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DEVISING A METHOD FOR CALCULATING THE TURBOSHAFT GAS TURBINE ENGINE PERFORMANCE INVOLVING A BLADE-BY-BLADE DESCRIPTION OF THE MULTI-STAGE COMPRESSOR IN A TWO-DIMENSIONAL SETTING

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The design and adjustment of modern gas turbine engines significantly rely on the use of numerical research methods.

This paper reports a method devised for calculating the thermogasdynamic parameters and characteristics of a turboshaft gas turbine engine. The special feature of a given method is a two-dimensional blade-by-blade description of the compressor in the engine system. Underlying the calculation method is a nonlinear mathematical model that makes it possible to describe the established processes occurring in individual nodes and in the engine in general. To build a mathematical model, a modular principle was chosen, involving the construction of a system of interrelated and coordinated models of nodes and their elements.

The approach used in modeling a two-dimensional flow in the compressor makes it possible to estimate by calculation a significant number of parameters that characterize its operation.

With the help of the reported method, it is possible to estimate the effect of changing the geometric parameters of the compressor height on the characteristics of the engine. To take into consideration the influence of variable modes of air intake or overflow in various cross-sections along the compressor tract, to determine the effect of the input radial unevenness on the parameters of the compressor and engine in general.

To verify the method described, the calculation of thermogasdynamic parameters and throttle characteristics of a single-stage turboshaft gas turbine engine with a 12-stage axial compressor was performed. Comparison of the calculation results with experimental data showed satisfactory convergence. Thus, the standard deviation of the calculation results from the experimental data is 0.45 % for the compressor characteristics, 0.4 % for power, and 0.15 % for specific fuel consumption.

Development and improvement of methods for calculating the parameters and characteristics of gas turbine engines make it possible to improve the quality of design and competitiveness of locally-made aircraft engines

Keywords: gas turbine engine, throttle characteristic, axial compressor, blade-by-blade two-dimensional modeling

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1. Introduction

Mathematical modeling of thermogas-dynamic parameters of gas turbine engines (GTEs) is important and is used at different stages of the life cycle, starting with the selection and optimization of the parameters of the estimation mode, in the process of fine-tuning, modernization, and improvement, as well as to analyze the impact of operating conditions on engine characteristics. In many cases, it is necessary to be able to assess the impact of the input unevenness of the flow, changes in geometric parameters in the design process that arose during fabrication or as a result of the wear of a flow-through part.

To this end, it is necessary to have modern calculation methods that make it possible to clarify existing approaches to modeling the flow in gas turbine engines. Therefore, it is a relevant task to devise a new, more advanced calculation method.

2. Literature review and problem statement

Aircraft engine companies and research organizations have developed powerful software systems that make it possible to solve many problems related to the mathematical modeling of thermogas-dynamic processes in gas turbine engines. The most known ones include NPSS, GasTurb, GSP, PROOSIS. In the Russian Federation, DWIGw, ASTRA, GRAD packages, as well as methods and software developed in CIAM, have been commonly applied. A comparative analysis of most above software suites is given in work [1]. Many developers and manufacturers of aircraft engines have their "in-house" methods, less common due to the peculiarities of work of these organizations, for analyzing the parameters and characteristics of GTE, for example, [2].

Underlying such packages are methods for calculating GTE parameters based on node-by-node modeling. Engine components are considered as "black boxes" with predefined characteristics.

All models and methods for calculating GTE parameters are evolving. When using models of nodes of high-fidelity, it becomes possible not only to improve the engine model and obtain more accurate results but also to study the processes in the flow-through part of the engine more deeply.

Some of the most challenging components to model are blade machines. The author of the known software package GasTurbJ. Kurzke argues in [3] that realistic compressor maps are the key to high-quality gas turbine performance calculation.

The characteristics of the compressor required for modeling GTE processes can be obtained experimentally. The existence of large volumes of experimental data allows them to be summarized using statistical methods. An example is work [4].

Paper [5] suggests a library of characteristics of engine elements that can be used directly or by scaling in accordance with the specified parameters of the compressor for the designed GTE. In the literature, there are quite a lot of different scaling rules to obtain characteristics. However, they do not consider the physical features of the phenomena taking place and do not take into account the geometric parameters of the flow-through part and blade rings.

Almost all known methods of GTE calculation have passed the way of increasing the level of modeling from the use of models of nodes of the 0th order using characteristics libraries to models of nodes based on the 3D methods of calculating the flow.

Thus, work [6] reports an improved object-oriented method for calculating the PROOSIS GTE. Its feature is the connection to the engine model of the results of the calculation of a multi-stage compressor in a one-dimensional statement.

Some studies suggest the possibility of using 1D, 2D, and quasi-metric (Q3D) methods for calculating turbomachines.

Paper [7] applied a model of the blade-by-blade turbine calculation; the compressor is represented as a single unit without detailing.

The authors of work [8] used the results from calculating a spatial flow in the fan and demonstrated how important it is for the model of a dual-circuit engine to determine the distribution of flow parameters along the radius in the internal and external circuits. The integration of the 3D method for calculating a fan consisting of an impeller, a rectifying apparatus of the outer circuit, and an input guide device of the internal circuit, taking into consideration the influence of the radial gap, is described in [9]. A fully integrated model of 3D fan calculation in the GTE model is reported in paper [10].

The use of 3D approaches to the calculation of the thermogas-dynamic parameters of gas turbine engine units increases the information content and accuracy of the results but, when building integrated models, the complexity of the combined algorithm increases. One of the reasons for this is the application of the principle of establishing by time in the calculation of spatial flow by solving the Navier-Stokes equations. This approach, used in most available software packages, requires additional approximations to enter the predefined flow rate mode within the computational cycle for calculating inconsistencies when modeling a process in GTE. Hence, it follows that the application of 3D calculation methods to study the flow in engine nodes significantly complicates the computation process and increases time costs.

Improving the accuracy of solving the tasks related to designing and analyzing the operational characteristics of the engine requires an increase in the amount of information received and taking into consideration the physical characteristics of the flow. The most acceptable for this purpose are two-dimensional approaches to the calculation of flow in blade machines, especially in multistage compressors.

Compressors in modern gas turbine engines, both for aviation and ground applications, are very loaded structures; various adjustment techniques must be used to ensure their effective and stable operation. That includes the use of rotary stator guides with rather complex programs for changing the angles of blade installation, as well as the transfer of working fluid from the flow-through part of the intermediate stages in a multistage compressor. In addition, there is a selection of air from the flow-through part of the compressor for cooling the hot parts of the GTE tract, interior air conditioning, and other needs. Moreover, the amount of selected air in modern GTE can reach 20...25 % of compressor inlet flow.

The above factors significantly affect the parameters of the compressor, its total characteristics, and, accordingly, the parameters and characteristics of the engine in general. They must be taken into consideration when performing the calculation; which necessitates the use of an appropriate toolset.

Based on the above review, a task can be set to devise an improved version of the method for calculating GTE performance characteristics. It should provide for taking into consideration a change in the geometric parameters of compressor blade rings in different cross-sections in terms of blade height, the angles of installation of rotary guides, and the program for their adjustment. As well as assess the impact of selection and re-transmission of working fluid from the flow-through part, radial unevenness of the flow at the inlet, the erosion wear of the blades and flow-through part during operation.

The dependences that make it possible to take into consideration the effect exerted on the characteristics of the compressor by a change in the angle of installation of blades in an input guide device (IGD) in the form of correction coefficients, reported in some studies, for example, [11], are unlikely to be common. The task becomes more complicated if it is necessary to adjust not only the IGD but also several (two or more) rotary guide devices (GDs) or optimize their adjustment program for the designed GTE. To resolve this issue, it is necessary to integrate a multi-stage compressor blade-by-blade calculation module into the engine model.

To take into consideration the influence of air transfer on the characteristics of the compressor, generalized dependences were proposed in work [12]. It is obvious that they cannot take into consideration the whole variety of existing options for the location of valves and the values of the flow rate of the air being passed. Therefore, the task of taking into consideration these effects when modeling GTE is advisable to solve using a blade-by-blade model of the compressor.

The blade-by-blade model of a multistage compressor in a one-dimensional statement is used in the method of calculating the performance characteristics of a turboshaft two-stage GTE with a free turbine [13]. The use of this stage-by-stage approach makes it possible to resolve the issues of taking into consideration the impact exerted on the characteristics of the engine by the rotation of stator blades, reflow, as well as the selection of working fluid from the flow-through part of the intermediate stages of the compressor. However, air selection and reflow under actual conditions are carried out at the periphery of the flow-through part. Therefore, more accurate values for the parameters at the inlet to the bypass valve or the system of secondary air coming from the compressor to cooling for its calculation can be derived by using two-dimensional methods for calculating the flow in the compressor.

3. The aim and objectives of the study

The aim of this work is to devise a method for calculating the thermogas-dynamic parameters of GTE and its characteristics using a two-dimensional description of a multi-stage axial compressor. Such a method would make it possible to improve the level of modeling and, accordingly, the accuracy of results in calculating the parameters of the engine and its characteristics.

To accomplish the aim, the following tasks have been set:

– to improve the current verified method of calculating the parameters and characteristics of the gas turbine engine [13, 14] by replacing the 1D approach used to calculate the thermogasdynamic parameters of the axial compressor with a 2D approach;

– to verify the results of the engine calculation by comparison with known experimental data;

– to demonstrate the possibilities of the calculation method, regarding the influence of rotating the stator blades of the compressor, on engine characteristics.

4. The study materials and methods

Our study is based on the use of theoretical methods for calculating thermogas-dynamic processes in a turbo-shaft GTE, as well as methods of mathematical modeling.

The node-by-node mathematical model of the engine was built at the Department of Aircraft Engine Theory, the National Aerospace University named after N. E. Zhukovsky "KhAI" (Ukraine); it is supplemented with an integrated module of two-dimensional calculation of a multistage axial compressor, developed at the same department. That has made it possible to simplify the process of harmonizing the modules.

The research object chosen is a turboshaft GTE with a single-shaft gas generator and a free turbine. It is schematically shown in Fig. 1.

The compressor is axial; it has 12 stages and 5 rotary blade devices: inlet guide vane (IGV) and guide vanes of stages I, II, III, and IV (GV1, GV2, GV3, GV4).

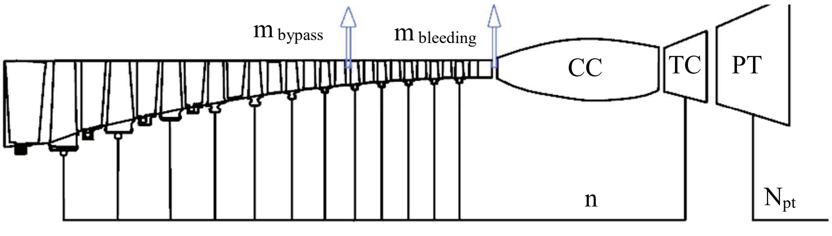


Fig. 1. Estimation scheme of turboshaft gas turbine engine

5. The results of studying the parameters and characteristics of the engine using the devised calculation method

5. 1. Improving the method of calculating the parameters of a gas turbine engine

We have improved an earlier built method and proposed an object-oriented approach to the calculation of turboshaft GTE parameters and its operational characteristics under stationary operating modes. A new component of the method is the calculation of a two-dimensional axisymmetric flow in a multi-stage compressor.

The mathematical model of GTE, used in the construction of the method, has a modular structure. It includes models of the zero level of the main components of the engine: an input device, combustion chamber, turbine, output device, transition channels. In their calculation, the generalized dependences reported in works [14–17] have been used. The module for calculating the parameters of a multi-stage compressor in a two-dimensional setting is integrated into the GTE model. A simplified block diagram of the method for calculating the characteristics of a gas turbine engine is shown in Fig. 2.

The main system of equations used in the calculation method is identical to the system of equations given in [13]. The system of equations presented there is intended to analyze the performance characteristics of a two-stage turboshaft GTE with a free turbine involving a blade-by-blade compressor calculation in a one-dimensional statement (1D).

Unlike [13], in this work, we use a module for calculating a two-dimensional (2D) axisymmetric flow in a multistage compressor. Fig. 2 shows a block diagram for calculating GTE with a single-shaft gas generator and a power turbine.

Calculation of compressor parameters under the program-specified engine calculation mode is carried out for a general case, taking into consideration the selection (or reflow) of air from the flow-through part. Averaging the parameters of the two-dimensional flow by the height of the blade makes it possible to determine the degree of increase in the total pressure *PR* and the isentropic efficiency η_{si}^{*} of all stages based on the inhibited parameters, and then the values of work and the power consumed by the compressor cascades.

The system of equations of flow balances and powers of the corresponding stages of the compressor and turbine, supplemented with the engine adjustment program, form an equation system with "inconsistencies":

$$\begin{cases} m_f\left(1-\Delta\overline{m}_{bleeding}-\Delta\overline{m}_{coolingTC}-\Delta\overline{m}_{bypass}+q_{fuel}\right)-m_{gTC}=\varepsilon_1, & (1)\\ m_f\left(1-\Delta\overline{m}_{bleeding}-\Delta\overline{m}_{coolingTC}-\Delta\overline{m}_{bypass}+q_{fuel}\right)-m_{gPT}=\varepsilon_2, & (2)\\ m_f O_C^{*}-m_{gPT}O_{PT}^{*}EFF_m=\varepsilon_3, & (3)\\ A_e-A_{e.d.}=\varepsilon_4, & (4)\\ T_g^{*}-T_{gd.}^{*}=\varepsilon_5 \text{ or } \overline{n}_{core}-\overline{n}_{cored.}=\varepsilon_5. & (5) \end{cases}$$

Equations (1) and (2) notate the balance of flow rate through the compressor and turbine of the compressor and through the compressor and power turbine; equation (3) is the balance of powers on the shaft of the gas generator; equation (4) is the condition of no-change in the area of the output device; equation (5) is the condition of adjustment by changing the temperature of the gas or the speed of rotation.

The values of "inconsistencies" in proportion to the successive approximations using Newton's method and the convergence of the computational process decrease to the predefined permissible values of the solution accuracy (value ε_0 in the diagram).

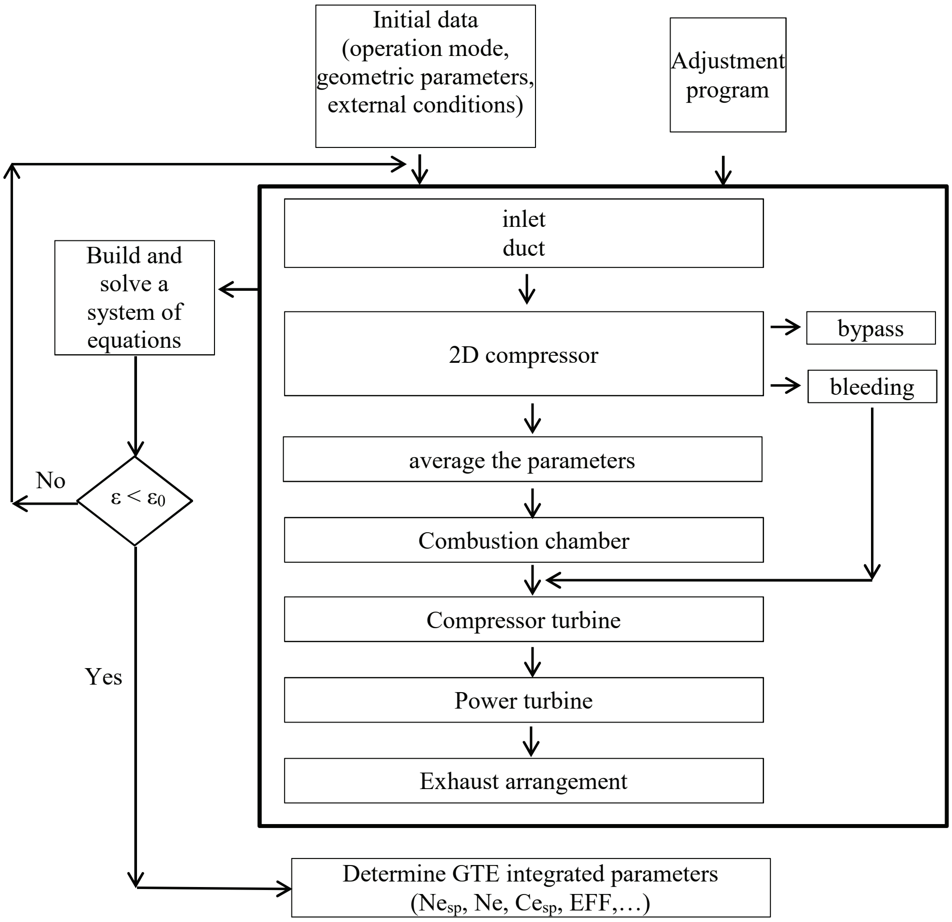


Fig. 2. Block diagram of the method for calculating the thermogasdynamic parameters of a turboshaft gas turbine engine with a two-dimensional description of the compressor

The compressor parameters necessary for solving the system of equations (1) to (5) that describe a working process in GTE, were obtained using the method of calibrating gas-dynamic calculation of the two-dimensional subsonic flow in an axisymmetric setting. The main provisions of the method are given in work [18]. The method of calculating the compressor makes it possible to reflect the influence of various factors on the characteristics of the engine in general. These include changing the geometric parameters of the flow-through part and blade rings in various cross-sections along the radius, changing the angles of installation of rotary GD, the selection and reflow of working fluid from the flow-through part. That makes it possible to reflect the impact of these parameters on the characteristics of the engine in general.

The method of calculating the compressor makes it possible to approximately take into consideration the effects of the turbulent transfer of flow parameters in the radial direction. It also enables forming the end boundary layers, taking into consideration the supply of energy from the core of the flow and their effect on the flow in the core.

Turbulent mixing makes adjustments to the process of flow formation and significantly affects the radial diagrams of the flow parameters. The use of conditional separation of the process of energy exchange in the blade rings and the turbulent exchange makes it possible to simplify the description of the actual workflow in the stage.

To perform the calculation, the flow path is divided into current streams. The characteristics of the profile gratings located at different radii are determined using semi-empirical dependences published in the literature. To find the operating mode of each elementary cross-section of the stage under a predefined operating mode of the compressor, the variational principle of the maximum flow of mechanical energy proposed in [19] is used.

Turbulent exchange is described using mass, momentum, and energy transfer equations by large-scale turbulent vortex formations. That makes it possible to assess the degree of alignment of the radial unevenness of the flow in the stage and the multistage compressor.

The calculation of the boundary layer on the surfaces limiting the flow-through part of the compressor is carried out taking into consideration the supply of energy from the core of the flow as a result of the turbulent exchange. That makes it possible to stabilize its thickness as the flow moves along the flow-through part, which corresponds to the actually observed phenomena.

Reducing the flow of air through the stage leads to an increase in the angles of flow on the blades, an increase in the amount of losses. When critical values of the angles of flow are reached, disruptive phenomena occur in individual cross-sections of a blade ring. In the case when most elementary blades of a stage work under the mode of detachment, it is assumed that the stage in general has reached the boundary of the region of steady operation.

With an increase in flow, with negative angles of flow, the flow rate in the minimum passage cross-sections of the interblade channels reach critical values. These channels are considered to be "locked". The flow rate that has not passed through them is redistributed and passes through the channels adjacent in height of the blades. If most of the pass cross-sections are "locked", the stage is generally considered to be operating under a "locking" mode.

To derive the value of the degree of increase in pressure *PR* and isentropic efficiency η^*_{sc}, the integration of flow parameters by height is carried out provided that mass, energy, and entropy are conserved in averaged and averaging flows.

Under the predefined mode, these parameters are used in the GTE model when forming equations of the balance of parameters by cascades and equations of inconsistencies.

The PROK software package implements the calculation algorithm described above and is the basis of the 2D flow calculation module in a multistage compressor in the GTE characteristics calculation method.

5. 2. Verification of the method of calculation of engine specifications

The improved method of calculating the characteristics of the gas turbine engine and the corresponding set of programs have been applied to the analysis of flow parameters in the turboshaft GTE.

To perform the calculation of GTE parameters involving the module for two-dimensional calculation of the flow in the compressor, it is necessary to set the geometric parameters of the flow-through part and blade rings in various cross-sections for the height of the blade.

Fig. 3 shows the characteristics of the compressor obtained by calculation in the range of relative speeds $\overline{n}=0{,}9...1{,}0$ in the form of dependences of the degree of pressure increase and isentropic efficiency according to the parameters of the inhibited flow due to the airflow rate at the inlet. The parameters are assigned to the corresponding values under an "estimated" mode:

$$\overline{PR}=\frac{PR}{PR_d},\quad \overline{\eta}_c^*=\frac{\eta_c^*}{\eta_{cd}^*},\quad \overline{m}=\frac{m}{m_d}. \qquad (6)$$

The same figure shows, for comparison, the results of experimental studies of a given compressor, reported in work [20].

When comparing the results of the calculation with the experimental data, the standard deviation was 0.45 %. The maximum deviation is 1.73 % at a relative speed of 0.9. Satisfactory coordination of the results allows us to conclude that it is expedient to connect this module to the GTE model.

The method of calculating the flow in the compressor makes it possible to consider the flow structure at different radii of all stages during the operation of the compressor in the engine system.

Fig. 4 shows the change in total temperatures along the radius in the cross-sections behind the impellers of all stages. Fig. 4 demonstrates that by the ends of the blades, the values of the parameter increase due to the presence of end boundary layers and secondary currents and, responsibly, the growth of total losses.

Fig. 5 shows how the angles of flow ($i=\beta_{1g}-\beta_1$) change on the impeller blades along the radius under the same mode. There is also an increase in the angles of flow at the ends of the blades due to the inhibition of the flow in the end layers and other end effects.

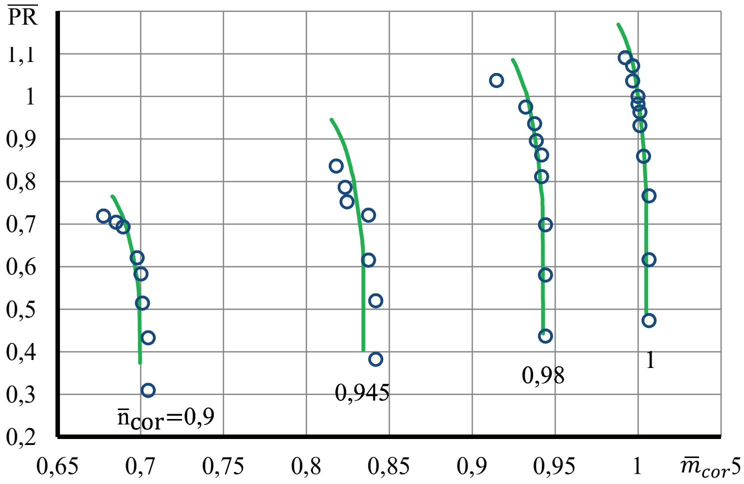


Fig. 3. Compressor characteristics: ○ — experiment [20]; —— — calculation using a mathematical model

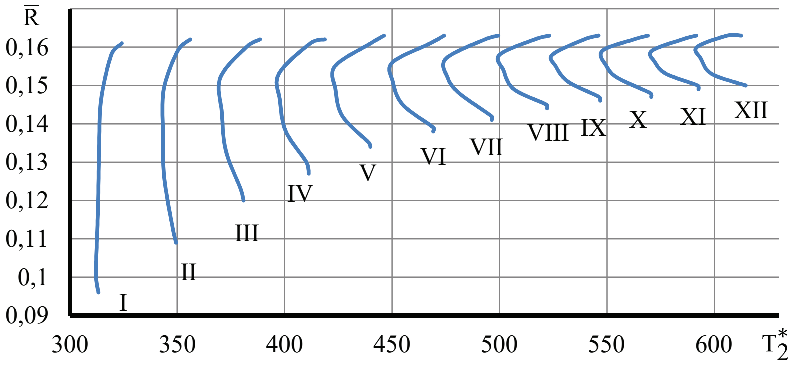


Fig. 4. Distribution of the total temperature behind the compressor stage impellers for blade height

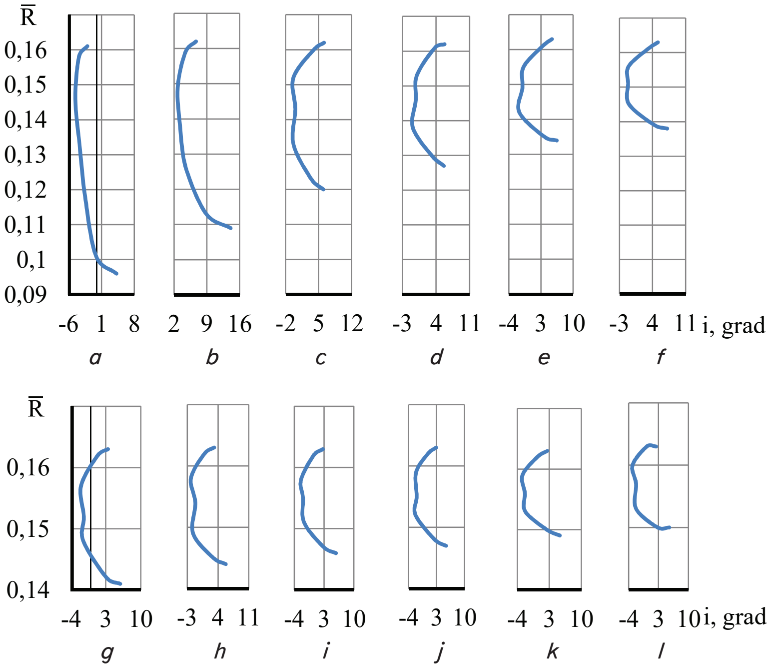
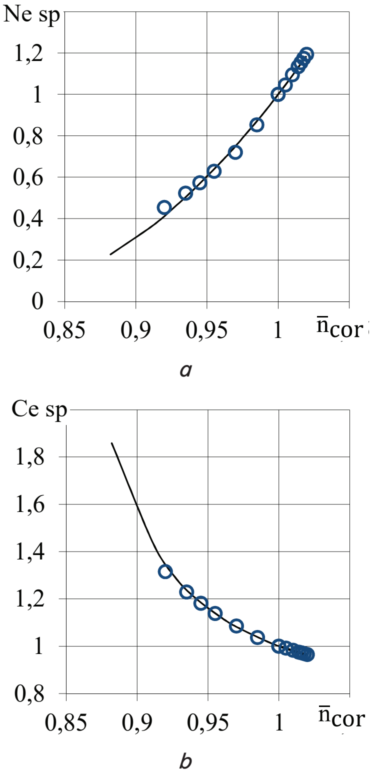


Fig. 5. Distribution of flow angles on the blades of the rotors of the compressor stages by radius: *a* — Rotor 1; *b* — Rotor 2; *c* — Rotor 3; *d* — Rotor 4; *e* — Rotor 5; *f* — Rotor 6; *g* — Rotor 7; *h* — Rotor 8; *i* — Rotor 9; *j* — Rotor 10; *k* — Rotor 11; *l* — Rotor 12

The same data on the flow parameters in the compressor can be acquired under any mode corresponding to the conditions of joint operation of GTE units.

Fig. 6 shows a change, depending on the rotation frequency, in the specific power $N_{e\,sp}$, specific fuel consumption $C_{e\,sp}$ of a given GTE. There are also experimental data for comparison [21].



a

b

Fig. 6. Throttle characteristics of the gas turbine engine: *a* – dependence of power change on the reduced rotation frequency of the gas generator rotor; *b* – dependence of change in the specific fuel consumption on the reduced rotation frequency of the gas generator rotor; ○ – experiment [21]; ——— – calculation using a mathematical model of a gas turbine engine

It follows from Fig. 6 that the results of the calculation of the throttle characteristic show satisfactory agreement with experimental studies. Thus, the standard deviation of the calculation results from the experimental data is 0.4 % for power and 0.15 % for specific fuel consumption.

5. 3. Possibilities of the improved method of calculating the engine in solving practical tasks

Fig. 7 illustrates the results of calculating the throttle characteristics of the engine in question using the improved calculation method. There are also the results of calculating the boundary of the stable operation region for different speeds in comparison with the experiment reported in [20]. This calculation was carried out using the program for adjusting rotary guide vanes, laid down in the design of the GTE. It is shown in Fig. 8 in the form of the dependence of change in the angle of blade installation $\Delta\gamma=\gamma-\gamma_d$ (*d* is the estimated mode) on rotation frequency. With a decrease in the rotation frequency, the blades are turned to "close", which provides for sufficient reserves of stability.

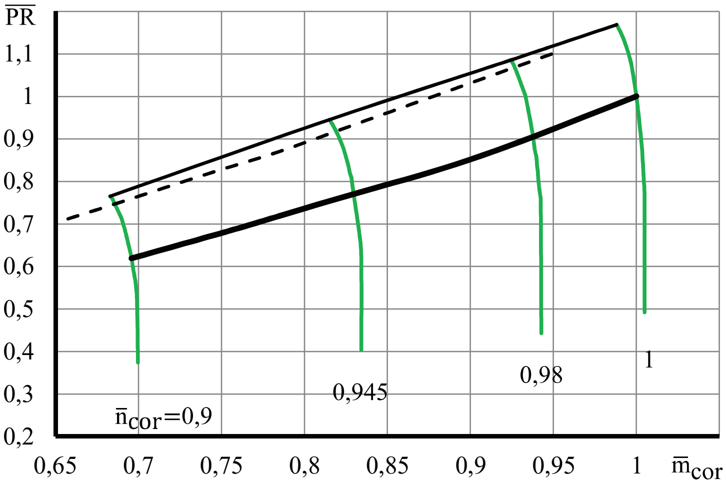


Fig. 7. Line of joint modes of operation of gas turbine engine units on the compressor characteristics: ——— – pressure branches; ——— – the estimated boundary of the region of steady operation; – – – – – – experimental boundary of the region of steady operation [20]; ━━━ – line of operating modes

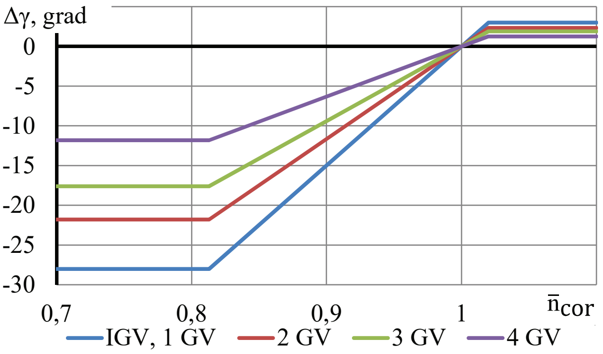


Fig. 8. Rotary blade ring control program

As an example, Fig. 9 shows the results of calculating the characteristics of the compressor and the throttle characteristics of the GTE under study in the absence of rotation of the IGD blades and at stages I, II, III, IV stages. It follows from Fig. 9 that, in this case, the boundary of the region of steady operation approaches the line of joint modes of operation of the nodes as the rotation frequency decreases.

In the absence of adjustment of rotary devices, the stability reserves calculated in the form of dependences *SM* on the rotation frequency are significantly reduced. The *SM* value is defined as [16]:

$$SM=\frac{PR_{sl}/m_{sl}-1}{PR/m-1}-1, \qquad (7)$$

where the index "*sl*" denotes the modes of operation of the stage near the stability boundary.

Using the improved method, based on data on the line of operating modes and the boundary of the stability region, as well as dependence (7), we have determined stability reserves. Fig. 10 illustrates a change in the stability reserves with a decrease in the rotation frequency in the presence and absence of adjustment of the blade devices of the first stages.

Fig. 9, 10 illustrate the possibilities of our method to take into consideration a change in the geometric parameters of blade rings and, in particular, the angles of installation of the guide vanes in accordance with a predefined program.

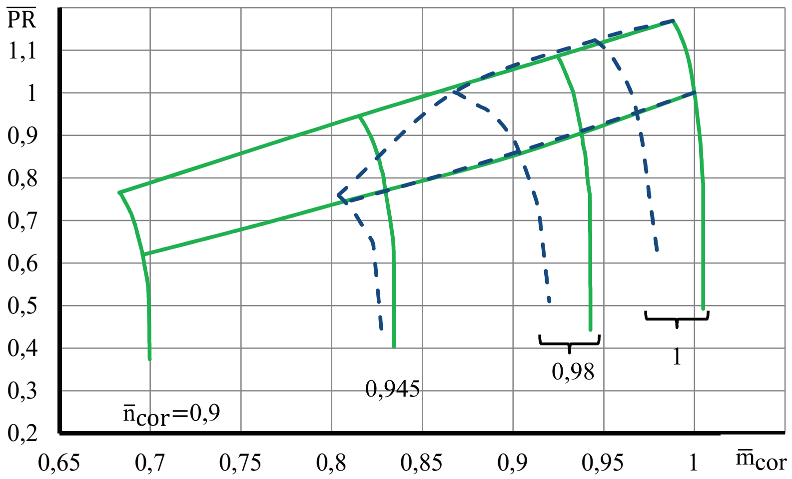


Fig. 9. Line of joint operating modes and compressor characteristics, taking into consideration and without taking into consideration the adjustment of the position of stator blades:
- - - – no adjustment; ——— – adjustment

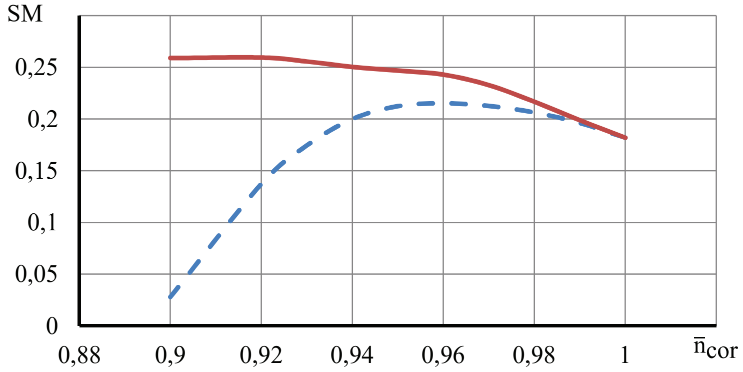


Fig. 10. Stability reserves with and without blade rotation:
- - - – without rotation; ——— – with rotation

6. Discussion of results of studying engine parameters and characteristics using the devised calculation method

A method for calculating the performance characteristics of a turboshaft GTE has been proposed. The method is based on a mathematical model having a node-by-node structure (Fig. 2). It has a series of advantages, based on a refined mathematical description of the compressor. In contrast to existing methods given in open literature sources, for example [1, 2, 6, 13], in our work, to determine the GTE characteristics, a 2D calculation of the compressor was integrated into its model.

The verification of a given method, demonstrated in Fig. 3, 6, has shown a satisfactory match between the calculations and experimental data [20, 21]. In addition, Fig. 4, 5 illustrate that at the end surfaces there is an increase in the values of the total temperature and angles of flow. Such results are explained by the existence of end boundary layers and secondary currents, which reflects actual processes and end effects.

Our paper shows the possibility of taking into consideration the influence of rotation of the adjustable guide devices of the first 4 stages and IGD in accordance with the predefined control program on the specific parameters of the engine, flow parameters along the flow-through part, the current inside the compressor (Fig. 9, 10). Such data cannot be acquired by using those calculation methods in which the compressor model is represented as a "black box", for example [1, 2]. It is obvious that the current study does not demonstrate all the possibilities of the proposed method of calculation; they will be shown in subsequent works.

In addition to the advantages presented, a given paper has a number of limitations. In particular, to perform the GTE calculation using a given method, it is necessary to have sufficiently complete information about the geometric parameters of the flow-through part and blade rings of the compressor. At the initial stages of design, such information is usually not available.

Further research in this area could include works related to increasing the level of modeling of thermogasdynamic processes in other GTE nodes. Such advancement of GTE models would improve the accuracy of results to be obtained and could allow for a more detailed analysis of the physical processes occurring in the engine.

7. Conclusions

1. The earlier devised method for calculating thermodynamic parameters and characteristics has been improved by replacing the module for calculating the parameters of the axial compressor. The use of a two-dimensional approach to determining the parameters of the compressor instead of a one-dimensional one could significantly expand the scope of GTE-related research, as well as improve the accuracy in determining its parameters.

2. As a verification of the proposed method, the characteristics of the compressor and the throttle characteristics of the engine in the form of dependences of power change and specific fuel consumption on the reduced rotation frequency of the rotor of the gas generator have been shown. The reported results demonstrate clearly that the data acquired from the calculation and the experimental data are satisfactorily consistent. Thus, the standard deviation of the calculation results from the experimental data is 0.45 % for the compressor characteristics, 0.4 % for power, and 0.15 % for specific fuel consumption. Radial diagrams of the total temperature behind the impellers and the angles of flow on blade rings are given.

3. As an example of the possibilities of the method for calculating the GTE parameters, we analyzed the influence of changes in the geometric parameters of the compressor blade rings on the characteristics of the engine under study. In particular, the influence of adjusting the angles of installation of the first 4 guide devices and the input guide vane has been shown. The results of calculating the engine without turning the blade rings indicate a significant deterioration in the characteristics of the engine. In particular, the head of the compressor significantly decreased while the reserve of gas-dynamic stability at the reduced rotation frequency of the gas generator of 0.9 was less than 5 %.

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