DETERMINATION OF OPERATING CHARACTERISTICS OF NAVAL GAS TURBINES LM2500

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Abstract

In the process of operation of naval gas turbine is necessary to know their parameters depending on their load, resulting from the swimming speed of the ship. The above equation is the operating characteristics. Classify them into: static (rotating, full-load, collaboration engine power with the receiver), dynamic (starting, acceleration and deceleration) and the universal.

The paper presents the results of preliminary tests concern develop rotating characteristics an object of investigations work in the stationary states. The object of investigations was the main propulsion engines frigate type Oliver Hazard Perry which is supplied with the Polish Navy. The propulsion system consists of two naval gas turbine LM2500, reduction gear, shaft line and adjustable screw propeller. Preliminary tests were carried out during the departure of the ship to sea in a marine power plant. The measurements recorded in the engine load range from the minimum to the nominal used to develop characteristics. During the test engines have been simultaneous and the balanced load. In order to allow comparison of operating characteristics of engines tested, as well as references to the various weather conditions, the results of measurements on which it was set, brought to so-called "regulated by weather conditions". For these characteristics, using statistical analysis, were determined dependence of approximation. The received relationships can be used on need of technical diagnostics as well as the more far investigations of considered object of investigations.

Keywords: *naval gas turbine, operating characteristics, power transmission system*

1. Introduction

In practice operating marine power plant, and also marine propulsion systems, there is a need for their analysis, comparing different solutions and evaluate the technical condition. The above analysis is carried out mostly at the economic, operational and energy aspects. Labour economics marine power plant is usually in the background, for this reason that the ship is intended to perform specific tasks. Operational indicators of marine power plant show its reliability, the possibility of overloading the main engines, the ability to perform maneuvers, the permissible period between the repairs etc. However, energy indicators, such as: efficiency, specific fuel consumption, power and torque, determine the swimming speed of the ship, its range etc. [1, 5].

The operation of marine propulsion systems with naval gas turbines is characterized by a different specificity than the classic operation in ship combustion engine. This is due to the different design and construction, the pursuit of another thermodynamic cycle, the implementation of a continuous transformation of internal energy and a large range of variation of operating parameters, in particular rotational speed. In the most general concept of naval gas turbine consists of a gas generator and free power turbine. Gas generator, as the name suggests is designed to produce a working medium (gas) with defined parameters, while the free power turbine provides drive for power receiver. Between the rotors of the gas generator and a free power turbine there is no mechanical coupling, there is the coupling of thermo-gas-dynamic. It allows for independent work of both the gas generator and free power turbine. Therefore, the flow channels between the

gas generator and free power turbine is the accumulation of the working medium, which is too high loads of free power turbine (accompanied by reduction of its rotational speed) can lead to undesirable processes that could lead to engine damage (phenomenon pompage). Conclusion that these dynamic coupling of thermo-gas-dynamic has the greatest impact on the different specificities of operation of naval gas turbines. There are two types of ships equipped marine propulsion systems with naval gas turbines in the Polish Navy. These are missile corvettes type Tarantula and a frigate rocket type Oliver Hazard Perry [5].

In the exploitation process of naval gas turbines is necessary to know their parameters depending on their load, resulting from the swimming speed of the ship. The above equation is the operational characteristics. Engine operating characteristics allow the identification of areas of their applications, analysis of performance and economical operation [1, 5]. In the case of naval gas turbines characteristics is the result of cooperation machines which are the main components of the engine. They include a compressor, combustion chamber and turbine. Moreover, as already mentioned, in the naval gas turbine is the free power turbine, which is not mechanically coupled to the gas generator, and only thermo-gas-dynamic [5].

This paper presents the identification of the object of investigations and the results of preliminary tests on the development rotating characteristics of naval gas turbine LM2500, included in the propulsion system frigate type Oliver Hazard Perry, in the stationary states. Preliminary tests were carried out during the departure of the ship to sea in a marine power plant conditions. The measurements recorded in the engine load range from a minimum to a nominal used to develop characteristics, at the simultaneous and evenly load.

2. Classification characteristics of naval gas turbine

Operating characteristics can best be defined as a graphical or an analytical presentation of the basic values defining engine performance, and the parameters of working medium, in its distinctive sections, the size of the working conditions of the engine working with a specific energy receiver [2, 4, 5].

The energy state of the engine (generator gas) depends on the values of the energy-dependent engine control lever (jet fuel) and directly affecting the engine power (enthalpy gas stream). In case of two-rotor naval gas turbine such parameter is the rotational speed of the gas generator, while in case of an three-rotor naval gas turbine (with a separate power turbine rotor and two-rotor gas generator) is mostly rotational speed of high pressure rotor. The basic energy parameters characterizing the work of each engine are: effective power (useful), torque, rotor rotational speed and engine specific fuel consumption. These parameters depending on the state of the energy the engine can take the values: maximum, nominal, and minimum performance [1, 4, 5, 7]. It moreover can distinguish other additional parameters that characterize the operation of the engine. In case of naval gas turbines for these parameters are:

- temperature and absolute pressure of the working medium in a typical cross-sections corresponding to the nodal points of the thermodynamic cycle engine. The temperature and absolute pressure can be static or total,
- streams of air mass, fuel and exhaust gas,
- compression compressor.

During operation of naval gas turbines can distinguish the following energy states:

- ***stationary*** in the range of minimum power (commonly called "idle run") for maximum power, including as special: the maximum, nominal (calculated), under partial (operating), minimum power,
- ***nonstationary***, which include start-up or stop the engine and acceleration and deceleration.

Therefore, the classification can be made operating characteristics of naval gas turbines for [5]:

- static:

  - rotating,
  - full-load,
  - collaboration engine power with the receiver,
- dynamic (transient):
  - starting,
  - acceleration and deceleration,
- general or universal.

The paper presents the functional dependences of rotating characteristics of object of investigations, which represent the dependence of engine operating parameters on the rotational speed of the gas generator, while maintaining the rotational speed of a free power turbine resulting from cooperation with the receiver of energy in the form of adjustable screw propeller. Dispose of rotating characteristics is possibility to determine of full-load and collaboration engine power with the receiver characteristics.

3. Preliminary tests

Preliminary tests had on aim the measurement of parameters of work the considered of object of investigations, in aspect of determine rotating characteristics. The object of investigations was naval gas turbine LM2500, which are the main propulsion engines, a guided missile frigate Oliver Hazard Perry. The preliminary tests were conducted at one of the frigates occurring in the Polish Navy, under actual working conditions in the marine power plant of the ship out to sea. Tests were carried out for steady energy state, determined on the basis of the rotational speed of the gas generator, ranging from minimum to nominal load test facility. Engine load was carried out in accordance with the powertrain control program, which, depending on the set pitch selects the optimum setting fuel flow and angle of the vanes in the first six degrees of axial compressor motors.

The measurement was made on the simultaneous and evenly loads with both engines. For the measurements used in portable measuring-registrant system Multichannel Recorder TYPE 908416161C plus reading and writing was measured performance with digital display located on the desktop in the main control centre engine. For each fixed load parameters were measured for 60 s, with a sampling rate of 2 Hz and then averaged. Conducting performance measurement was preceded by calibration of the individual measuring circuits together with their uncertainties.
Propulsion system type missile frigate Oliver Hazard Perry (Fig. 1) consists of three basic components: the main propulsion engines LM2500, with the module automation, reduction gear and line shaft with adjustable screw propeller [7].

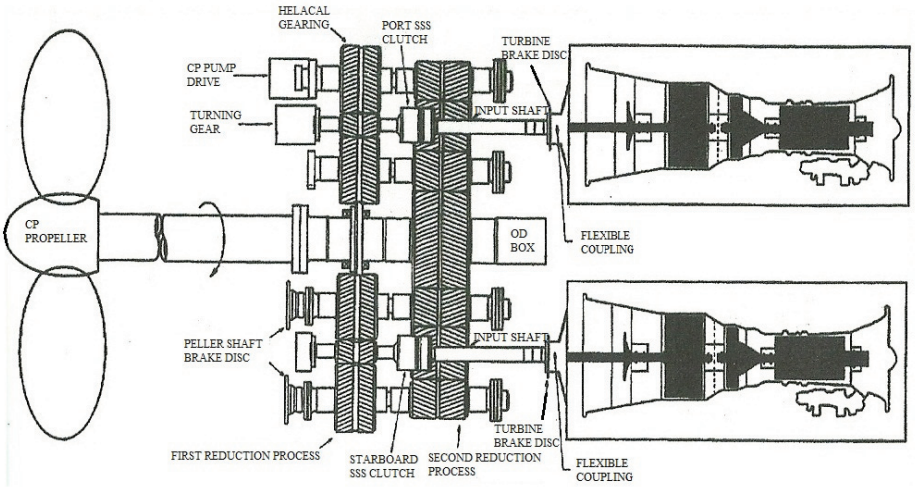

Fig. 1. Propulsion system of frigate type Oliver Hazard Perry [7]

Main propulsion engines are two naval gas turbines LM2500 production General Electric. LM2500 engine (Fig. 2) is the two-rotor design, with axial flow of medium. It consists of two main parts: a gas generator and free power turbine engine mounted together. Gas generator consists of 16-hundred axial stage compressor, annular type combustion chamber equipped with 30 injectors and a two-stage high pressure turbine. For gas generator is located six stage free power turbine connected to the gas generator in a thermo-gas-dynamic [7].

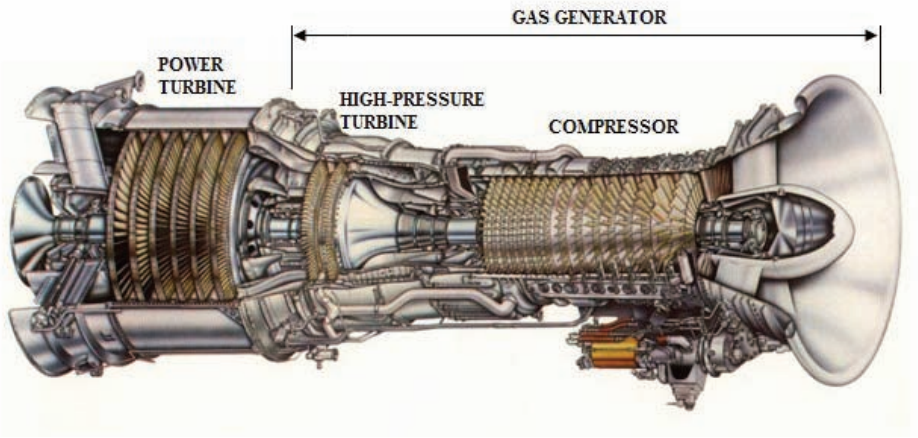

Fig. 2. Cross-section of naval gas turbine LM2500 [7]

4. Results of preliminary tests

With the results of measurements of the work made an object of investigations on individual areas of fixed, brought it to SI units or their multiples and the ambient pressure is taken into account when determining the absolute pressures. In order to allow comparison of the characteristics of rotary engines tested, as well as references to the various weather conditions, the results of measurements on which it was set, brought to so. regulated by weather conditions. For normalized weather conditions shall be of the following parameters: barometric pressure $p_{0WZ} = 101325\,Pa$, absolute temperature $T_{0WZ} = 288.15\,K$ and absolute humidity $\varphi = 0$ [2,5].

Based on the results of measurements were determined rotating characteristics of object of investigations. The characteristics represent the relationship of the main parameters of object of investigations depending on the rotational speed of the gas generator, while maintaining the rotational speed of a free power turbine resulting from its collaboration with the receiver of energy in the form of adjustable screw propeller. Because of the simultaneous and equally the load of both engines during a test to determine the characteristics, the results of measurements recorded on both engines.

Subsequently, the obtained characteristics were determined according to the approximating. Their designation used statistical analysis. The statistical analysis is the process of processing data (measurements carried out in accordance with the approved scheme of the experiment) in order to detect regularities in the phenomena studied, and their interpretation using the methods of mathematical statistics. Allows you to designate the same object function tests, which may also constitute the mathematical model. Based on the results of statistical analysis obtained useful information for the object of investigations and formulate the conclusions of the research. The most popular measure of the resulting functions fit to the results of the research object of measurement is the coefficient of determination R^2 and the average error of approximation $\sigma(y)$ (called the standard deviation). Apart from the statistical analysis was also carried out a substantive analysis of test results. This analysis applies in particular to verify the mathematical model obtained on the compliance of the physical phenomena taking place during the relevant object of investigations, including theoretical foundations and principles of its operation [3, 6].

To approximate the rotating characteristics least-squares method was used, with the use of polynomials. The rotating characteristics of the object of investigations concerned with the functional relationship presented, coefficient of determination R^2 and the average error of approximation $\sigma(y)$, shown in the following figures.

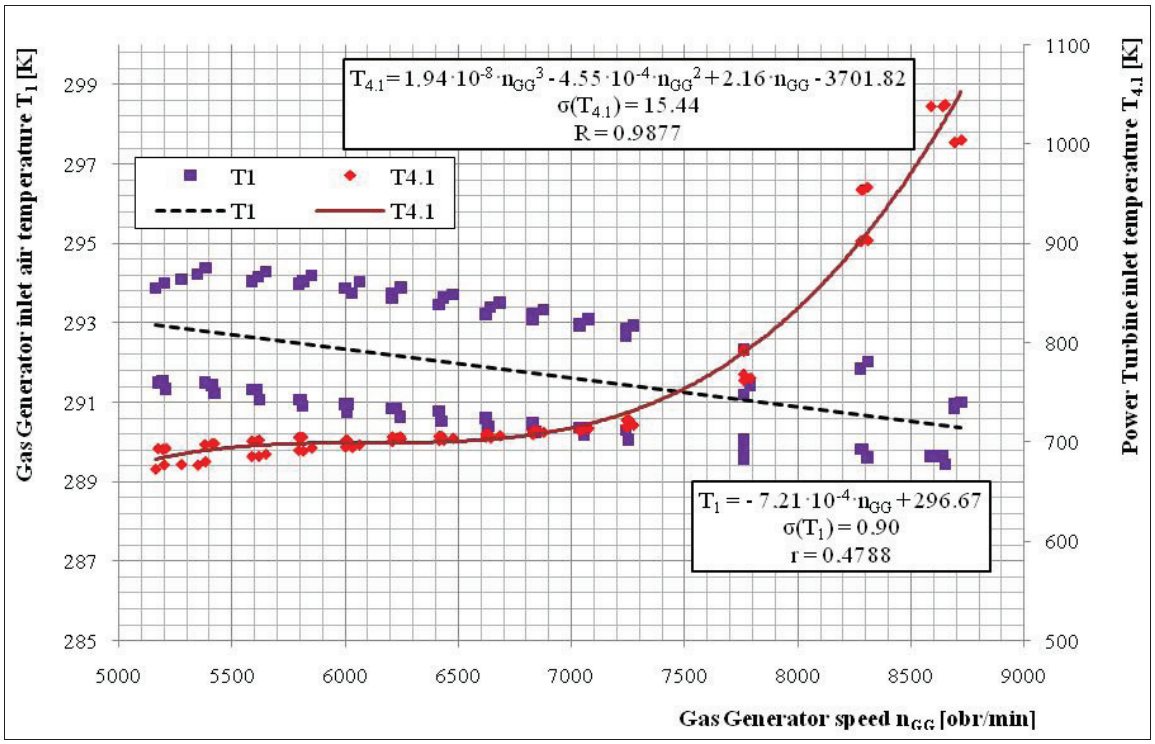

Fig. 3. Mileage approximating function and the results of the measurements Gas Generator inlet air temperature T_1 and Power Turbine inlet temperature $T_{4.1}$, registered for the fixed LM2500 engine operating conditions, depending on the Gas Generator rotational speed n_{GG}

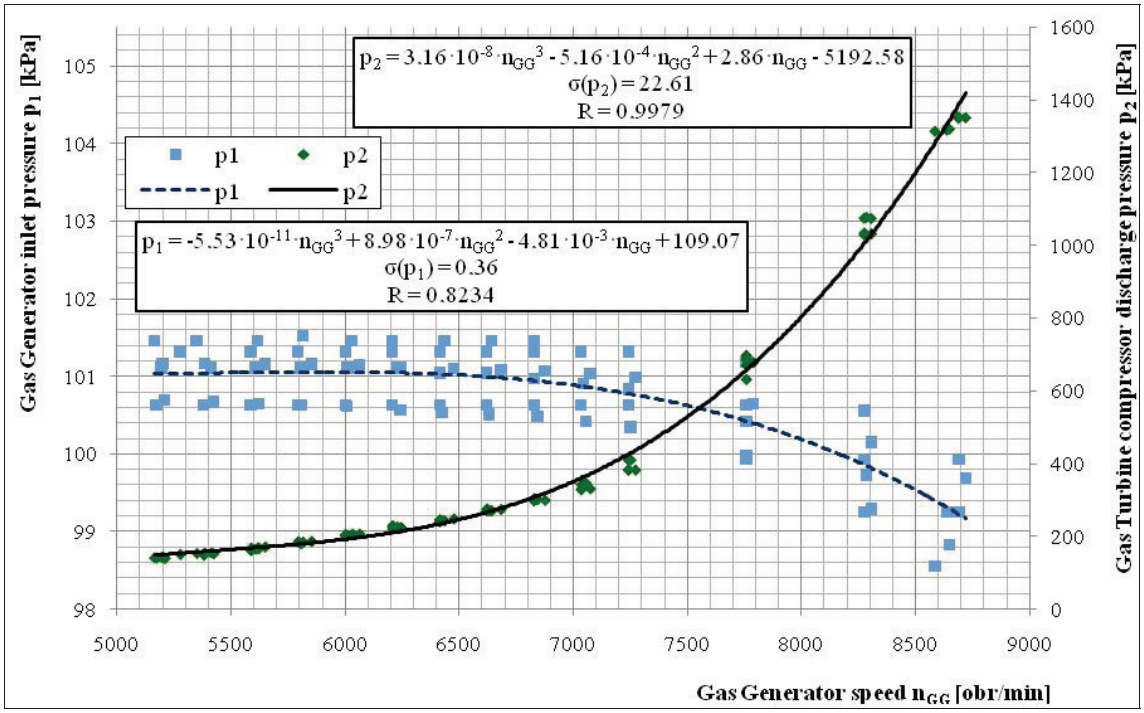

Fig. 4. Mileage approximating function and the results of the measurements Gas Generator inlet pressure p1 and Gas Turbine compressor discharge pressure p2, registered for the fixed LM2500 engine operating conditions, depending on the Gas Generator rotational speed nGG

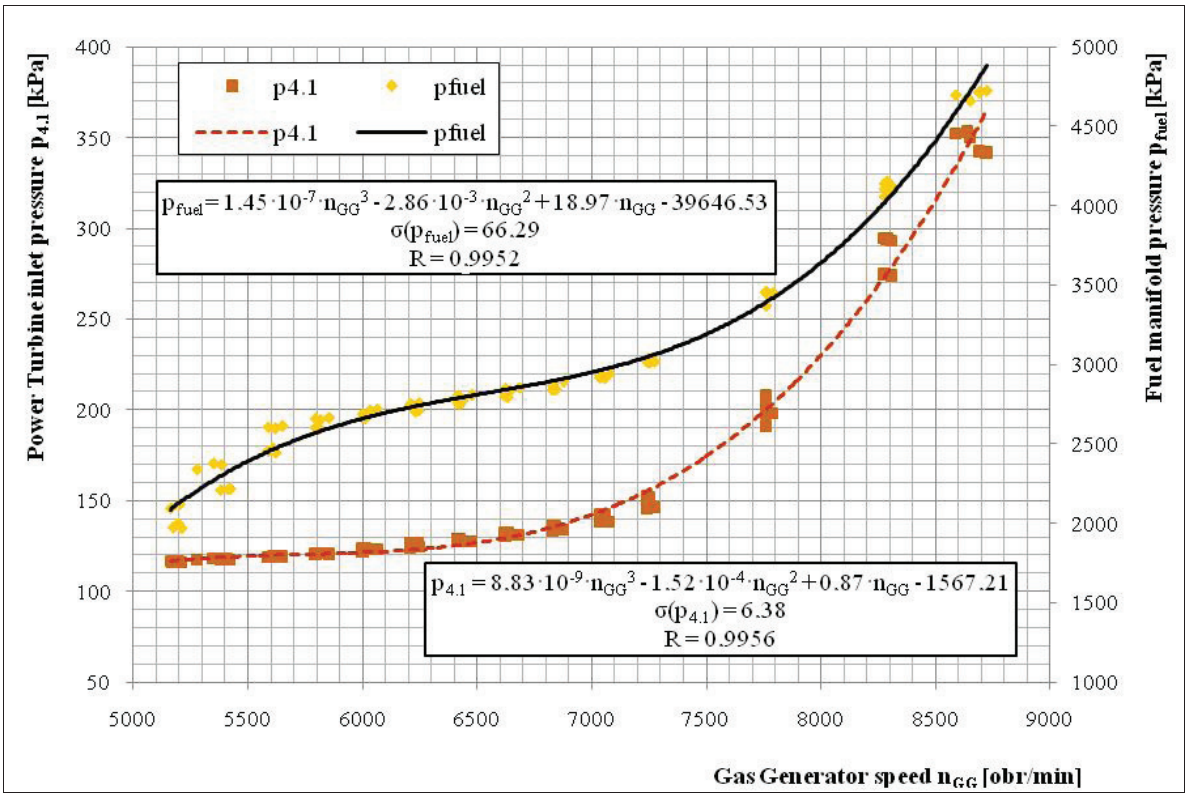

Fig. 5. Mileage approximating function and the results of the measurements Power Turbine inlet pressure p4.1 and fuel manifold pressure pfuel, registered for the fixed LM2500 engine operating conditions, depending on the Gas Generator rotational speed nGG

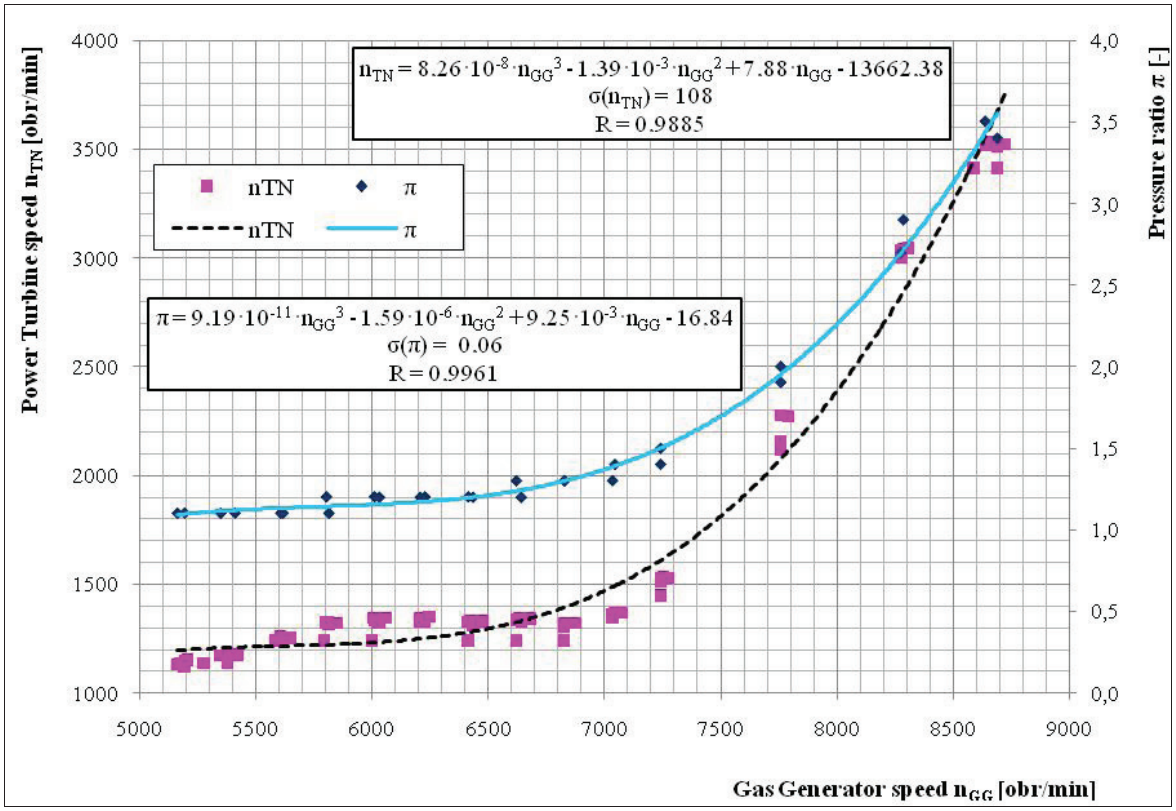

Fig. 6. Mileage approximating function and the results of the measurements Power Turbine speed nTN and pressure ratio π, registered for the fixed LM2500 engine operating conditions, depending on the Gas Generator rotational speed nGG

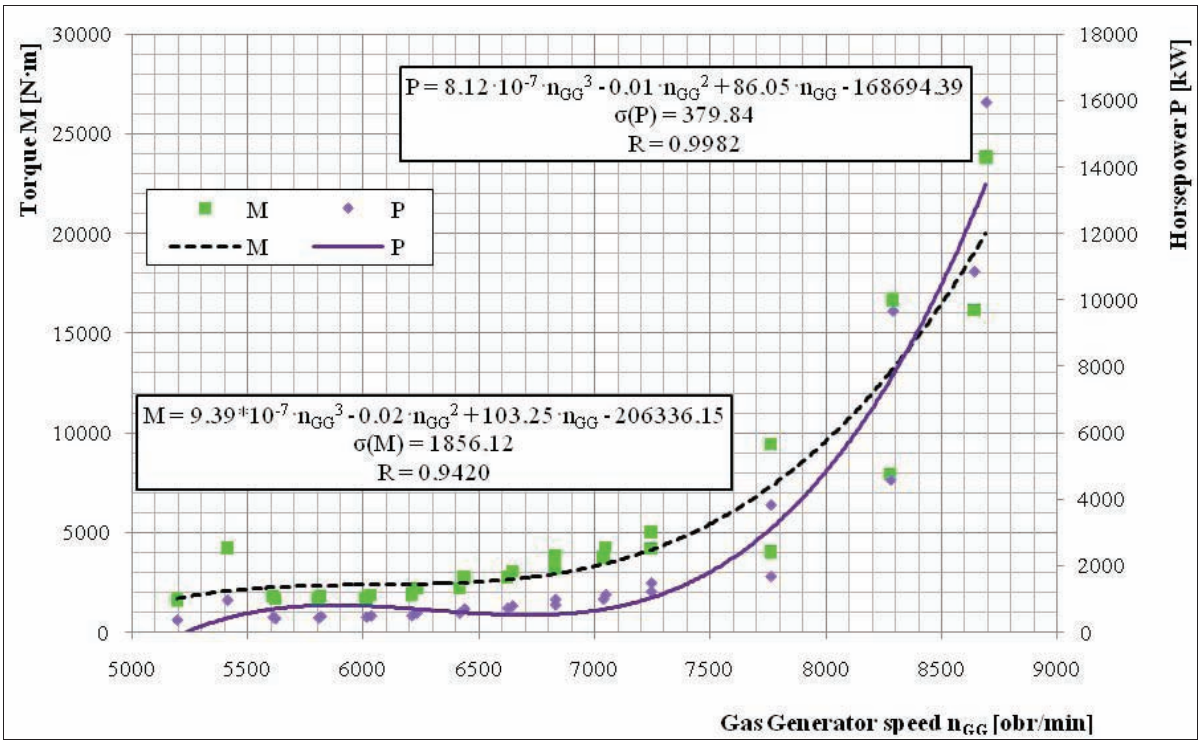

Fig. 7. Mileage approximating function and the results of the measurements torque M and horsepower P, registered for the fixed LM2500 engine operating conditions, depending on the Gas Generator rotational speed nGG

When assessing the functional characteristics obtained according to turnover object of investigations and comparing them with the information contained in the ship's documentation can be concluded that both the nature of the course and the extent of variation of the parameters of work is consistent with the ship's documentation. The course of the characteristics that, depending on the load parameters is nonlinear. Non-linear dependence arises from the fact of cooperation with the free power turbine propeller with adjustable pitch. Only the characteristics of air temperature before the compressor have a linear relationship with nature. Noticeable also is the linear nature of the curves in the range from minimum load to the load, which is reaching the maximum pitch. Stroke occurs when the screw rotational speed of the generator exhaust gases of about 7000 rpm. The characteristics also show that a significant increase in engine power occurs at the maximum pitch, with the cooperation of a free power turbine with a screw at its maximum, a fixed pitch. Upon reaching the maximum pitch engine delivers an output of about 1400 kW, with a maximum capacity of 18500 kW.

5. Conclusion

The possibility of determining the operating characteristics allow their use in the wider process of diagnosis. Thus, there is the possibility of conscious life by the technical condition. Observation of trends, changes in the course of operating characteristics, and selected diagnostic symptoms allows obtaining information which may be used in decision-making supplies for naval combat readiness, maintenance, adjustment or replacement of engine components, as well as repairs. This information may also be used when upgrading or constructing new engine design.

Developed according to functional characteristics of naval gas turbine LM2500 will allow for the analytical determination of engine operating parameters on the basis of gas generator rotational speed, which represents the energy state, for arbitrary parameters of the environment. These dependencies allow the determination of engine operating parameters in an approximate way, but with sufficient precision engineering applications, the need for further research of this

type of engine.

Knowledge and experience of operating characteristics are also used in the process of education and training of persons responsible for the operation of such engines, carried out at the Department of Mechanical and Electrical Engineering of the Naval Academy in Gdynia. This is particularly important because incorrect operation often leads to serious defects, which affect the combat readiness of the ship, and thus also generates large and unexpected costs in the process of operation.

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