THE ENERGETIC DIAGNOSTICS OF NAVAL PROPULSION SYSTEM WITH NAVAL GAS TURBINE

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Summary

The method of determining the energetic balance of naval power unit with the naval gas turbine is presented in the essay. The laboratory station with the gas turbine was used in introductory researches.

Elaborating the energetic balance of the engine allows to conduct an analyze of energetic processes which occur inside. Results of the analyses may be used due to improving the economy of the engine work what is equal with the increase of its effective efficiency. What is more, in respect of qualitative and quantitative changes of particular components of energetic balance it can be used as an indicator of change of the engine running-in or a change of its technical state.

Keywords: diagnosing, a energetic balance, a naval gas turbine.

1. INTRODUCTION

The need of constant control and diagnosing of naval gas turbines is significant in the process of exploiting. It caused the necessity of creating a range of methods of diagnosing. Thanks to them it is possible to estimate the technical condition and determine the range and frequency of essential service maintenance which is the result of the exploiting strategy. The strategy is focused on reliable long-term functioning at the lowest cost.

The wear of parts of engine as well as of the whole engine may occur while exploiting gas turbine engines. Most common processes which affect such consumption and simultaneously the possibility of loss of usefulness for the further exploiting are following: fatigue, low-cycle fatigue of material, creeping, vibro-creeping, changes in the material structure, erosion, corrosion, brittle cracking and rubbing rotating parts of an engine with immovable ones. In processes of the energy exchange, in the result of use of operational properties of machine elements, as well as of the machine as such, the dissipation of energy may appear. The amount of the energy which is possible to dissipate is restricted by the boundary value $E_G$. This is the value for which the machine is unfit for use. The current amount of dissipated energy $E_d(\Theta)$ in a particular period of exploiting may be regarded as dimension of the advancement of use processes [2].

The quantitative assessment of the dissipated energy allows to conduct the energetic balance in the process of the naval power unit exploiting. The energetic balance composes the quantitative comparison of the energy which supplies the engine while working. There is a possibility to determine the effective efficiency of the engine on the basis of the energetic balance. The effective efficiency expresses the quantitative percentage of the provided energy which is changed into output mechanical energy.

The method of determining the energetic balance of naval power unit with the gas turbine engine is presented in the essay. The laboratory station with the gas turbine GTD-350 was used in introductory researches.
2. THE RESEARCH OBJECT IDENTIFYING

The laboratory station contains miniaturized naval power unit with the gas turbine [3]. A propulsion unit consist of: a main engine, a clutch, a gear, an engine shafting as well as a screw propeller. In the station a Froude’s water brake of HWZ-3 type is the mechanical energy receiver. In respect of operation principles the brake puts under load the engine in similar way as the screw propeller with changing spiral lead. A general view of the laboratory station with gas turbine GTD-350 power unit is shown in the figure 1.

![Laboratory Station](image)

The station is used in a didactic process of exploiting naval gas turbines as well as in initial researches about exploiting and diagnosing [3, 4].

3. THEORETICAL BASIS OF ENERGY BALANCE ELABORATING

The energy balance is a quantitative configuration of all types of energy which take part in energetic processes in particular machines or devices. The energy balance is determined on the basis of energy and mass conservation laws [1, 5, 6].

If a particular object is in a steady working state (in a thermodynamic equilibrium state) the changes of energy of the system does not appear \( \Delta E_u = 0 \). Therefore, the input energy (input energy flux) will be equal with the output energy (output energy flux). It may be shown by the following equation [1, 5, 6]:

\[
\dot{E}_d = \dot{E}_w
\]  

The above assumption is also related to the equation of substance balance which can be presented as:

\[
m_d = m_w
\]  

At the beginning of the energy balancing of a particular object it has been separated by a conventional control balance shield. It can be crossed not only by energy in a heat and work form, but also by the substance which brings the kinetic and potential energy. Such a thermodynamic system is treated as an open system which is motionless in respect of reference level. It is assumed that the flow is unidirectional, homogenous in every section which is orthogonal to the axis of flow direction determined by the control shield. It allows to assign equal, in every point of the section, medium value of parameters of the state and the function of the state to particular control sections. The input working substance (working medium) is air and fuel and output substance is exhaust gas. Moreover, it is assumed that in a propulsion engine processes of compression and expansion are adiabatic and irreversible and the process of combustion is treated as total and complete. It is also assumed that the particular thermodynamic system is in a state which is steady in time (in a thermodynamic equilibrium state) [1, 5, 6].

For the thermodynamic system which is defined in such way, taking into account equations (1) and (2), the equation of the energy balance may be presented in following way:

\[
\dot{I}_p + \dot{Q}_d + \dot{I}_{pow} = \dot{I}_{spal} + P_e + \dot{Q}_{ut}
\]  

\[
\dot{I}_p - \text{a stream of fuel enthalpy;}
\]

\[
\dot{I}_{spal} - \text{a stream of emission enthalpy;}
\]

\[
P_e - \text{effective mechanical energy which is formulated by the effective power transferred to the energy receiver;}
\]

\[
\dot{Q}_d - \text{a stream of fuel chemical energy;}
\]

\[
\dot{Q}_{ut} - \text{a stream of output energy losses.}
\]

In the respect of II principle of thermodynamics, according to which during changing the heat into the work the energy is dissipated, it is possible to introduce to the equation (3) a dimensionless quantity which is called propulsive efficiency [5,7]:

\[
\eta_n = \frac{\dot{E}_{mech, ut}}{\dot{E}_d} = \frac{P_e}{\dot{I}_p + \dot{Q}_d + \dot{I}_{pow}}
\]  

The propulsive efficiency express the efficiency of all devices which enter into the composition of the considered object which are: the propulsion engine, gear with the clutch as well as the energy receiver [7]. Then, the equation (4) will be presented as follows:

\[
\eta_n = \eta_e \cdot \eta_{PK} \cdot \eta_h
\]
\( \eta_e \) – effective efficiency of the engine;
\( \eta_{pa} \) – efficiency of the gear with the clutch, it
ranges from 0,97 to 0,99;
\( \eta_b \) – brake efficiency, for water brakes it ranges
from 0,97 to 0,99.

Those efficiencies express mostly the
mechanical losses connected with friction, doing
a work to the propulsion of all underslung devices
which are indispensable in providing with proper
work and transferring turning moment to the energy
receiver.

4. INITIAL RESEARCHES

Preliminary researches were aimed at measuring
physical quantities of the considered object during
working under the particular load. Those quantities
were indispensable in determining the energy
balance in entire range of load changing.

A measuring-recording computer system
AMW-34AIN was used in measuring and recording
physical quantities.

On the basis of results reduced to normal
weather conditions summands of the balance
equation (3) were determined. The results of
calculations are presented in the figure 2.

On the basis of results it was also possible to
determine the efficiency of the considered propulsion
\( \eta_a \) as well as the effective efficiency of
the engine \( \eta_e \). Relationship between propulsion
efficiency \( \eta_a \), effective engine efficiency \( \eta_e \) and
load is shown in the figure 3.

On the basis of the elaborated energy balance it
can be stated that values of particular components
of the balance are related and proportional to the
load of an engine. Those relationships show a linear
dependence. On the grounds of dependence courses
of particular components of the balance on the
engine load, which are presented in figure 2, it can
be stated that:

- changes of energy which is pulled out together
  with emission \( I_{spal} \), the mechanical effective
  energy \( e_P \) as well as the power delivered to
  the compressor stay in the permanent
  proportions in the entire range of load
  changing. It is stated that participation of the
  energy pulled out with the emission \( I_{spal} \) in
  the whole range of load changes is about 50%
  of input energy. Similarly, the participation of
  the power delivered to the compressor is about
  20% of the input energy;
- in the energy balance the participation of the
  energy losses \( Q_{ot} \) decreases with the load
  engine increase. It causes an increase of the
effective engine efficiency showed in the figure
3 and a decrease of specific fuel consumption;
- the participation of energy losses \( Q_{ot} \) in the
  considered range of engine load changes
decreases from 25% to 14% of input energy,
while the participation of mechanical effective
energy \( P_e \) increases from 7% to 12%.

On the Sankey diagram the graphical illustration
of the percentage participation of particular
components of energy balance related to the input
energy can be presented. Using the dependence of
particular components of energy balance equation it
is possible to create the Sankey diagram for any
engine load. In the figure 4 there is presented the
exemplary Sankey diagram created for nominal
engine load.
According to the above figure low effective efficiency $\eta_e$ is characterized for the engine. In the considered range of engine load changes this efficiency ranges from 7% to 13%. In such cases it is possible to make the engine more similar to the Carnot cycle what can be achieved by, for instance, regeneration of the heat which is pulled out with the emission.

5. SUMMARY

The elaborated method of determining the energy balance of naval propulsion unit with a gas turbine allows to conduct a quantitative analysis of internal energetic processes. It allows also to define in a quantitative way components of the balance equation and their dependence on the engine load. Results of these analysis may be used in improving the economy of their work what is equal with increase of effective efficiency. Crucial matter for diagnosing is a possibility of quantitative evaluation of dissipated energy in the exploiting which can be measure of the degradation of the technical state of the considered object. What is more, in the respect of quantitative changes of particular components of the energy balance, it can be regarded as an indicator of change of engine running-in course or its technical condition.

6. BIBLIOGRAPHY


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