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ВЕСТНИК ЕВРАЗИЙСКОГО НАЦИОНАЛЬНОГО УНИВЕРСИТЕТА ИМЕНИ Л.Н.ГУМИЛЕВА. СЕРИЯ ТЕХНИЧЕСКИЕ НАУКИ И ТЕХНОЛОГИИ
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Simulation of the operating conditions in a gas turbine engine combustion chamber

Abstract: The article sets out the basic principles of computer simulation of a gas turbine engine combustion chamber, as well as their research methods. The influence of various factors was analyzed on the mode of operation of the GTE and their accounting capabilities in the simulation. The results of numerical simulation are given for various versions of burner devices with microflare devices. Model matching is available with known experimental data.

Keywords:: combustion chamber, turbulence, nitrogen oxides, simulation.

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Introduction. The combustion chamber is one of the main components of a gas turbine engine and its efficiency, reliability, toxicity and multifuel capability almost completely determine the same engine performance.

The combustion chamber of a gas turbine engine must satisfy a wide range of requirements, its relative importance depends on the type of engine. Common to all combustion chambers are the following requirements[1]:
- high completeness of fuel combustion;
- wide limits of sustainable combustion;
- lack of pressure pulsations and other manifestations of instability caused by the combustion process;
- low total pressure loss;
- output field of gas temperature (i.e., the degree of temperature non-uniformity over the chamber cross section) must satisfy the maximum durability condition of turbine rotor blades and nozzle blades;
- low emissions of smoke, unburned fuel and gaseous pollutants;
- minimum construction cost and ease of maintenance during operation;
- the configuration and dimensions of the chamber must be compatible with the motor circuit;
- great resource;
- the ability to work on various fuels.

Only significant changes in design of the gas turbine engine front-end devices with the organization of micro flame burning can satisfy the above requirements for a gas compressor. Microflame burning implicates breaking a single torch in the combustion chamber into many micro flames, and it can be organized with the expansion of combustion chamber front with the establishment of a large number of micro atomizers. However, these atomizers should be perfect and accurate in their identities. And we consider that it is possible to work out one micro-nozzle on a model and bring it to the perfection. In particular, consider the formation of NO in that kind of micro modular atomizers.

Methods. According to the Zeldovich mechanism during a fuel combustion, the reaction of nitric oxide formation has a thermal nature [2]:

$$N_2 + O_2 \leftrightarrow 2NO - 180,2kJ/mol \quad (1)$$

This reaction proceeds according to a chain mechanism involving atomic oxygen:

$$O + N_2 \leftrightarrow NO + N$$

$$N + O_2 \leftrightarrow NO + O$$

The reaction rate (1), according to [2], has the form:

$$\frac{dC_{NO}}{d\tau} = \frac{5 \cdot 10^{11}}{\sqrt{C_{O_2}}} exp[-\frac{86000}{RT}] \cdot [C_{O_2} C_{N_2} \frac{64}{3} exp(-\frac{86000}{RT}) - C_{NO}^2] \quad (2)$$

where C_{O_2}, C_{N_2} and C_{NO} are the instantaneous concentrations of the reaction components; τ is the reaction period, s; T is the reaction zone temperature; R is the gas constant. The equilibrium nitric oxide concentration time for various temperatures is presented in table 1

Table 1 – Equilibrium nitric oxide concentration time

t,°C	1230	1330	1430	1530	1630	1730
$\tau_{[NO]}$, s	8150	910	140	22,9	4,07	1

It follows from reaction (2) that the formation of NO depends on the concentration of O_2 and the temperature in reaction zone [3, 4].

But in the conditions of a gas turbine combustion chamber for determining emissions of nitrogen oxides, it is necessary to take into account other parameters [5], which are determined from the expressions

$$\overline{N} = \frac{Z_S^2}{\Psi_\tau}; Dm = \frac{\overline{N}}{K_1 K_a^{n-1}}; \tau = \frac{\rho_a V_g}{G_a} \quad (3)$$

then

$$EINO_X = \frac{10^3 \Psi}{Z_S^2 \rho_S} \mu_{NO_2} w_a^\tau \varphi(Dm) \tau \quad (4)$$

where $EINO_X$ is nitrogen oxide emission index.

Formula (3) and (4) characterize the effect of no equilibrium composition of the combustion products and reaction time on the final concentration of NOx. The above analytical calculations show that the formation of NO is affected not only by the values of such parameters as temperature T, concentration of reacting substances Z, residence time and pressure, but also their fluctuations. For example: non-uniformity of temperature field, structure of gas flow in the high-temperature zone and flow turbulence in the burner [5].

Based on the analysis, it is possible to determine the main criteria that should correspond to the gas turbine engine combustion chamber:
- uniform temperature field, without local high-temperature zones;
- efficient and intensive mixing of oxidizer and fuel;
- high heat intensity in order to reduce the reaction products residence time in the high temperature zone.

All existing methods and organizations of fuel combustion in gas turbine engines are determined by the provision of above points. For example, there are developments by Siemens, ABB by burning a pre-prepared mixture, which also includes DLE technology. It implies burning a "pre-mixed lean mixture" to intensify mixing and create a uniform temperature field. But such homogeneous chambers have a narrow range of stable operation and the risk of fuel supply pipes thermal destruction, since they are in the combustion zone. There is also a combustion chamber with staged burning, in which, due to the stepwise air supply, a uniform low temperature level in the combustion chamber is ensured. The negative side of the stepped combustion chambers is that they increase the overall dimensions of engine and the operating efficiency is determined with the unit loading.

Multi-burner combustion chambers have a good environmental performance. Alstom has burners under the brand EV and AEV, NOx emissions when used do not exceed 15 ppm [6].

18 burners were installed in ABBGT10 gas turbine engines (23 MW), and 72 burners in ABB GT13E (> 150 MW), in the form of two circular rows.

General Electric LM6000 gas turbine burners are also known, the combustion chambers of which are made in the form of two rings. In the outer two rings there are 60 atomizers, in the inner ring are 15. This arrangement of rings makes it easier to work under partial load. 75 nozzles are connected by 30 stems with pre-mixing devices. LM6000-PD turbines have NOx emissions close to 25 ppm, at a power of 50 MW.

Analysis of multi-burner combustion chambers shows that they have a good environmental and energy performance. But micro flame devices will have even more improved environmental characteristics. Micro flame burning of fuel is organized by creating a whole system of numerous small flames in the combustion chamber [6].

Micro flame technology will be as close as possible to the requirements for the gas turbine combustion chambers presented above. In them, dividing the torch into many mini torches contributes to the formation of a uniform temperature field, as well as reducing the length of the combustion chamber by 3 times. In micro flame devices, the yield of nitrogen oxides is reduced due to a decrease in local zones of elevated temperature and an increase in the thermal stress of the combustion chamber.

It was shown above that the mixing intensity also affects the formation of NOx. Therefore, if we organize micro flame technology with vortex intensification and burning of a pre-prepared mixture, this will allow us to minimize harmful gas emissions, while ensuring complete combustion of fuel and high reliability of the combustion chamber in a wide load range. Devices that operate on this principle include micro modular air atomizers (MAA).

In MAA the following principles of microflame burning are laid:
- fuel supply is carried out in the cylinder of micro modules, which are in large numbers parallel to the axis of gas turbine combustion chamber along the front;
- each micro module mixes fuel with air;
- and at the output of each micro module there are stabilizers that hold micro flames;
- the step between the axes of micro modules is chosen so that micro flames do not merge..

Micro modules can be of various designs. Strict specifications are imposed on their manufacture for the accuracy and purity of surface treatment and identity (sameness), because more than a hundred MAAs could be installed in one annular combustion chamber.

Discussion. In micro modules, the kinetic energy of the air flow is spent on crushing the gas stream and pre-mixing. At the inlet, the air flow swirls to ensure the preliminary preparation quality of the fuel assembly. The choice of the installation angle of the blades of input swirler affects the combustion efficiency of this fuel. To successfully stabilize the micro flame, registers of heat-resistant material installs at the micro module cylinder output. The combustion rate is ensured by the correct spin choice of the fuel-air mixture. Thus, in the annular gas turbine engine combustion chamber, micro module atomizer provides an increase in the heat stress of the combustion chamber volume, reduces in toxicity of the combustion products and decreases in the combustion chamber length.

The development and creation of such devices requires a number of studies to determine the optimal geometric parameters of the MAA, such as the step between registers, the length of preliminary mixing chamber, the installation angle of inlet air swirl, the angle of blades of the output swirl. They can be determined by conducting an experimental research method, by creating experimental combustion chambers. But this method has a number of significant drawbacks: for the organization and conduct requires large material and time resources; the impossibility of obtaining complete information at all points of the investigated object; for geometric optimization many experiments are necessary.

Therefore, such processes are currently being investigated using CAE and CAD systems. The advantage of research using computer simulation is that they adequately and completely describe real processes and replace the experimental research method or precede it, thereby reducing the material and time costs of creating a real model and give a complete description of the process under investigation. One of the best mathematical modeling software packages is ANSYS. Computational packages ANSYS Fluent and CFX are widely used to simulate combustion processes and hydrodynamics. General modeling capabilities of flow processes with chemical transformations are presented in Figure 1.

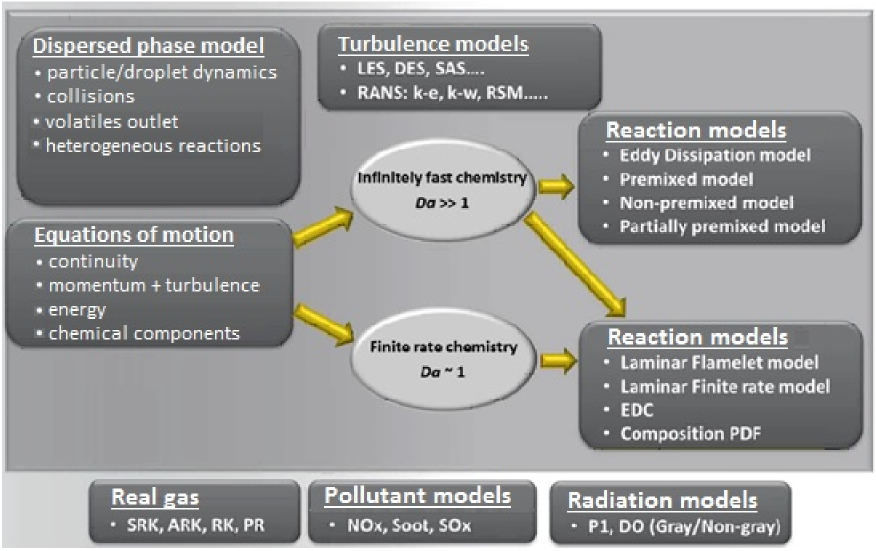

FIGURE 1 – Simulation Features in ANSYS Fluent and CFX

Schematically, the process of solving problems in these packages can be represented as follows:
- building geometry of an object;
- breakdown of the area into subdomains, meshing;
- setting boundary conditions and choosing a turbulence model.

The ANSYS software package has a wide variety of models for calculating turbulent flows. They differ from each other in the solution complexity and description accuracy of the flow.

The basic idea of the models is reduced to the assumption of existence of an average flow velocity and an average deviation from it: $u = \overline{u} - u'$. After simplifying the Navier-Stokes equations, in addition to unknown average velocities, the products of the mean deviations $u_i' \; u_j'$ appear in them. Different models model them differently. The models listed below are used in various engineering calculations depending on the required accuracy.

The variety of turbulence models will allow us to fairly accurately investigate hydrodynamic processes in which complex swirling flows take place.

In recent years, many attempts have been made to create a model for calculating the combustion process in the gas turbine unit combustion chamber, which allows predicting the characteristics of emissions. To date, the literature describes many systems for calculating the level of NOx emissions from the combustion chamber, which vary significantly in complexity, applicability and rigor. Currently, programs for modeling processes in the gas turbine engine have been created, but they are also far from perfect. So we used the ANSYS Fluent program for research. In [11,12,13] presents the results of numerical simulation of the above options burner devices with microflame devices. Three types of burners were considered in Fig. 2: a burner with corner stabilizers (a), in which fuel is fed to the symmetry axis of corner, a burner with blade profiles (b) in which fuel is fed into the space between the back of the profile and cover, and the third burner (c) operating according to the principle of counter-swirling jets. Figure 3 shows a view of the 3D model of MAA with an output register angle of $45°$.

The simulation area consists of an input register consisting of a group of flat blades with an angle equal to $45°$, nozzles for radial supply of gaseous fuel, an output register consisting of flat blades with different angles β.

The temperature and velocity circuits at various angles of the output register β_2 are shown in Fig. 4.

Figure 4 shows us the gradient of temperature. We can see that the torch is stretched when it is using angle stabilizers for $30°$. The high-temperature zone with a temperature of $2200K$ is shifted

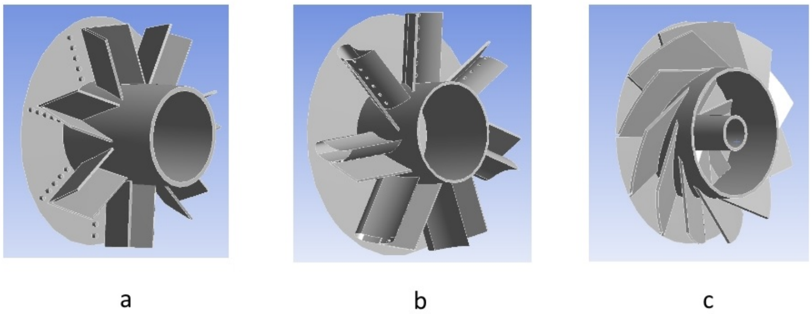

Figure 2 – Burners with stabilizers

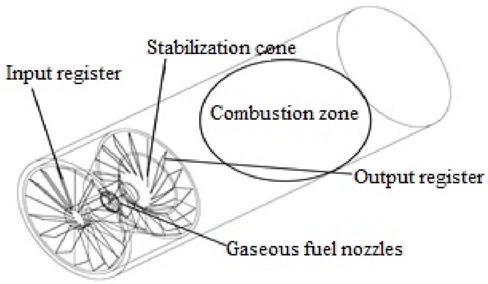

Figure 3 – Burner model

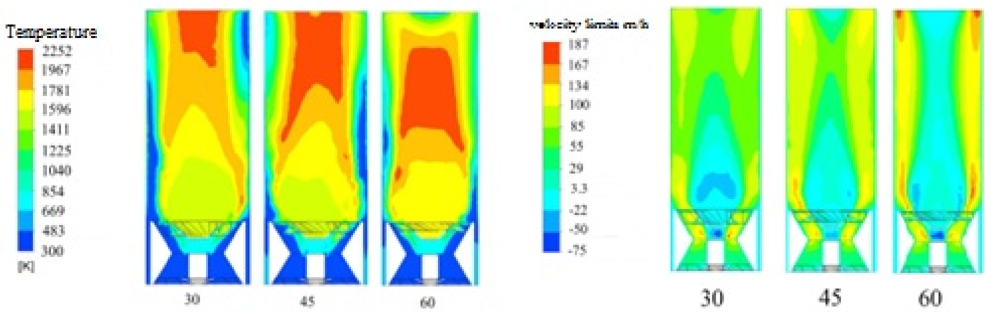

Figure 4 – Speed and temperature gradient in the combustion chamber

to the left side of the burners with profiled blades of $45°$. A relatively uniform temperature level is observed during counter-swirl stabilization with a blade angle of $60°$. The velocity gradient shows us that the uniform aerodynamic structure of the torch has a velocity of ~ 33 m/s. This is achieved by using torches with counter-swirl stabilizers. All these data obtained on the basis of computer simulation. They are relatively exactly consistent with previously obtained experimental values of temperature and velocity in the CCh [11].

Conclusion. The ANSYS Fluent program allows you to conduct a preliminary analysis of proceeding processes in the MAA.

Thus, when creating fuel-burning devices, such as micromodular air atomizers, the use of computer simulation with ANSYS software packages will help to fully investigate the processes proceeding in the combustion chambers, and also optimize the geometric parameters of the burner devices. At the same time, it would be wrong to talk about the complete replacement of experimental studies by numerical calculations; the question is design approaches that should complement each other.

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ГТҚ жану камерасының жұмыстық режимдерін модельдеу

Аннотация. Мақалада ГТҚ жану камерасын компьютерлік моделдеудің негізгі принциптері, сондай-ақ олардың зерттеу әдістері қарастырылады. Әртүрлі факторлардың ЖК жұмыс режиміне әсері және моделдеу кезінде олардың есепке алу мүмкіндігіне талдау жүргізіледі. Микрофакельді құрылғылары бар жанарғылардың әртүрлі нұсқаларын сандық үлгілеу нәтижелері келтірілген. Модельдердің белгілі эксперименталды деректермен келісуі көрсетілген.

Түйін сөздер. жану камерасы, турбуленттілік, азот оксиді, модельдеу.

С.Б.Садыкова [1] , А.М. Достияров [2] , А.М. Достиярова [3] , Н.Р.Картджанов [4]

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Моделирование рабочих условий камеры сгорания ГТД

Аннотация. В статье рассматриваются основные принципы компьютерного моделирования камеры сгорания ГТД, а также их методы исследования. Анализируется влияние различных факторов на режим работы КС и их возможности учета при моделировании. Приведены результаты численного моделирования различных вариантов горелочных устройств, имеющих микрофакельные устройства. Показано согласование моделей с известными экспериментальными данными.

Ключевые слова камера сгорания, турбулентность, оксиды азота, моделирование.

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