THE GAS TURBINE ENGINES OPERATIONAL PERFOMANCES MATHEMATIC SIMULATION METHOD

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Abstract: The gas turbine engine operational performances definition method based on blade–to-blade mathematic simulation of multistage axial compressor and high temperature cooling transonic multistage turbine using flow paths and middle radius blades geometric parameters is shown. The method allows to take into account air bypass and bleeding from compressor for the cooling and its blowing into turbine and their influence on the engine parameters.

As example, attained by calculation way the results of turbo-shaft engine operational performances and air by pass bleeding from compressor influence on the engine specific parameters, efficiency and stability margin are represented.

Keywords: AVIATION GAS TURBINE ENGINE, OPERATION PERFORMANCE, COMPRESSOR AND TURBINE GEOMETRICAL PARAMETERS, AIR BY-PASS.

1. Introduction

In modern practical designing it is paid a lot of attention to gas turbine engine aviation, marine and stationary applications mathematical simulation, definition their gas and thermo dynamic parameters and operational performances [1-4]. The methods for engines working processes investigation will be considered in this article.

The most simple per-unit engine models which are founded on the "black box" processes description level are widely used.

In these simulations the main units (compressor, turbine, combustion chamber, etc.) performances are set as external data using experimental results or generalized dependences. They don't allow to take into account the influence of many significant for engine performances factors. This article deals with the developing c of gas turbine engines stationary process simulations and performances. Three types of engine models will be considered and compared.

2. Theoretical model

Schematic representation of dual-rotor turbo-shaft gas turbine engine in per-unit modeling level is shown on Fig.1a. Such type of models and according calculation techniques are widely used in gas turbine engines design bureaus.

Their application allows to definite the engines operation performances such as thrust (or power), specific fuel consumption, efficiency and other parameters as the dependences of the flight high and speed, type of fuel, control system and so on. However, this approach doesn't make possible to analyze of the geometrical parameters modifying influence, air pulling from compressor flow path and it's blowing into turbine stage for cooling, opening bypass valves and so forth.

To increase the methods accuracy and effectiveness the simulation should have higher level detailed of thermo and gas dynamic processes in engine main units, which will allow to take into account their geometrical parameters, air bleeding and blowing.

The air bleeding from compressor path for different needs or its bypassing from the valves at low rotation speeds plays the significant role in engine operation and influence its performances.

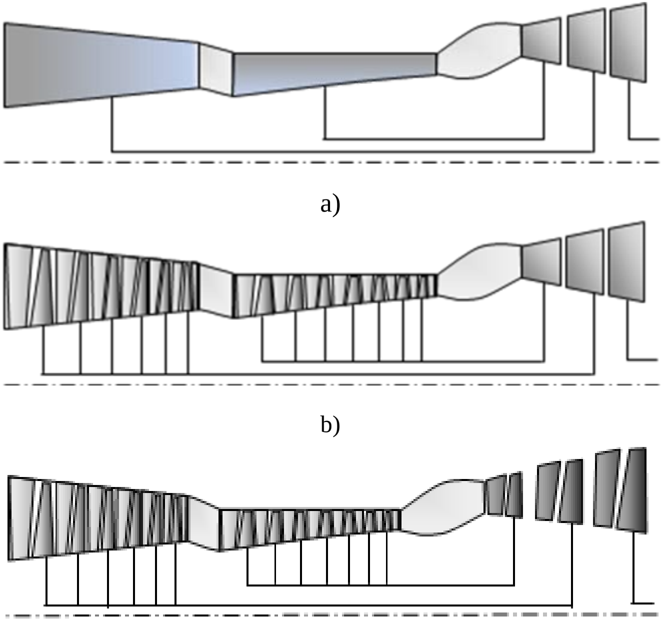
So the developing of the first difficulty level engine simulation Model A (Fig. 1a) and its modernization to the simulation founded by multistage compressor blade-to-blade description made possible to propose Model B.

This simulation is shown on Fig.1b. It considers the compressor flow path and middle radius blades geometry.

So Model B allows:

- to estimate the blades and flow path geometrical parameters changing influence on the engine operational performances;
- to check optimal values of variable guide vanes stagger angles for designing and modernization engine control system;
- to consider by-pass flow rate from the compressor flow channel and its influence on the engine parameters more accurate than if the Model A would be used;
- to estimate the compressor surge margin and identificate the stage, which is the source of the stall phenomenon on various rotational speeds.

The Model C is further development of calculation technique, which includes modernization of the multistage high temperature cooled turbine description accounting flow path and middle radius blades geometrical parameters. Fig. 1c illustrates Model C graphically.



a)

b)

c)

Fig. 1 *Gas turbine engine simulation schematically representation*
a) Model A; b) Model B; c) Model C

In addition to simulations possibilities previous Model C allows:

- to estimate blowing from the cooling system in turbine gas path air parameters and their influence the operation performances of GTE, especially its mass flow rate, temperature and other;
- to harmonize more accurately air flow rate taking away from compressor path for cooling of engine hot elements and air blowing in turbine stage on various regimes;
- to decrease the number of correction coefficients for identification mathematic model.

In fact, Model C has more possibilities then it was named above.

The developed calculation technique has the modular structure, which is opened to stocking. The modern version of software includes the second order difficulty compressor and turbine modules, which accounted their geometry and the first order simulation of combustion chamber, inlet diffuser and exit nozzle modules.

For stationary operation regimes the equations system includes the engine units working conditions with taking into account blade-to blade multistage turbine and compressor discretization and allows to calculate flow parameters in the engine flow path. The engine parameters cooling system, control program and environment conditions are set also.

Equations system combines mass flow rate and power balances for engine main units, turbine and compressor stages with accounting of air bypassing, bleeding and blowing.

Flow parameters are calculated by using system of turbo machines gas dynamic equations in one-dimensional statement. To accounting viscosity effects are used the published generalized dependences, which were tested in our laboratory.

In addition to data, which are setting for per-unit engine simulations, Model C requests compressor and turbine flow path and middle radius blades geometric parameters.

3. Practical Application

As the developed method practical application example, let us consider twin spool turbo shaft engine performances in wide range of operation conditions including the cases, when by-pass valves are opened. These regimes take place in gas turbine power plants at low level of rotating speeds.

Low pressure compressor performances attained by calculation by way as the pressure ratio and isentropic efficiency dependences from inlet air mass flow rate and rotational speed are shown on Fig. 2.

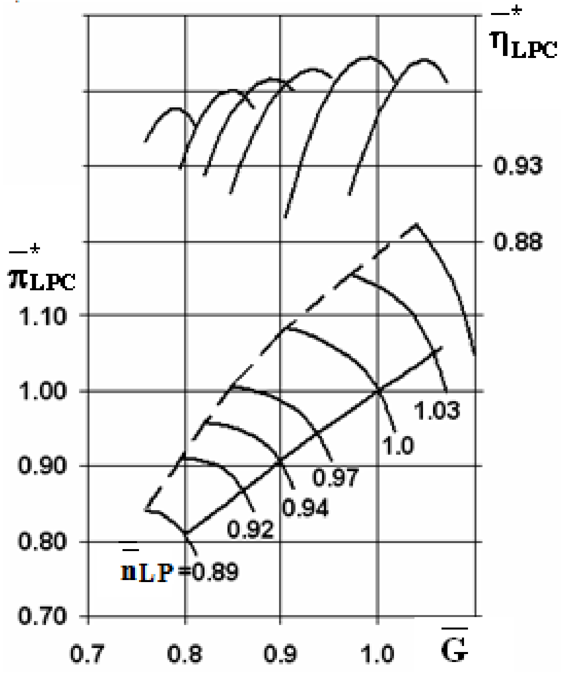


Fig. 2 *Low pressure compressor pressure ratio and efficiency dependences by inlet flow rate and relative rotational speed*

All parameters are represented in dimensionless form and divided by design point magnitudes. This map comparison with experimental data gave a good agreement. Fig. 3, 4, 5 illustrate high pressure turbine performances in the form of dependences mass flow rate parameter, isentropic efficiency and turbine absolute exit flow angle from turbine stage pressure decreasing ratio π_T^* and rotational speed λu with accounting the air blowing in turbine stage from cooling system.

These turbine and compressor characteristics as the curves aren't used in the engine performance calculations, and when the software calls corresponding module, only one point according to the operation conditions is calculated taking into account mass flow rate, rotational speed, flow angle and so on.

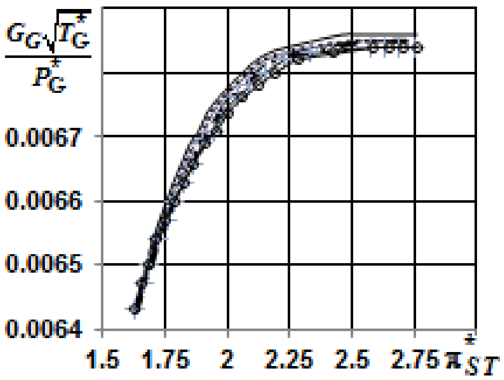


Fig. 3 *Gas flow rate parameter dependences by turbine pressure decreasing ratio and rotational speed*

- - - - – λ_u =0,42; ——— – λ_u =0,50; - -□- - – λ_u =0,54;
— — — – λ_u =0,58; ········ – λ_u =0,62; —+— – λ_u =0,66;
—○— – λ_u =0,70

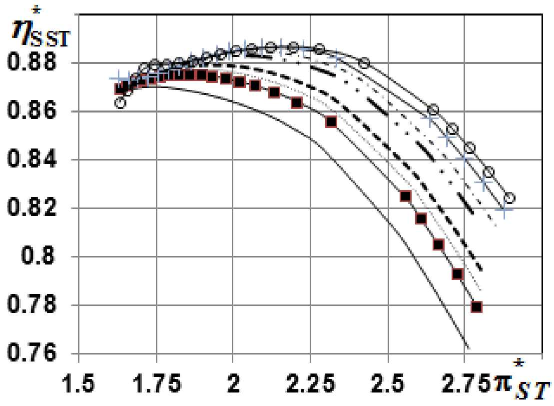


Fig. 4 *Turbine isentropic efficiency dependence by pressure decreasing ratio*

——— – λ_u =0,51; —■— – λ_u =0,54; ——— – λ_u =0,55;
- - - - – λ_u =0.56; —·· — – λ_u =0,58; —+— – λ_u =0,62;
—○— – λ_u =0,65

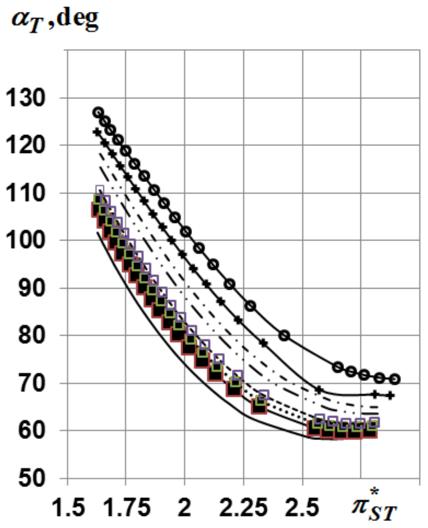


Fig. 5 *Turbine stage absolute velocity exit angle dependence by pressure ratio decreasing*

——— – λ_u =0,51; —■— – λ_u =0,54; ——— – λ_u =0,55;
- - - - – λ_u =0.56; —·· - – λ_u =0,58; —+— – λ_u =0,62;
—○— – λ_u =0,65

It is seen from Fig 5, that turbine operation conditions changing leads to varying gas flow parameters in wide limits, which is affected the next stage working regime. Only blade-to-blade turbo machines flow description gives the possibility to account its influence.

The stages reciprocal effects might be significant. As example, let us consider the turbine nozzle vanes incidence angle impact.

Fig 6 demonstrates the isentropic efficiency varying for different values of incidence angle. As follows from this figure turbine stage efficiency changes by 1-2% and that factor influence engine operational performances significally.

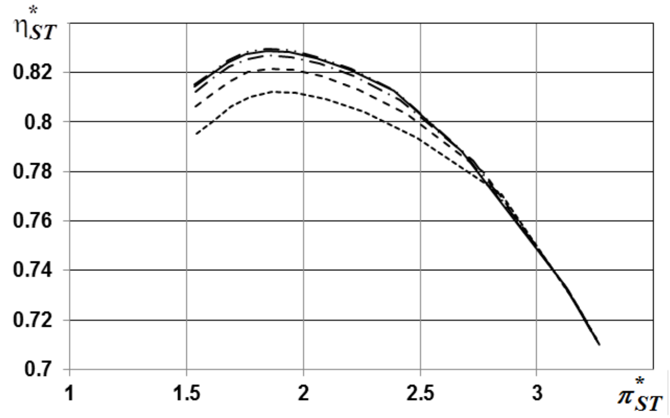


Fig. 6 *The turbine stage nozzle vanes incidence angle influence isentropic efficiency*

――― – *i*=+40 deg; - - - - - – *i*=+20 deg; - · - · - · – *i*= 0 deg;
――― – *i*= -30 deg; — · · — · – *i*= -40 deg;

The blade-to-blade discretization of gas dynamic processes in multistage turbine is the new part of presented gas turbine engine simulation. It allows to take into account not only the parameters of main gas flow, but also blowing from cooling system in gas path air parameters. Fig. 7 graphically illustrates isentropic efficiency by turbine pressure ratio decreasing dependences for different values of blowing air relative temperature. The air temperature magnitudes are divided by the incoming the turbine stage main stream gas temperature.

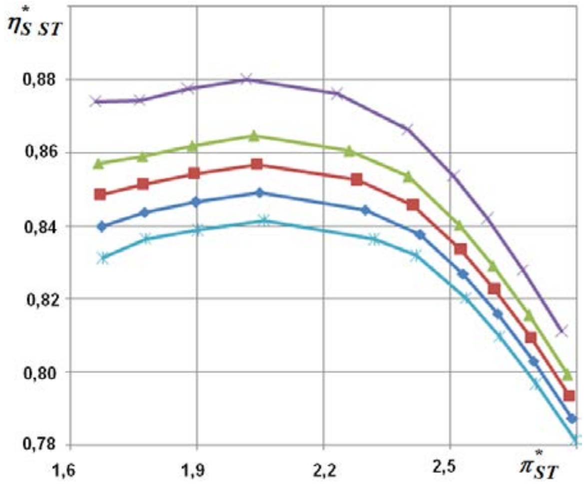


Fig. 7 *Dependences the turbine stage isentropic efficiency by the relative temperature of blowing in the path cooling air*

—✳— – $\frac{T_A^*}{T_G^*}=0,3645$; —◆— – $\frac{T_A^*}{T_G^*}=0,4645$;

—■— – $\frac{T_A^*}{T_G^*}=0,5645$; —△— – $\frac{T_A^*}{T_G^*}=0,6645$;

—✕— – $\frac{T_A^*}{T_G^*}=0,8645$

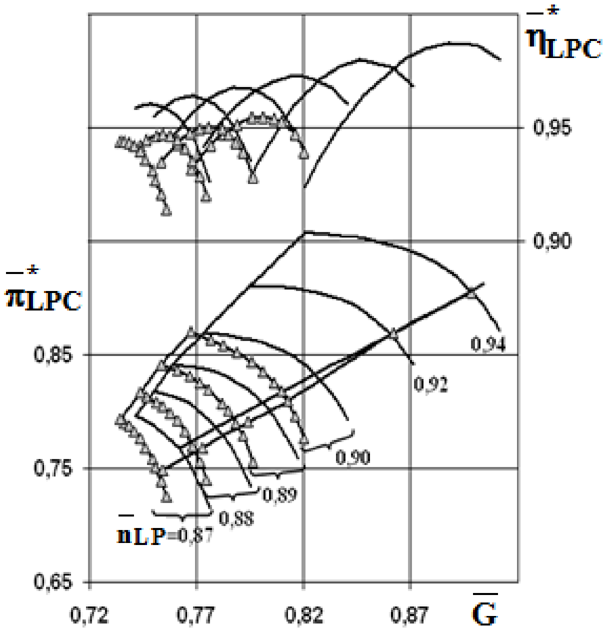


Fig. 9 *The flow bypassing from compressor channel influence compressor performance*

――― – *valves are closed*
—△— – *valves are opened*

From Fig. 7 one can see, that blowing air temperature increasing leads to the isentropic efficiency value growth. In this case the thermo dynamic losses are decreased and efficiency of cooled turbine stage is raised. However, the effectiveness of blade metal cooling is diminished. That is the traditional question for designers.

Named above and many others turbine and compressor flow features influenced the gas turbine engine performances may be calculated with assistance of presented method and correspondent software.

Fig. 8 shows the engine performances as dependences of effective power and specific fuel consumption from the fuel consumption getting in calculation way in dimensionless form. If $\overline{G}_T \geq$ 0,7 the bypass valves are closed. The most advantage of considering calculation method may be received from investigation of changing compressor and turbine blades geometrical parameters, stagger angles of variable guide vanes, bypass mass flow rate influence on engine operational performances, which was presented in [5, 6].

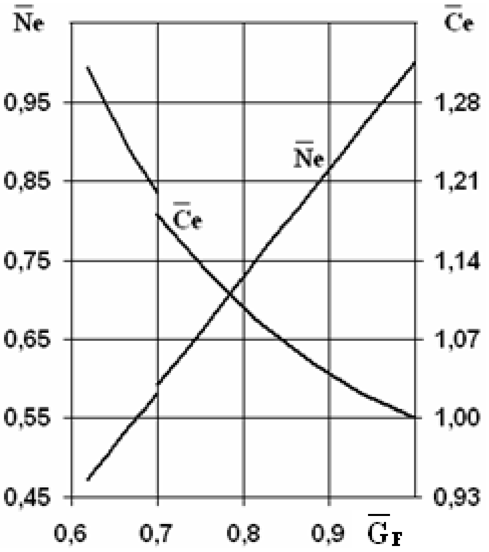


Fig. 8 *Effective power and specifically fuel consumption dependences by fuel consumption*

Further let us consider the opening of low pressure compressor bypass valves located above third stage influence the compressor map and engine performances. The relative mass flow rate bleeding from the compressor channel through the valves divided by the inlet mass flow rate equals 5 %.

As Fig. 9 illustrates, the valves opening leads to moving the performance curves in lower flow rate level and essential reducing efficiency of compressor. From Fig.10 one can see the blade incidence angle values for different stages of low pressure compressor.

When the valves are closed the first stages have the big values of incidence angles. The opening of the valves allows to reduce the angles and decrease the blade loading.

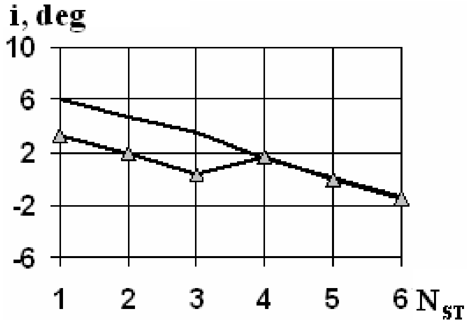


Fig. 10 *The blades incidence angles for different stages of low pressure compressor,* $\bar{n} = 0{,}9$ *near the working line*

——— *– valves are closed*

—△— *– valves are opened*

As a result, Fig 11 illustrates the surge margin of compressor calculated by using of the described above technique. So, the bypass valves opening gives the possibility to increase the surge margin of compressor at low rotational speeds.

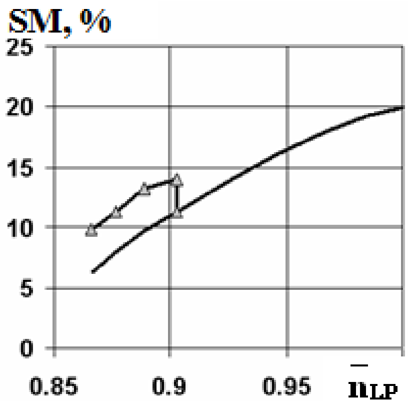


Fig. 11 *Low pressure compressor surge margin dependences by its relative rotational speed*

——— *– valves are closed*

—△— *– valves are opened*

The surge margin growth decreases the engine integral parameters. From Fig 8 it could be quantity estimated the increasing of specific fuel consumption and reducing of power, while the bypass valves are opened.

4. Conclusions

The gas turbine engine operational performance investigation method founded on mathematic models of units and blade-to-blade description of the process in multistage axial compressor and high temperature cooled transonic turbine was presented .Its advantages and reasonable application for practical designing were demonstrated.

As it was shown, the developed method and software allow to estimate the influence of bypass mass flow rate on the engine operation performances and its value optimize for various operation conditions at low rotational speeds.

5. Literature

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