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Formation of algorithms for calculation of unstable modes of aviation gas turbine engine

An approach of formation the algorithms of calculation the unstable modes of the aviation gas turbine engine has presented. It is shown that the Euler method used in integration (or another, for example, the Runge-Kutta method of the fourth order), in combination with the numerical method of functional minimization used by the solver discontinuity (for example, Newton's method) is effective for solving a number of project reference tasks and at the same time allows you to make a process adding dynamic factor accounting to the SE model is simple and clear.

Introduction. The process of modeling and researching various unstable modes of aviation engine (AE) operation in the simulation system takes place in several stages according to the principles described in [1-7]. The basis for the formation of mathematical models of gas turbine engines is the principle of simulation modeling, which allows to realize the universality of the process of forming engine models and to ensure the connection with external conditions and with the project reference situation. The subject basis of the system is: output modules (library of functional elements) that describe the processes in the elements of the gas turbine engine (GTE) and its automatic control system (ACS) in uniform requirements that ensure the simplicity of their joint work as part of the model; conditions of joint operation of these modules; the technology of setting conditions for various project reference tasks.

The goal of this research is the formation of the main stages of the algorithm for calculation the unstable modes of aviation gas, which ensure the principles of the synthesis of thermo gas dynamic models, the implementation of the law of conservation of matter, the law of conservation of energy.

Formation of the engine model. According to the named initial positions, the engine model formation algorithm consists of the following main stages:

1) synthesis of the model through its set of elementary typical modules (structural elements (SE)), which determine the selected scheme and indication of thermo gas dynamic, mechanical, hydraulic, etc. (flow tracing);

2) setting parameters and characteristics of modules (SE);

3) setting the conditions that implement the given project reference task (formalized construction of a system of managed non-connections);

4) setting conditions for the problem of multivariate and (or) multimode analysis and (or) synthesis (with tabulation of parameters).

The nomenclature of input and output parameters, reserved "ports" for SE information connections allow you to create models of various engines and Energy Installations (EI) from them, perform various design reference procedures with the help of a solver (SIM processor), and solve problems arising in operation taking into account object modeling.

The system allows you to simulate the unstable modes of operation of various schemes: multi-shaft, double-circuit, with an afterburner, as well as various mechanization, actuation of valves, bypass belts, rotation of input guide devices, control of the geometry of the jet nozzle, etc.

The synthesis of the model is carried out according to the engine scheme [1, 5]. Consider the mathematical model of an arbitrary engine. In the proposed technology, models are formed, their debugging, testing and use are carried out, with a consistent increase in the nomenclature of factors that are taken into account, including time factor and dynamic factors. Therefore, at the initial stage, SE models for modeling any engine (in stationary modes) include the following equations.

Power balance equation:

$$N_{Ti} - N_{Ci} - N_{AGGR} = 0, \tag{1}$$

where i is the number of the rotor (single-shaft, two-shaft, continuous GTE).

For the main combustion chamber, the relative fuel consumption is determined taking into account the variable heat capacity of air and combustion products in the heat balance equation

$$q_H = f\left(T_G^*, T_C^*, \eta_z, Hu\right). \tag{2}$$

Characteristics of compressors:

$$\pi_{Ci}^* = f\left(G_{F\_GIVi}, n_{givi}\right);\ \eta_{Ci}^* = f\left(G_{F\_GIVi}, n_{givi}\right). \tag{3}$$

Characteristics of turbines:

$$A_{Ti} = f\left(\pi_{Ti}^*, n_{Ti}\right);\ \eta_{Ti}^* = f\left(\pi_{Ti}^*, n_{Ti}\right). \tag{4}$$

Characteristics of the combustion chamber (and afterburner in the case of TREF):

$$\eta_G = f(P_C^*, \alpha_{CCh}). \tag{5}$$

Characteristics of the jet nozzle:

$$\mu_n = f\left(\pi_n^*\right);\ \varphi_n = f\left(\pi_n^*\right). \tag{6}$$

Control programs are set by condition

$$Y_j = f\left(X_j\right), \tag{7}$$

where Y_j are parameters whose values are maintained by the regulation system (regulated parameter); X_j are parameters that provide regulation (regulatory, control actions).

Monitoring of dynamic factors. The inertia of the rotors is taken into account by an algorithm based on the energy equation, accounting for it is necessary even in low-frequency processes. To account for this factor, the dynamic correction for power (transmitted from the compressor to the turbine) is determined in the SE (compressor or turbine, or in both SEs with the division of the moment of inertia into parts) in accordance with the equation: $\Delta N_{dyni} = \left(\frac{\pi}{30}\right)^2 \cdot J_i \cdot n_i \cdot \frac{dn_i}{dt}$.

Calculations can be carried out in different forms of specifying external influences, when the dependence of any parameter on time is explicitly specified, when the dependence of a pair of parameters is specified on each other. These problems can be solved by models where the elements of the control system (for example, the fuel supply regulator) are present explicitly, in the form of modules with their static and dynamic characteristics, and implicitly in the form of cycles in the calculation law. In the first case, the static characteristic, for example, of the fuel supply regulator, is used in the same way as the characteristics of compressors and turbines, only here we have the dependence of fuel consumption on the pressure behind the compressor and the rotation frequency (or for example α_{ECL}). In dynamics, dynamic characteristics can be used to form fuel supply control algorithms.

For supported parameters (for example, for fuel consumption) there is the possibility of setting values in the form of a tabular function or algorithmic dependencies. The tabular function is placed in a file and the values of the supported parameter are read in the calculation process depending on the selected argument (for example, $G_T = f(n_K)$, $G_T = f(P_K)$, $G_T = f(\tau)$).

Initial values (first approximations) of varying parameters are also specified in the calculation law. The method is implemented in the LabVIEW system solving systems of nonlinear equations [3,4], allowing to solve differential equations (DEE) describing unstable modes of opeation of aviation GTE using Newton's and Euler's methods (Runge-Kutta).

For remote control solutions describing unspecified modes of operation GTE, the system uses the Euler method (or to achieve more high accuracy - Runge-Kutt method of the fourth order) [2,5]. By the system solves the reduction of inconsistencies to the errors specified in the parameters successively each of the equations in the calculation law, maintaining the values of the specified constants by varying the parameters. So, the system of equations is solved at the initial time. Further, during the calculation modes that have not been established, the connection between temporary subspaces is carried out through integrated parameters (pressure derivatives, temperature, costs, revolutions, etc.). Solving DEE by the Euler (Runge-Kutta) method (initial conditions are set directly in nodes, the derivatives are in finite differences), the system begins to solve the system of complex equations of a new moment of time, etc.

The joint use of methods gave good results: provided reducing calculation time, stability of the computing process and the ability to effectively manage the accuracy of calculations. Accuracy of the solution equations when calculated by the iterative method ultimately boil down to ensuring selection conditions through successive approximations.

The accuracy of the calculation will depend on a number of factors:

1) factors determined by objectivity, credibility and depth descriptions of the processes taking place in the engine;

2) factors related to the reliability of the reference and the original material;

3) factors determined by accepted methods or methods of calculation.

Conclusion. The possibility of accounting for the first two groups of factors is basically determined by the modern level of engine theory. To the third group of factors include the following: the value of the final step of approximations in the calculation, the accuracy of ensuring selection conditions, etc. When solving a complex the selection of the system of equations is carried out by the sequential method approximations in the form of "rings", the specified value is selected parameter, the fulfillment of the selection conditions is calculated, after which the selected parameter changes, etc. "Ringing" at the decision of each the equation is "covering" with respect to the following equation. The actual error of execution "covered ringing" is always less error when performing "covers".

If you specify the value of the error of the fulfillment of the selection conditions, which is equal to the value of the actual error caused by the approximation steps, then convergence of approximations may be difficult. Therefore, it is desirable that the specified error of meeting the selection conditions was greater than the actual one errors. The calculation error of the engine output data is composed from errors in fulfilling all selection conditions.

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