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Simulation of ship propulsion gas turbine dynamics - - an educational laboratory model

SUMMARY

The paper presents mathematical model of an aircraft two-shaft gas turbine which operates on the basis of a simple open cycle. The model was used to simulate dynamic characteristics of the gas turbine. The simulation language Simulink, a part of Matlab package, was applied for educational purposes.

INTRODUCTION

The simulation was carried out for an aircraft two-shaft gas turbine of small output, which operates on a simple open cycle. The engine (Fig. 1), installed in the laboratory of Ship Automation and Turbine Propulsion Division, Faculty of Ocean and Ship Technology ?, Technical University of Gdańsk, consists of one compressor (C), one combustion chamber (CC) and two turbines: the high-temperature 1-stage turbine (CT) driving the compressor and the low-temperature 2-stage power turbine (PT) which was coupled, on the stand, with the hydraulic brake (B). The compressor had 7 axial stages and final centrifugal stage. The longitudinal cross-section of the gas turbine and its view on the laboratory stand is presented in Fig.1b,1c.

The nominal parameters of the engine were as follows :

Power output N_e = 236 kW
Compressor rotational speed n_{CT} = 40 600 rpm
Power turbine rotational speed n_{PT} = 24 000 rpm (of the turbine shaft)
Brake shaft rotational speed n_B = 1493 rpm
Pressure ratio π = 5.1
Temperature behind the combustion chamber T_3 = 850°C.

MATHEMATICAL MODEL OF GAS TURBINE DYNAMICS

The control system shown in Fig.2 was assumed to regulate operation of the gas turbine within wide range of power engine loading between the minimum and maximum outputs. In the considered case i.e. the aircraft gas turbine the fuel pump is driven by the compressor shaft.

The gas turbine is supplied with the fuel mass flow m_f throughout the combustion chamber. The fuel mass flow is controlled by the fuel control system. The control inputs were as follows :

n^*_{CT} - compressor turbine rotational speed set point
h_B - hydraulic brake setting corresponding to the load torque.

Changing the set point value n^*_{CT} as well as h_B setting gives the change of different control variables, and as a result several steady state characteristics.

The dynamic model of the gas turbine dynamics was elaborated [1,2,3] by considering the gas turbine as composed of the following parts :

- compressor and compressor turbine
- combustion chamber
- power turbine, gear boxes and hydraulic brake
- control system.

Each element has the output and input signals [1,2]. The dynamic model of the whole controlled object in question is presented in Fig.3. The following inputs to this system were assumed :

- the mass flow rate m_f
- the hydraulic setting h_B.

The output variables were as follows :

- the compressor turbine rotational speed n_{CT}
- the power turbine rotational speed n_{PT}
- the gas temperature behind the combustion chamber T_3.

The scheme of the control system dynamic model is presented in Fig.4.

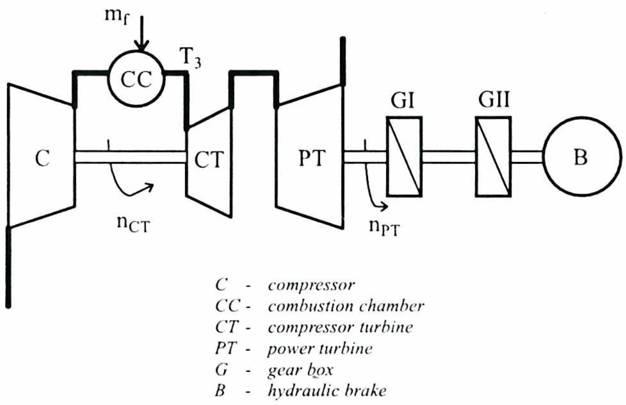

Fig.1a. *Scheme of the two-shaft gas turbine*

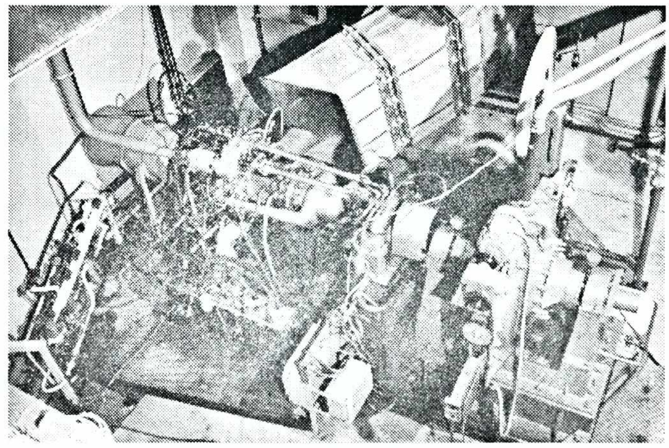

Fig.1b. *View of the gas turbine on the laboratory stand*

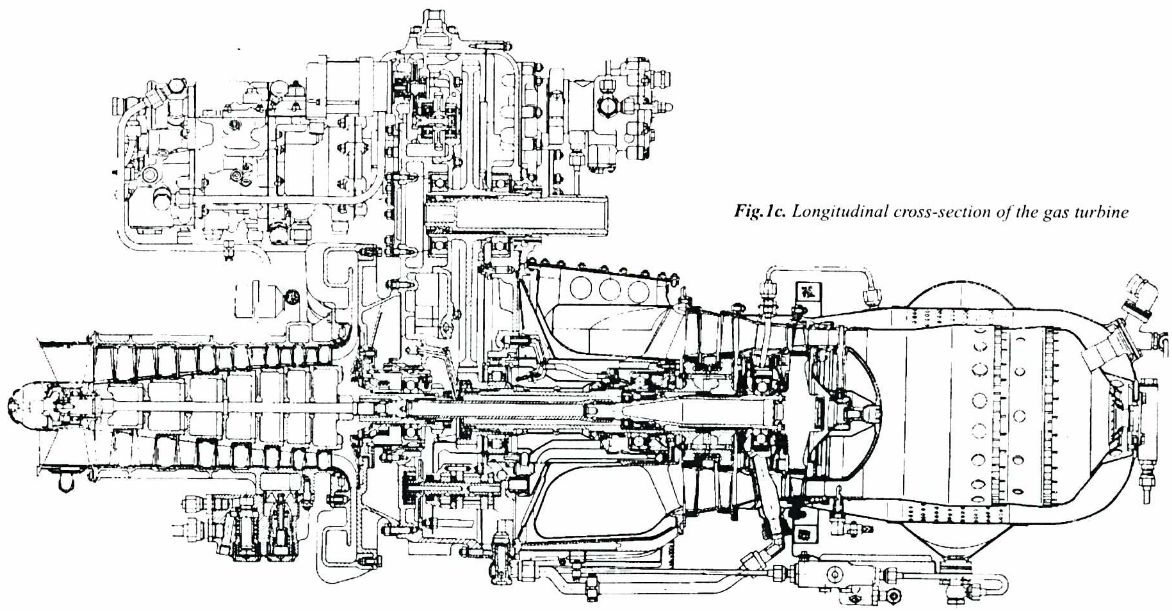

Fig.1c. *Longitudinal cross-section of the gas turbine*

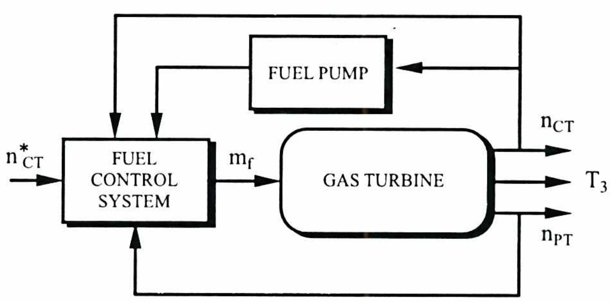

Fig.2. *Scheme of the gas turbine control system*

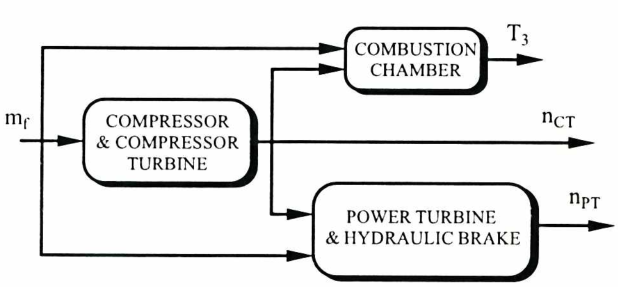

Fig.3. *Simplified block diagram of the gas turbine and hydraulic brake model*

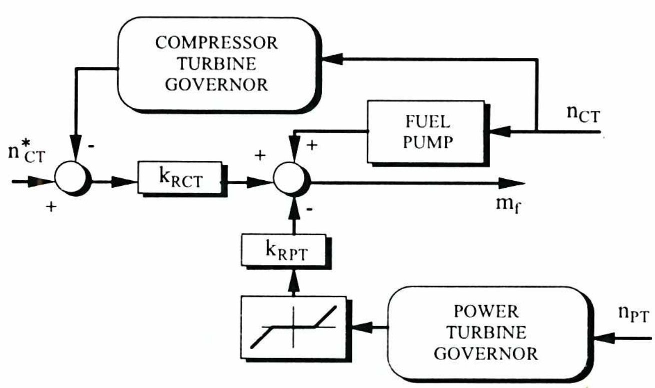

Fig.4. *Simplified block diagram of the gas turbine controller*

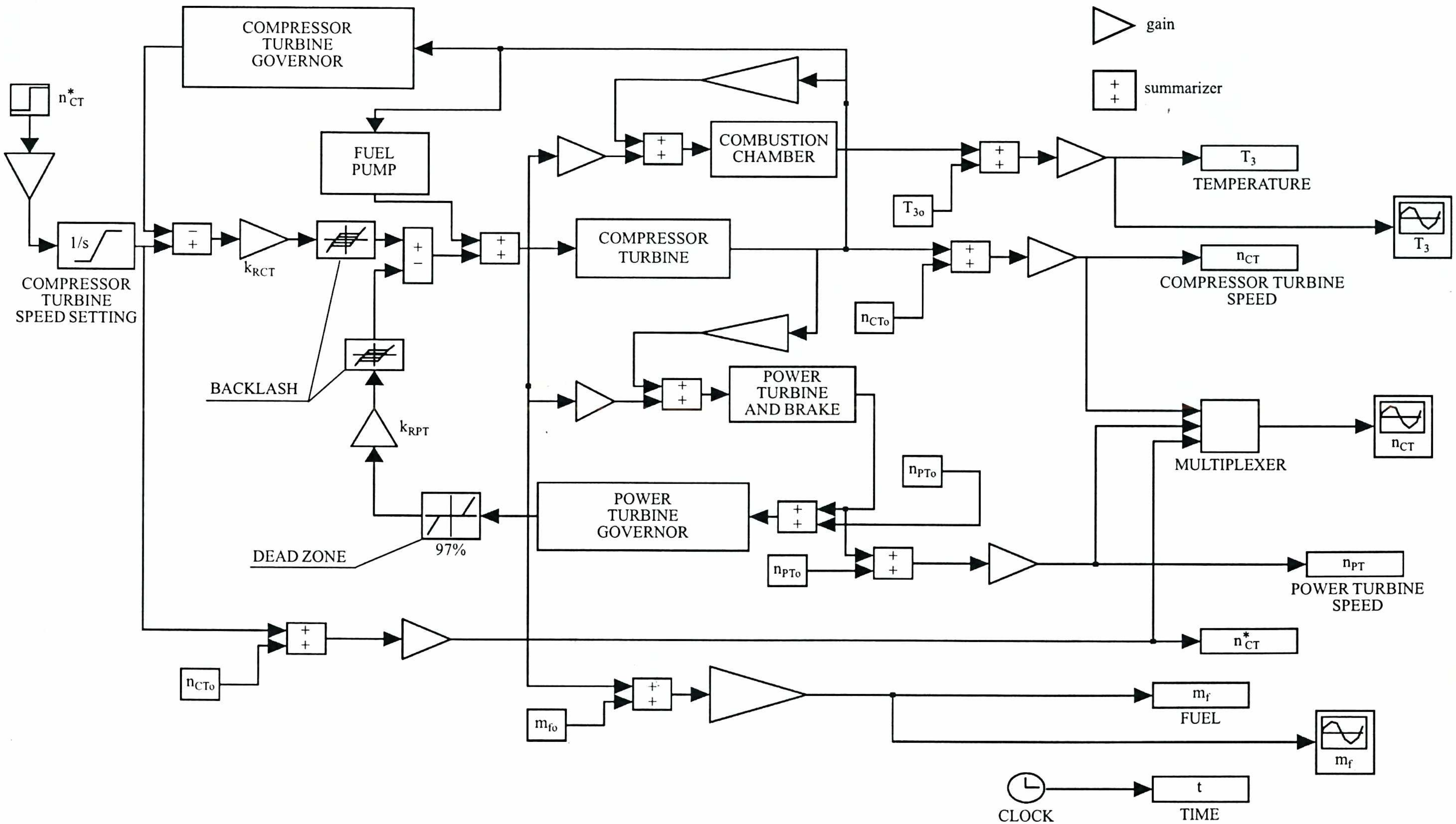

Fig.5. Block diagram of the gas turbine contol system (in of Simulink language)
index „o" - steady-state value index
k_{RCT}, k_{RPT} - speed governor coefficient of CT and PT, respectively

The input variables of the system were as follows :

- the compressor turbine speed setting n^*_{CT} - from the operating deck
- the compressor turbine speed n_{CT} - from the compressor turbine shaft
- the power turbine speed n_{PT} - from the power turbine shaft.

The fuel mass flow rate m_f was the output variable from the control system.

SIMULATION OF GAS TURBINE DYNAMICS BY MEANS OF SIMULINK LANGUAGE

The simulation of gas turbine dynamics was made on the basis of the mathematical models of its particular elements. The simulation language Simulink, a part of Matlab package was used [2]. The computer software is very simple. It operates under the Windows system and makes it possible to perform the computational simulation by using the block diagram method. The block diagram of gas turbine dynamics is presented in Fig.5.

DYNAMIC CHARACTERISTICS OF THE GAS TURBINE

Two operational ranges were taken into account (Fig.6a,b,c) :

→ the first in which the compressor turbine governor operates
→ the second in which the power turbine governor is active.

The compressor turbine rotational speed set point was the input signal to the control system. Its change is presented in Fig.6a. Transient processes of rotational speed of both turbines as well as combustion chamber temperature was simulated.

EXPERIMENTAL VERIFICATION AND CONCLUSION

Results of the experimental investigations of the gas turbine dynamics [4] and the results of the simulation are compared in Fig.7. Both results show good convergence. The presented transient processes are responses to the fuel flow step change.

The described simulation model of gas turbine dynamics may be recommended among others for education of students at the Technical University of Gdańsk.

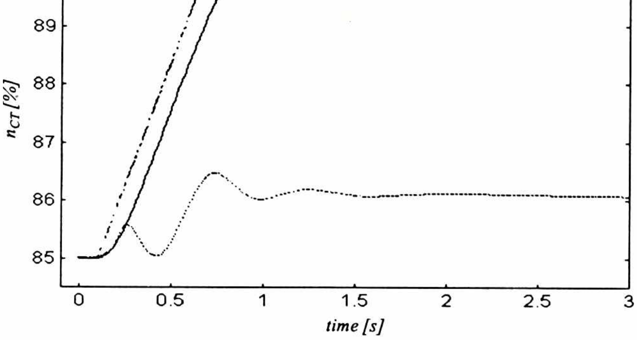

Fig.6a. Transient response of the compressor turbine speed n_{CT}
-·-·-·- *the input signal of the compressor turbine speed setting*
——— *the operating field of the compressor turbine speed governor*
.... *the operating field of the power turbine speed governor*

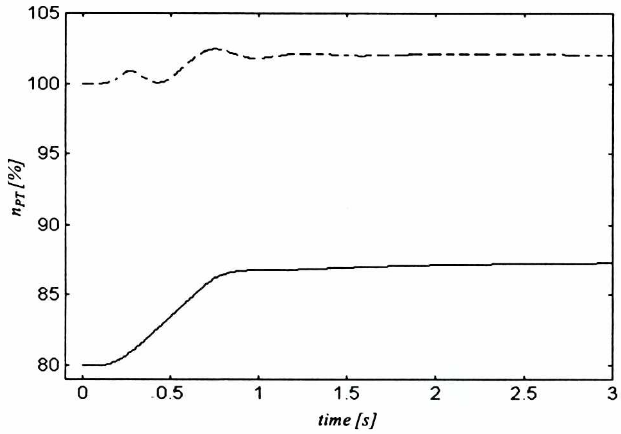

Fig.6b. Transient response of the power turbine speed n_{PT}
——— *the operating field of the compressor turbine speed governor*
.... *the operating field of the power turbine speed governor*

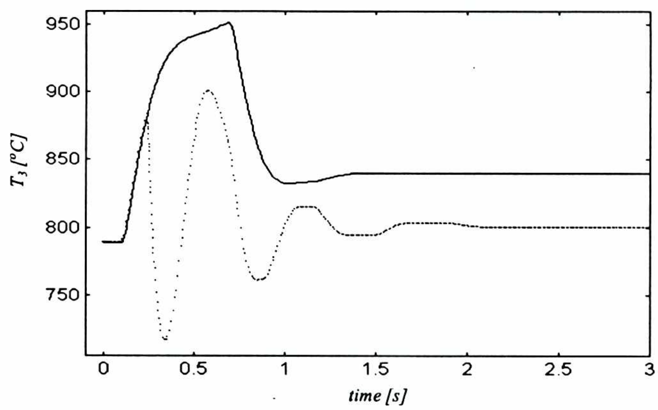

Fig.6c. Transient response of the gas temperature behind the combustion chamber T_3
——— *the operating field of the compressor turbine speed governor*
.... *the operating field of the power turbine speed governor*

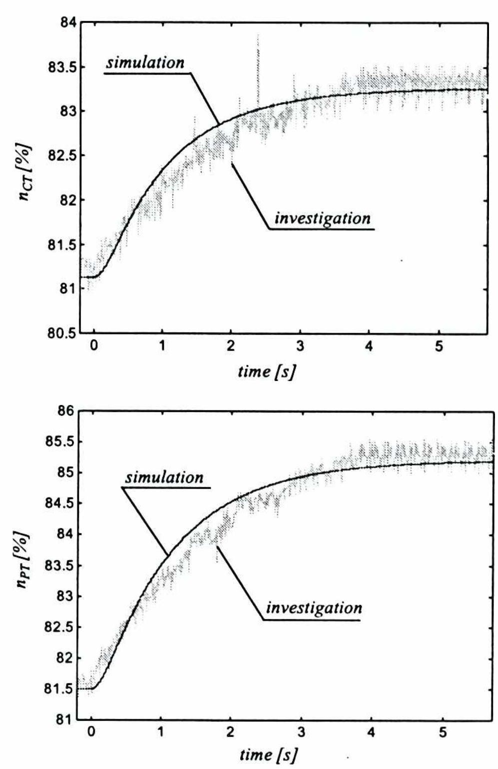

Fig.7. Transient processes of the gas turbine response to the step disturbance of the fuel flow rate before the combustion chamber (Comparison of the experimental investigations [4] and simulation results)

Appraised by Zygfryd Domachowski, Prof.,D.Sc.

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Conference

DESIGNING OF SHIP AUTOMATION SYSTEMS

On 4 October 1999 a seminar was arranged by the Automation Department, Faculty of Automation and Electrical Engineering, Technical University of Gdańsk, devoted to the problems related to realization of the research project on :

„A knowledge-database-supported system for aiding ship automation design"

Two papers provided an introduction to the main part of the seminar, namely :

„Role of knowledge engineering in design"
- by Prof. Wiesław Traczyk,
Technical University of Warszawa

„Visual methods in knowledge engineering"
- by Prof. Tatiana Gawriłowa,
St.Petersburg Technical University

The following papers were presented during the main part of the seminar :

- „General information on realization of the research project in question - presented by Prof. Zbigniew Kowalski, the supervisor of the working team
- „Ship automation design process" - by J. Piotrówski, of Gdańsk Shipyard, Jerzy Dziworski, of ABB firm, and Bogdan Olejnik, of NORD firm
- „A knowledge-database-supported system" – by Stefan Zieliński, Technical University of Gdańsk
- „A database for expert system" – by Maria Meler-Kapcia, Technical University of Gdańsk, and Bogdan Olejnik, of NORD firm
- „Simulation research methods used in expert system" by Ryszard Arendt , Technical University of Gdańsk
- „A database for classification society rules" – by Henryk Pepliński, Polish Register of Shipping, and Piotr Dzwonnik, Technical University of Gdańsk.

The seminar was ended by the paper on :
„Automatic elaboration of conceptual models" – by Aleksandr Kolesnikow, Assoc.Prof., Kaliningrad Technical University.

The well run seminar was intended to confront the system elaborated by the Automation Department against experience and demands of the automation specialists working at shipbuilding industry. They formed a group representing a dozen or so industrial enterprises. By taking part in a conclusive discussion they effectively contributed to accomplishment of the seminar aim.

Conference

AGAIN AT SEASIDE

On 21 to 23 September 1999 Jurata, a small seaside resort on the Hel Peninsula was the place of holding XIII Symposium on :

„Liquid fuels and lubricants for maritime economy"

Already for 24 years, every other year, this scientific conference has gathered mainly practising specialists and scientists engaged in production, utilization and testing of fuels and lubricating oils for shipping industry. Also representatives take part in it of engine manufacturers and those dealing with tribological and ecological issues tightly connected with oil products. Therefore the symposium is a forum to discuss vast scope of both theoretical and practical problems.

First ten meetings were initiated and organized by Maritime Institute, Gdańsk, and next the initiative was taken over by „Explonaft" Training Centre, Warszawa, to organize XI and XII Symposium deep in the land. Now it came back to the seaside.

In XIII Symposium 50 persons took part representing :

- 6 shipping companies
- 4 shipyards
- 4 oil refineries
- 8 oil distributing enterprises
- 9 universities and scientific research centres.

The participants had the occasion to hear and discuss 15 papers dealing with the following group of topics :

- Diagnostics of operation of the combustion engines and wear processes of their elements
- Coatings against frictional wear
- Lubricating systems of ship diesel engines
- Problems of husbanding the oil products on ships
- Processing the oil fuels for combustion in ship engines
- New determination methods of liquid fuel parameters.

The following papers were deemed the most interesting :

- „On possible application of the photo-acoustic spectrometry (PAS) to wear diagnostics of the friction nodes" – by J.Motylewski, K.Krawczyk, Insitute of Basic Engineering Problems, Polish Academy of Sciences, Warszawa, and B.Wiślicki, Aviation Institute, Warszawa
- „Determination of heat of combustion and calorific values of the liquid fuels" – by J.M.Grudziński, Maritime University of Szczecin
- „Analysis of possible application of a static homogenizer to preparation of waste fuel oils for combusting in engines and boilers" – by M.Piekara, Maritime University of Szczecin
- „Analysis of concentration changes of some metallic elements in fuel oils during ship engine operation" – by J. Krupowies, Maritime University of Szczecin
- „Some exploitation aspects of ship tanks for liquid oil products" - by W.Ostaszewski, Explonaft, Warszawa.

An opportunity was also given to the Symposium participants to make acquaintance with products of the firms : Fuel and Marine Marketing, Alfa Laval and Fisher-Rosemount which presented their instruments, equipment and services in line with the theme of the Symposium.

XIII Symposium was held under the Polish Navy Command patronage which made it possible to take part in the voyage around the Puck Bay , to visit the armament museum and places of heroic defence of the Hel Peninsula in 1939, as well as the seal farm.