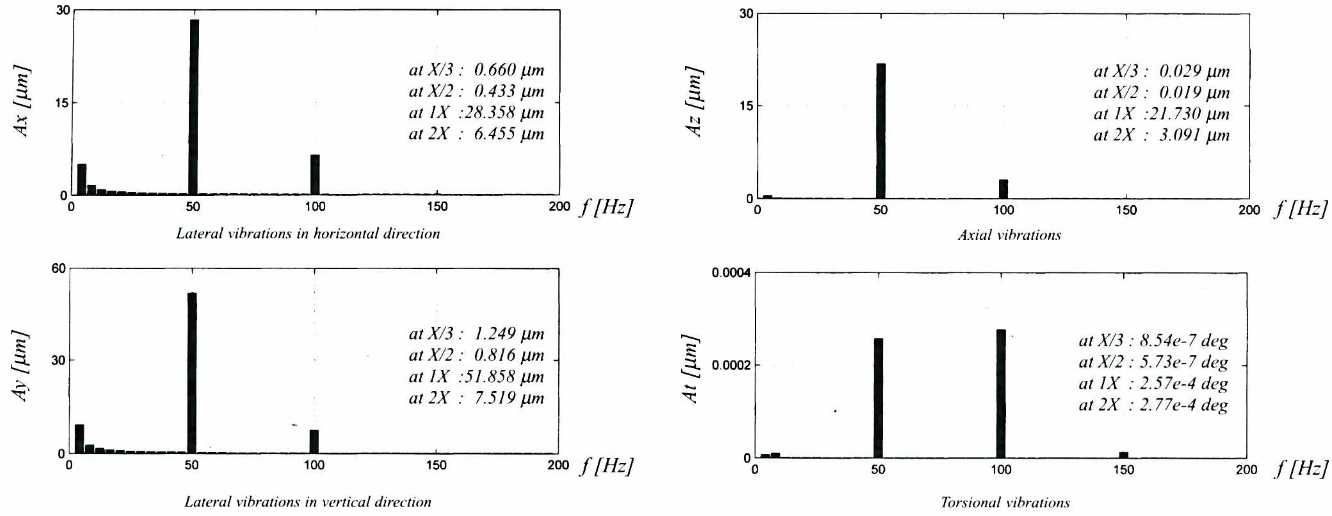

Fig.4. *Coupled spectra of lateral, axial and torsional vibrations in the middle of generator rotor. Cracked rotor ($P_1 = P_2 = 30$ %)*

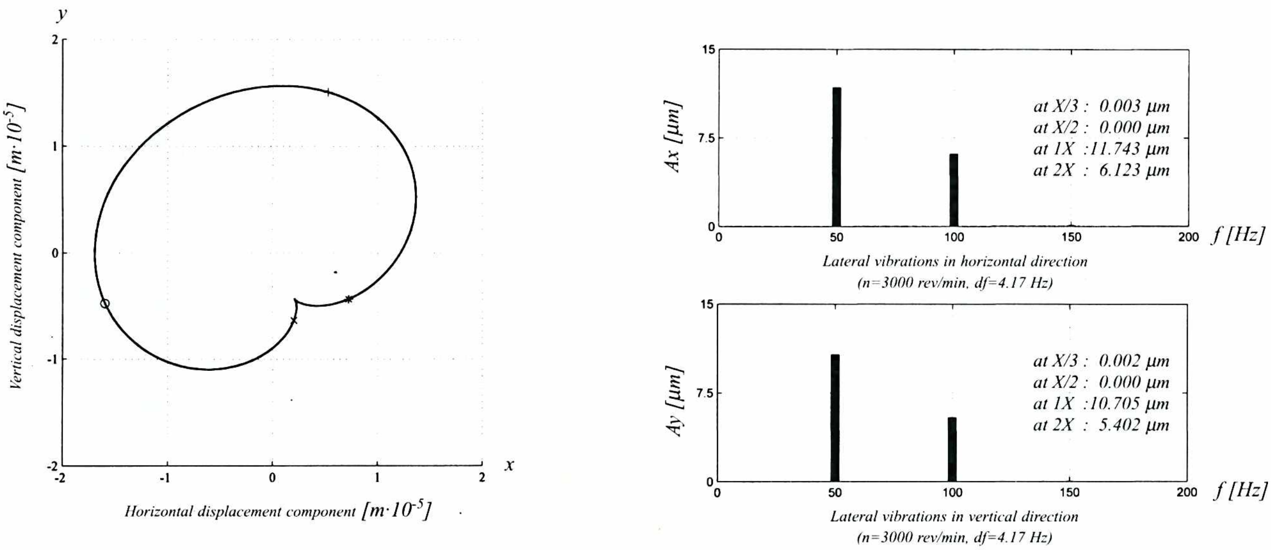

Fig.5. *Trajectories and vibration spectra for the middle part of the generator for the reference case $P_1 = P_2 = 0$ %*

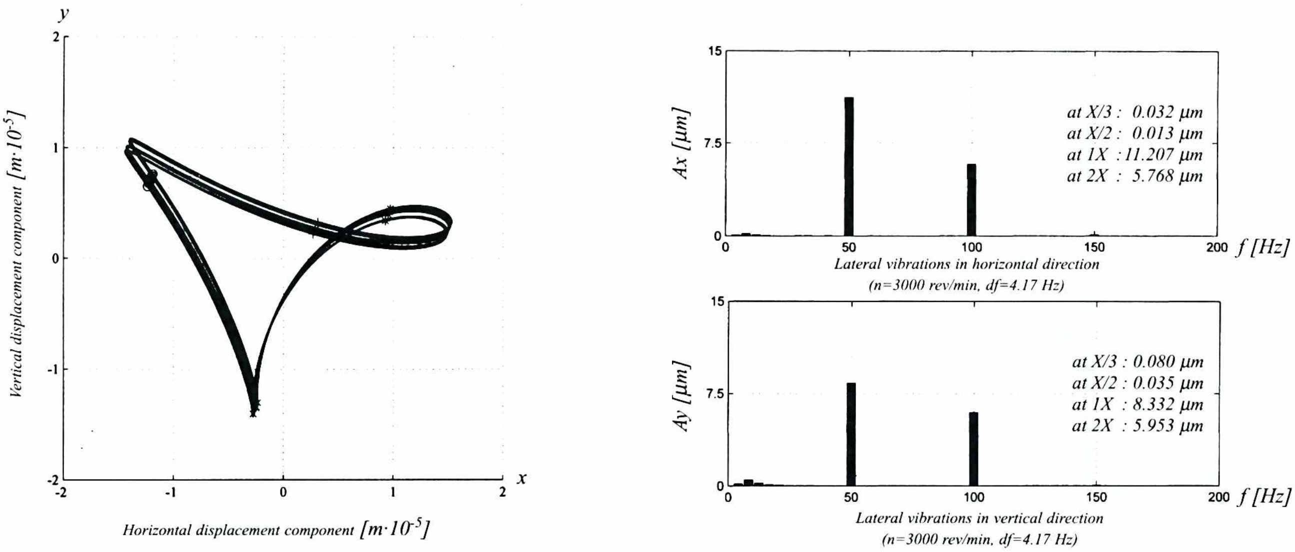

Fig.6. *Trajectories and vibration spectra for the middle part of the generator. Cracked rotor ($P_1 = P_2 = 10$ %)*

CONCLUSIONS

From the presented investigations the following conclusions can be drawn :

- In the assumed model of 13K215 turboset it is not possible to generate coupled bending, axial and torsional vibrations without including rotor's structural imperfections such as misalignments or cracks, despite the presence of the strongly non-linear elements (slide bearings) within the system.
- The rotor cracks proved to be the generation mechanism of strong coupling of bending, axial and torsional vibrations.
- For the considered cases the magnitude of the axial vibrations can be of the same order as of the lateral ones.
- A strong anisotropy is characteristic for the torsional vibration distribution along the line of rotors : 2X component of a significant value in the generator vibration spectrum and large vibration amplitude in a medium pressure part of the rotor.
- Rotor crack diagnostics based only on the vibration spectra can be misleading.

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

NOMENCLATURE

A - amplitude of vibration
df - resolution power of analysis
D - shaft diameter
f - frequency
P - coefficient of rotor cracks, defined as relation of cracks depth to rotor diameter in [%]
t - time
x, y - horizontal and vertical displacement components of vibration, respectively
xa - absolute horizontal vibration of bearing bush
ya - absolute vertical vibration of bearing bush
xr - relative horizontal vibration of bearing bush
yr - relative vertical vibration of bearing bush
X - spectrum line related to rated angular velocity of rotor
τ - dimensionless time ($\tau = \omega t$)
ω - angular velocity

Indices

a - of absolute vibration of bearing bush
t - of torsional vibration
z - of axial vibration
x,y - horizontal and vertical vibration, respectively
1,2 - location of cracks in middle of shaft spanes of IP turbine and generator, respectively

Symbols of the points in the figures No 2, 5 and 6

o - key phaser position for $\tau = 0^o$
x - key phaser position for $\tau = 90^o$
* - key phaser position for $\tau = 180^o$
+ - key phaser position for $\tau = 270^o$

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Conferences

E Forum of junior scientists

On 19÷20 June 2000 at Borówno near Bydgoszcz 2nd Conference – Forum of Junior Scientists was held on :

Scientific Problems of Machine Building and Exploitation

Such conferences are organized on an initiative of the Regional Group, Utility Foundations Section, Mechanical Engineering Committee, Polish Academy of Sciences, and hosted by Mechanical Faculty of Bydgoszcz Academy of Technology and Agriculture .

They are designed as meetings of junior scientists in the form of discussion - to improve their effectiveness - between „angry young people" and „their masters" during which :

- senior scientists present their experience concerning promotion, reviewing and carrying out scientific work
- junior scientists present topics of their current research
- individual consultations are also possible.

Forum subject matters cover scientific problems - both theoretical and applied ones - in the area of machine building and exploitation.

The meetings are also used to arrange education through presentation of special lectures and of accomplishments of outstanding junior scientists.

All presented papers are published in the Conference proceedings.

In the Forum meetings scientific workers take part from all Polish scienific centres and university faculties dealing with machine building and exploitation as well as management.

Ports 2000

On 27÷29 September 2000 2nd International Conference on :

Maritime Engineering and Ports

was held in Barcelona. To its program four papers prepared by Polish scientists were also included. Three of them, elaborated by authors from Maritime University of Szczecin, dealt with the following topics :

- *The safety of ship movement in a port channel* - by W.Galor
- *Neural method of sea bottom shape modelling for spatial maritime information system* - by A.Stateczny
- *Designing an expert system for traffic management of Szczecin - Świnoujście fairway* - by W.Uchacz and T.Kwiatek

The fourth paper (by J.Apanowicz, Polish Naval Academy) was titled :

- *Alternative positioning systems of vessel on approach to sea port – on the example of Szczecin - Świnoujscie team of ports.*