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AERODYNAMIC FLOWS INSIDE GAS TURBINE COMBUSTION CHAMBER MODULE

The article contains the results of experiments on the research of aerodynamic parameters in the cylindrical module of the combustion chamber in a gas turbine. The intensity of turbulence and flow velocity are considered in the article as the main factors affecting the efficiency of the formation of the fuel-air mixture and, as a consequence, the efficiency of its subsequent combustion. The air flow is studied under isothermal conditions inside two cylindrical channels of different diameters with swirl blades at the inlet. Turbulence intensity and flow velocity are obtained for various points inside the channel. The graphical format for the result presenting was chosen as the most convenient for understanding. The factors influencing the value of intensity and speed are given on the basis of the analysis of experimental data. The study of the structure of the air flow in the channels gives us the opportunity to determine the fuel injection zones. The article may be of interest to researchers and specialists in the field of power and aerodynamics.

Keywords: fuel-air mixture, turbulence intensity, gas turbine engine, swirler blades, combustion chamber.

Introduction

The environmental friendliness and efficiency of modern gas turbine engines and units are determined mainly by the operation of their combustion chambers. The main toxic compounds during fuel combustion are nitrogen oxides NOx. Their generation proceeds according to the Zel'dovich mechanism [1] under the conditions of a combustion chamber.

Analysis of works [2, 3] shows that the values of various parameters affect the formation of NOx: such as temperature – T, pressure – P, time – t of the stay of reaction products in the combustion zone, concentration of reactants – Z and their fluctuation. Many methods of suppressing nitrogen oxides are aimed at reducing the temperature level of the flame. Some of them are not effective enough, since the products of incomplete combustion of CO, CnHm, etc. increase (for example, increasing α in the combustion zone). It affects not only the environmental aspects of the combustion chamber, but also the economic. Other methods have reached the limit of their perfection and cannot meet modern requirements for the emission of harmful emissions. A combination of known methods is microflaring and «lean» combustion. The combination will give good efficient and environmental parameters in new devices. The formation of a «lean» fuel-air mixture depends on the flow structure [7] in such devices.

Physical and chemical processes take place in the combustion chambers of gas turbine engines and have the following difficulties: the need to take into account the specifics of turbulent flows, the multi-phase and multi-component nature of the medium, heat and mass transfer, radiation transfer, etc. All this does not allow building rigorous models of the flow structure in fuel-burning devices and requires experimental studies under isothermal flow conditions.

Turbulence intensity and flow velocity are among the main parameters characterizing the flow. The flow has a speed $u=\bar{u}+u'$ at any fixed point of the turbulent flow. The speed consists of two components: $\bar{u}$ – average, constant in time, and u' – deviation from the average speed $\bar{u}$, which is called pulsation. The ratio of the RMS pulsation velocity to the average flow velocity is called the turbulence intensity:

$$\varepsilon = \frac{\sqrt{u'^2}}{\bar{u}} \times 100\% \qquad (1)$$

Turbulence intensity is usually expressed in %.

Materials and methods

This article describes the results of the experimental study of the parameters of an isothermal air flow inside two cylindrical channels with different diameters and swirl blades at the inlet. Considered flow parameters: turbulence intensity and velocity. The general design of the investigated cylindrical channels (thickness d = 2 mm) is shown in Figure 1, which consists of a cylindrical body with an inner diameter D=46 mm and a length L=150 mm the first, and the second – D=71 mm and a length L=250 mm. Cylindrical channels at the inlet have a swirler with eight blades with the same rotation angles β=30°. The blades are surrounded by an annular rim with a width (height) h=3 mm.

Such a channel is used as an air nozzle for the preparation of fuel-air mixtures in the front devices of the combustion chamber, so the flow structure in them is of practical value in the design of similar devices.

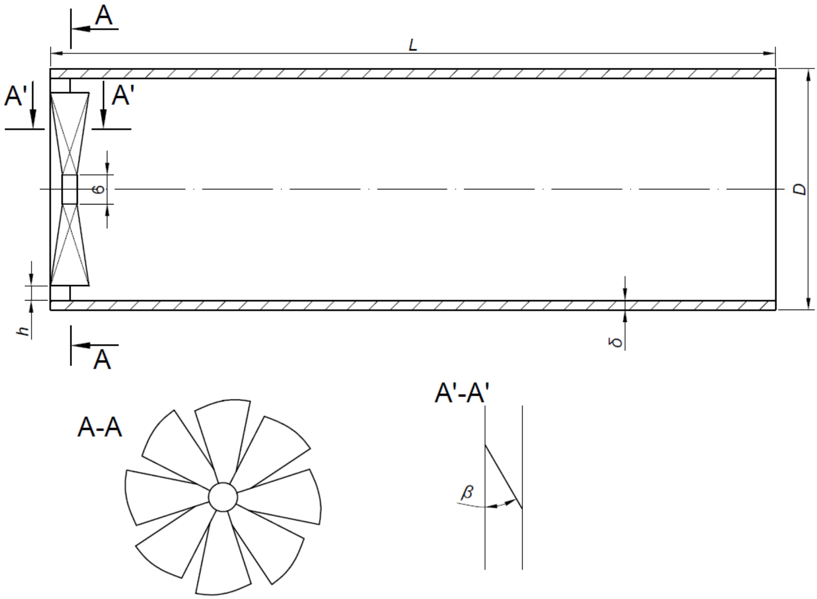

Figure 1 – Channel with inlet swirler

The experiment was carried out on a stand. The scheme of the stand is shown in Figure 2. The stand consists of a fan for air supply; a wind tunnel, at the outlet of which the test samples with a calibration tube (Witoszinski nozzle) and a hot-wire anemometer of constant temperature are installed. The sensitive element of the hot-wire anemometer is a tungsten filament sensor.

The hot-wire anemometer was calibrated [6] at the beginning of the experiment at different flow rates at the exit from the Witoszinski nozzle in front of the samples under study. The Pitot tube was placed in the center of the measurement nozzle. Dependence E=f(u) was determined by the value of the Pitot tube at different fan performance.

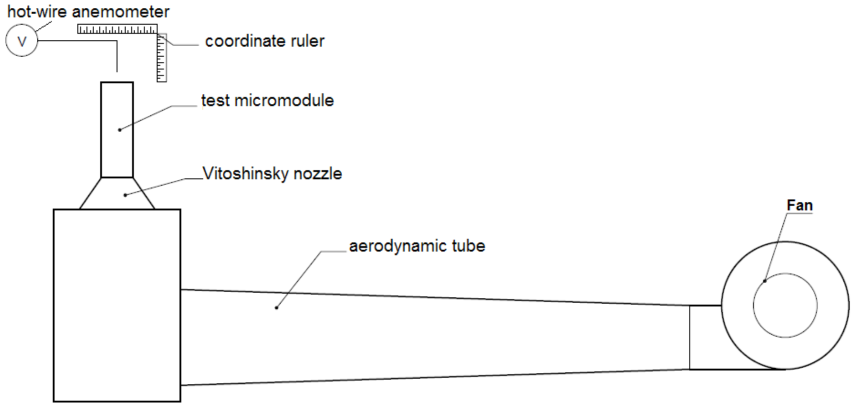

Figure 2 – Scheme of the experimental stand

Hot-wire anemometer readings at the points under study make it possible to calculate the intensity of turbulence from the following equation [4, 5]

$$\varepsilon = \frac{4\bar{E}(\bar{e} - e_0)}{\bar{E}^2 - \bar{E}_0^2} \times 100\% \tag{2}$$

where Ēo – bridge voltage in the absence of flow in the pipe, V;

Ē – constant component of the bridge voltage with flow in the pipe, V;

ē – ripple component of the bridge voltage with flow in the pipe, V;

ēo – system error, V.

The average flow velocity ū of selected points inside the channel was determined based on the function E=f(u) by the following equation

$$\bar{u} = \left(\frac{\bar{E}^2 - A}{B}\right)^2 \tag{3}$$

where A, B – coefficients of calibration dependence, which are determined from the graph E=f(u) [4,5].

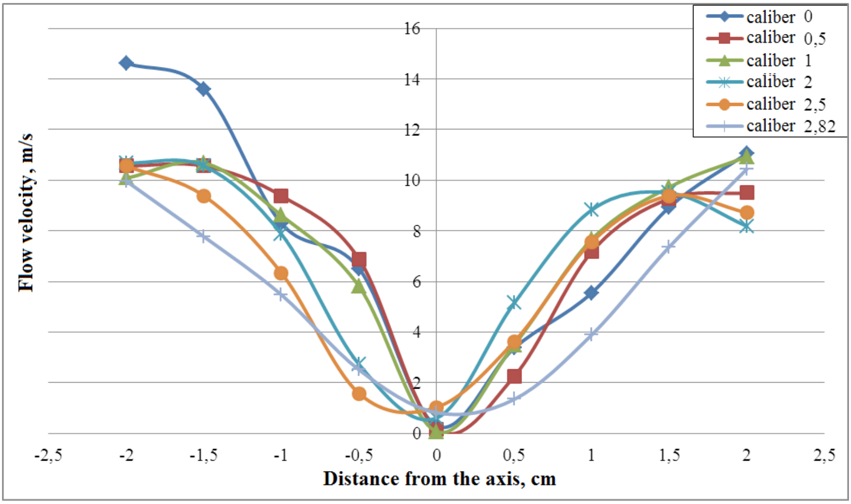

Figure 3 – Flow velocity inside the channel Dins=46 mm

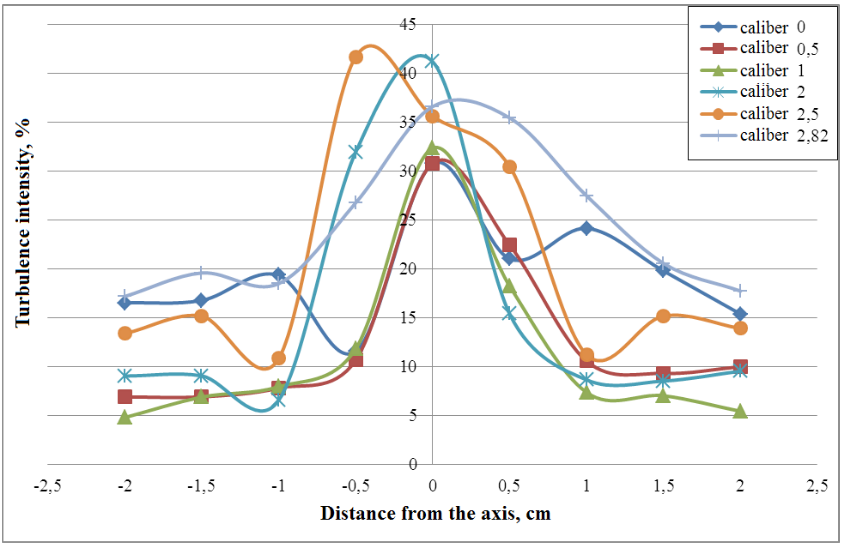

Figure 4 – Turbulence intensity inside the channel Dins=46 mm

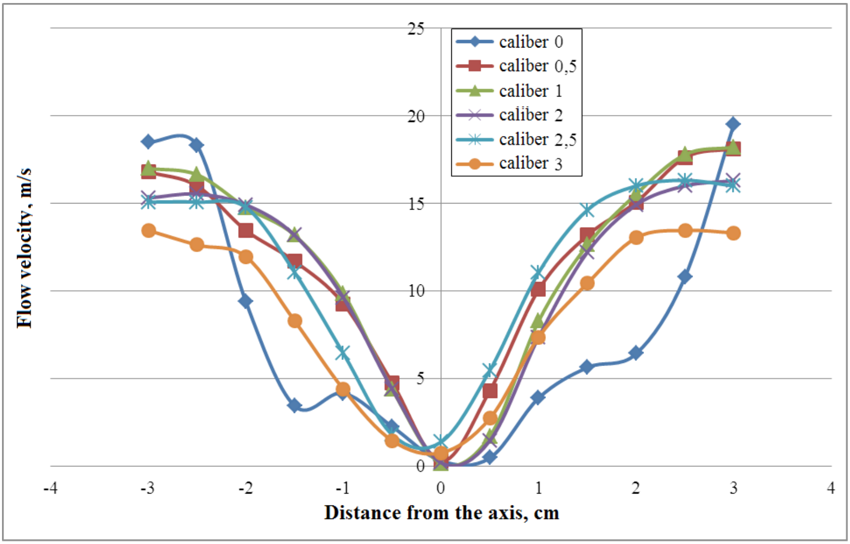

Figure 5 – Flow rate inside the channel Dins =71 mm

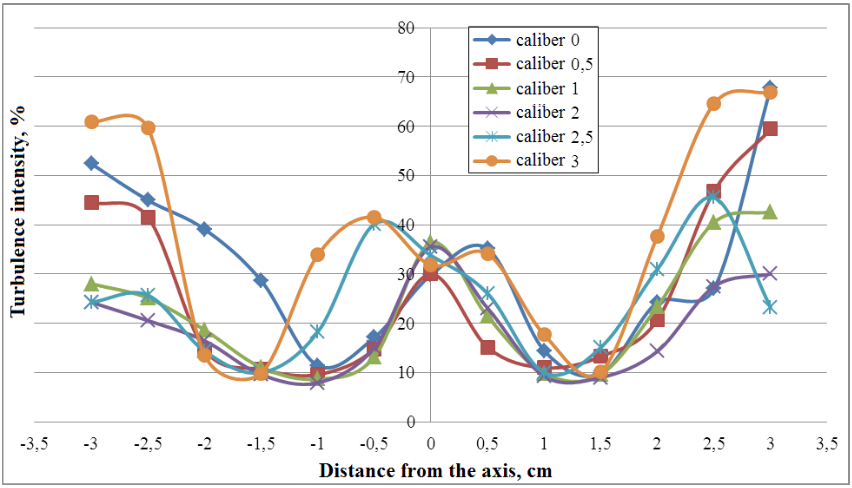

Figure 6 – Turbulence intensity inside the channel Dins =71 mm

Results and Discussion

Processing of the experimental data shows that the flow velocity has a similar cross-sectional gradient in both channels, i.e. the air flow velocity inside the channel increases from the center to the periphery (toward the wall). This form of change in the velocity graph is due to the fact that the inlet swirl swirls the air flow, increasing the tangential component of the velocity, which is concentrated on the periphery of the channel due to the centrifugal forces of the flow, thereby creating a zone of low pressure and low velocity in the center of the cylindrical channel.

We see in Figure 3 that the flow velocity is 0.3 m/s on average inside the channel with D=46 mm in the center at a distance of up to the caliber 2, and the velocity reaches 13 m/s at the periphery. The speed is 1 m/s at calibers 2.5 and 2.82 in the center, and near the walls – 9 m/s, i.e. the flow velocity towards the channel outlet tends to balance over the cross section. A similar picture is observed at D=71 mm (Fig. 5.), but due to the fact that the diameter of the channel is larger, the swirler blades create less aerodynamic resistance, so the flow velocity is higher than at D=46 mm. Figure 5 shows that the velocity in the center increases from 0.3 to 1.3 m/s along the calibers, and closer to the wall it decreases from 18 to 13 m/s.

The study of the turbulence intensity (ε) shows that its maximum value takes place in the center of the channel at D=46 mm and close to the wall at D=71 mm. The achievement of such values at these points is due to various reasons. A large value in the center of the channel (near the axis) is achieved by the fact that a zone with a reduced average velocity is formed in the center of the channel due to the peripheral movement of the swirling flow. As we see from equation (1), the intensity is characterized by a pulsation of the average velocity, and therefore the oncoming flows from the center to the wall and vice versa create high pulsations in the center. In addition, the dependence of the intensity of turbulence is inversely proportional to the average speed. As a result, the layer that has a high average velocity at the periphery has a lower turbulence intensity compared to the center.

However, a high value of ε is noticed at D=71 mm, on the periphery closer to the wall. The boundary layer appears when a flow flows on the surface of a solid wall, in which small eddies and flow velocity pulsations are formed due to friction, which leads to an increase in the intensity of turbulence. This phenomenon is called «wall» turbulence.

The chart of ε in Figure 4 shows that the intensity of turbulence increases from the inlet to the outlet of the channel, along the axis from 30 to 36 %, and along the periphery from 5 to 17 %. The large value of ε 15–16 % in caliber 0 near the wall is due to the fact that the rim circled around the blades creates a velocity pulsation.

The measurement results of ε in the channel D=71 mm (Fig. 6) show that the intensity of turbulence from the center to the walls of the channel decreases to a distance from the axis r=10 mm, then increases from r=15 mm to the wall. Here, also the influence of the annular rim on ε is observed in the zero caliber. The value of ε varies in all calibers: from 29 to 36 % on the axis, from 9 to 20 % at a distance r=10–20 mm, from 23 to 60 % at the wall. More developed «wall» turbulence is observed at D=71 mm compared to D=46 mm, which is associated with the following factors: larger diameter, larger surface area of contact with the flow; channel length, long path acting on the flow; high speed, which creates a significant flow disturbance along the wall.

Conclusion

The following conclusions were drawn from the work done:

1) As the length and diameter of the channel affects the intensity of the flow turbulence inside the channel, so does the inlet swirler. But the selection of the optimal channel dimensions should be carried out taking into account the flow velocity, since the «wall» turbulence also depends on the flow velocity.

2) Channels with an inlet swirler are used in the front devices of the combustion chamber to create a fuel-air mixture. Therefore, it is necessary to focus on experimental data on the study of the flow structure to ensure effective mixing when designing such devices, i.e. take into account the velocity field and the intensity of turbulence inside the channel.

3) The study of the structure of the air flow in the channels gives us the opportunity to determine the fuel injection zones.

4) The results of this work can be a scientific basis for research in the design or creation of efficient micromodular injectors.

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ГАЗ ТУРБИНАЛАРЫНЫҢ ЖАНУ КАМЕРАСЫ МОДУЛІНІҢ ІШІНДЕГІ АЭРОДИНАМИКАЛЫҚ АҒЫНДАР

Мақалада газ турбинасының жану камерасының цилиндрлік модуліндегі аэродинамикалық параметрлерді зерттеу эксперименттерінің нәтижелері келтірілген. Турбуленттіліктің қарқындылығы мен ағынның жылдамдығы мақалада отын-ауа қоспасының түзілу тиімділігіне және кейіннен жанудың тиімділігіне әсер ететін негізгі факторлар ретінде қарастырылады. Аэропоток әр түрлі диаметрдегі, кіре берісте бұралмалы қалақшадар бар екі цилиндрлік каналдың ішіндегі изотермиялық жағдайда зерттеледі. Турбуленттіліктің қарқындылығы мен ағынның жылдамдығы арна ішіндегі әртүрлі нүктелер үшін алынады. Нәтижелерді ұсынудың графикалық форматы түсінуге ыңғайлы болып таңдалады. Қарқындылық пен жылдамдықтың мәніне әсер ететін факторлар эксперименттік деректерді талдау негізінде келтіріледі. Каналдардағы ауа ағынының құрылымын зерттеу

бізге жанармай құю аймағын анықтауға мүмкіндік береді. Мақала энергетика және аэродинамика саласындағы зерттеушілер мен мамандар үшін қызықты болуы мүмкін.

Кілтті сөздер: отын-ауа қоспасы, турбуленттік қарқындылығы, газ турбиналы қозғалтқыш, құйындатқыш қалақшалар, жану камерасы.

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АЭРОДИНАМИЧЕСКИЕ ПОТОКИ ВНУТРИ МОДУЛЯ КАМЕРЫ СГОРАНИЯ ГАЗОВЫХ ТУРБИН

Статья содержит результаты экспериментов по исследованию аэродинамических параметров в цилиндрическом модуле камеры сгорания газовой турбины. Интенсивность турбулентности и скорость потока рассматриваются в статье как основные факторы, влияющие на эффективность образования топливно-воздушной смеси и как следствие на эффективность последующего горения. Аэропоток изучается в изотермических условиях внутри двух цилиндрических каналов различного диаметра с завихрительными лопатками на входе. Интенсивность турбулентности и скорость потока получены для различных точек внутри канала. Графический формат предоставления результатов выбран как наиболее удобный для понимания. Факторы, влияющие на значение интенсивности и скорости, приводятся на основе анализа экспериментальных данных. Исследование структуры течения воздуха в каналах дает нам возможность определить зоны впрыска топлива. Статья может представлять интерес для исследователей и специалистов в области энергетики и аэродинамики.

Ключевые слова: топливно-воздушная смесь, интенсивность турбулентности, газотурбинный двигатель, завихрительные лопатки, камера сгорания.

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