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EXPERIMENTAL INVESTIGATION OF WORKING PROCESS OF THE FRONT DEVICES WITH OPPOZIT FLOW TWISTINY, WHICH ARE USED IN THE COMBUSTION CHAMBERS WITH BEFINED ECOLOGICAL PERFORMANCES

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Abstract

Now for creation high-temperature and not toxin combustion chambers the large attention is given to new types of front devices ensuring highly effective burning with a minimum discharge of harmful substances.

In the given article the experimental researches of working process in combustion chambers with rotational flow for gas turbine engines are given. Are represented:

- Research of distribution of main parameters of flow in an aerodynamic trace behind the single rotational swirler installed in a free space.
- The analysis of influence of main designs data of the rotational swirler on it flameout of performance for pore mixture.
- The analysis of data's for improving the issuing performances of combustion chambers of air breathing engines.

Labels and reductions

ΔP_{κ} - difference of pressure on the burner, kPa;

T - temperature, K;

G – flow rate, kg\s;

W, U, Ur - magnitude of an environing, axial and radial component of velocity vector, m\s;

α_0 - the air-fuel coefficient defined on airflow and fuel through the burner;

α_{max} – the air-fuel coefficient on blowout of modes for poor mixture in the single burner;

r - radius, mm;

h - intervaned distance span, mm;

m - amount of blades, mm;

l - linear longitudinal size, mm;

l_i - length of cylindrical pipe, mm;

$\underline{l}$, $\underline{d}$ - dimensionless significance's of appropriate parameters referred to a radius air swirler r_{as};

$\underline{X}$, $\underline{r}$ - dimensionless significance's of coordinates of a jet behind the rotational burner referred to a radius air swirler r_{as};

0 - index designating a cut on outlet from of the burner;

κ - index designating a target cut of a branch pipe;

fs, as - indexes relating accordingly air-fuel and air swirler.

Introduction

The development gas turbine engine is accompanied by growth of their main parameters: pressure of an air behind the compressor and temperature of gas in front of the turbine. In this case more and more strong requests are imposed on a diminution harmful substances, polluting atmosphere, (CO , C_nH_m, NO_x, smoke); increase of efficiency of working process for large heating of gas; magnification of reliability of combustion chambers of the expense of improving their systems of cooling, and by a diminution of heat flows from a flame. The indicated circumstances cause of perfecting working process of combustion chambers and development of new methods of its organization.

For increase of intensity and combustion efficiency of fuel, decreasing coking and toxic of exhaust gases, and also improving of other working performances of combustion chambers the homogenization fuel of an air mixture is expedient. It demands of development of the new

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schemes of front devices ensuring a premixing outside of a zone of burning. The most perspective frontal devices for the gas turbine engine are the devices with swirlers. In such devices the process of mixture preparation and stabilization takes place.

The common principle for the wide class of swirler burners different types is the using of the energy of coaxial rotating jets for atomization of fuel, mixing it with air and flame stabilization. The burner of the given class is the rotational vortexical burning represented in a fig. 1, for want of which research the main features of working process which are inherent to the whole class of rotational burners with an opposite rotating of coaxial streams.

1. Statement of a problem of experimental researches

One their main requirements presented to front al devices of air breathing engines combustion chambers, is the maintenance of stabilization of a flame in a broad band of a wide range regimes. However as it is known, the burning of a homogeneous mixture is characterized by a narrower range of stable burning. For a heterogeneous mixture, that calls difficulties for want of maintenance demanded blowout of performances of the combustion chamber, especially on poor mixtures.

In the given article the results of an experimental research of a flow structure behind the burner are represented, as soon as renders defining influence to process of flame stabilization.

It is expedient to conduct a research of the burner parameter influence for process of flame stabilization using burners installed in a free space. In this case the parameters in swirrouding space are known. A research of working process physical bases of the rotational burning and revealing the influence of the most important design factors on it in this case is possible.

2. Description of a research objects, experimental installation

Experimental researches were conducted on burners, which scheme is represented in a fig. 1.

The burning consists of two sequentially located coaxial radial swirlers: fuel-air (FS) 1 and air (AS) 4. The blades in swirlers are installed in such a manner that the tangential entrance of an air in the twisting camera is ensured. Each swirler is characterized by a span of the channel $l_{fs(as)}$, intervaned by a distance $h_{fs(as)}$ and number of blades $m_{fs(as)}$. Usually $m_{as} = m_{fs} = m$. The rotating of streams in swirlers is made in the opposite direction.

The preparation of a fuel-air mixture is carried out before the burning. The fuel supplies realize by a set injector with a small pressure. That allows essentially reducing weight of fuel admission of equipment. Fuel-air swirler 1 have surrounded by a snail 6 in which the air and fuel is mixed.

The twisting cameras of a of swirlers have a common shear (cut 0-0), behind which the exit pipe of the burner 3 is installed. On a shear of a branch pipe can be installed cylindrical ring (length l_H).

During the flow of fuel and air through a snail and fuel-air swirler the atomization of fuel drops of and mixing have place. Through the air swirler only air passes, which rotates in opposite direction that the fuel-air mixture. In a cross section 0-0 both twisted jets osculate, the formation of the common twisting fuel-air jet takes place and as a result additional atomization and mixing takes place. The quality of fuel-air mixture improved. Further jet is distributed in an exit pipe of the burner and where burning takes place in the flame tube.

Five types of burners investigated and designated N 0, 1, 2, 3, 4. The burners 1, 2, 3 differed only by longitudinal sizes of fuel swirler l_{fs} and sizes of outlet tube. The burners 0 and 4 differ from burners 1, 2, 3 and from each other by main sizes of swirlers and by sizes of exit pipe. So the other burner 0 has a cone with bell form exit pipe, and remaining burners - direct cone with an angle of disclosure 50^0 (burner 1, 2, 3) and 45^0 (burner 4). In a number of experiments on an exit pipe of burner was installed additional ring cylindrical pipe. The main parameters of burner are shown in the table.

The table

Main parameters of burners

' of the burners	0	1	2	3	4
Parameters					
l_{fs}, mm	6	5,8	11,7	15,7	20,6
h_{fs}, mm	1	1,8	1,8	1,8	1,7
m_{fs}	6	10	10	10	10
r_{fs}, mm	8,5	12	12	12	14,5
l_{as}, mm	4	6,1	6,1	6,1	6,1
$_{as}$, mm	1	2,4	2,4	2,4	4
m_{as}	6	10	10	10	10
r_{as}, mm	16,5	43	43	43	43
β^0	$\beta=f(X)$	50	50	50	45
G_{fs}/G_{as}	1,125	0,57	1,13	1,38	1.08

The burners were investigated on experimental installation which scheme is represented in a fig. 2.

During an air tube with the adjusting valve 1 and measuring diaphragm 2 air income into receiver 3. On the outlet the researched rotational burning 4 are installed. The fuel from an fuel tank 5 with the help displacement system moves to the rotational burner 4 from injectors 10. The pressurization of a tank 5 is carried out by an air from a system of high pressure (or from cylinders 6) through regulating valves 7, 9 and reduction 8. A constant tanks pressure 5 supports by jet 11. The ignition of a fuel-air mixture is made by a burning system.

The starting fuel (petrol) and air moves to the electrical igniter 16, through cranes 14, and electromagnetic valves 15 which gives a heavily plume of a flame. In a trace behind the burner measuring instruments 12 on coordinate system 13, have three degree of freedom are installed: longitudinal and transversal transition, and also rotation of instruments 12.

During experiments the air and fuel consummations were measured. In each experiment the differences of pressure on the researched burner (ΔP_K) was measured. Behind burner the fields of axial and environing component velocities, the distribution of velocity, stagnation pressure, intensity of a turbulence and field of temperatures were determined.

Measurement of velocities and pressure were conducted with the help of special instruments and also by thermoanemometrical system. The measurement of temperature for in flame was carried out by cooled thermocouple. The differences of pressure were registered piezometry.

The difference of pressure on the burner (ΔP_K = 4... 10 kPa) was selected from a condition of choosing the same velocities as was in the burning located in the real combustion chamber (V ≈ 30... 50 m\s). At the same time, the auto modeling of flow in the trace after the burner was preserved (the Re ≈ (2... 5) 10^5).

3. Parameters of flow behind the burner

To determine the common regularities of flow, the structure in the cross-sections of a jet with out flame was determined. The typical distribution of pressure is represented in a fig. 4a (burner N 1 without ring instrument) and in a fig. 4b (burner N 2 with ring instrument).

In a trace behind the burner there is a developed zone of reversible flow which sizes depend on a diameter of a target cone $\underline{d}_K$. So the maximum diameter of a zone of reversible flow with out the ring instrument makes ~ 0,8$\underline{d}_K$ and is on a distance ~ 0,35$\underline{d}_K$ from its shear. Length of a zone of a reversible flow corresponds ~ 0,9...1,0$\underline{d}_K$. The boundary of a jet immediately behind the burner extends up to a size ~ 0,4$\underline{d}_K$, where the transversal size ~ 1,5$\underline{d}_K$ and further is saved practically constant. The installation of ring instrument to call in noticeable reorganization of flow.

In a fig. 4, as an example, the typical distribution of relative velocity-component axial $\underline{U}$, environing $\underline{W}$ and radial $\underline{U}_r$ are shown. The component velocities are referred to middle of a velocity V in a cross section 0-0 in a cross section $\underline{X}$ = 1,65 from a shear of a target cone of the burner N 2 for want of ΔP_K = 8,6 kPa and V = 24 m/s.

The structure of profiles is characterized of hardly twisted jets: near an axes the developed zone of reversible flow is observed, the direct flow places on a rim of a cross section, the maxim of peripheral velocities places more often inside a zone of reversible flow. It is necessary to mark a feature of current formed in researched burners by two opposite twisted streams: in all cross section behind a target cone of the burner the stream has a unilateral direction of rotation. The direction of rotation is determined by that swirler, from which the stream with a large moment of momentum follows.

The influence of ring instrument is exhibited mainly in decreasing of a radial velocity at expiration of a jet from a target cone of the burner. In this case the transversal extension of a jet decreases and the reversal zone of heavily return current and, therefore is reduced, the suction in it of an air from enclosing space is reduced.

Thus, being based to results of conducted experiments, it is possible to assume, that during the movement along the burner, forming an exit pipe the jets from separate swirlers have a mixing and as a result the ring jet with the one side rotating is created. This implying jet heavily ejected an air as from axis area, and from enclosing space. As a result of this and owing of stream rotating the pressure in axis area behind the burner decreases. Under an influence of the arisen pressure difference the compression of a jet. Also there are a joining of flow in a circulating zone and removal of a part of its mass in a recirculating zone.

Except a research of a structure for of cold pressurization's, the measurements of fields of temperatures behind burners with flame are conducted

In a fig. 5 the outcomes of a research of distribution of temperatures in two cross-sections on length (for $\underline{X} = 0$ and $\underline{X} = 1{,}6$) on operational modes of the burner № 2 before the flame blowout are represented. The fields of temperatures $\underline{T}$ ($\underline{T} = T/300$) in a trace behind the burner for want of factor of surplus of an air $\alpha_0 \approx 0{,}6$; $\underline{l}_H = 0$ (fig. 6a) and $\alpha_0 \approx 1{,}2$; $\underline{l}_H = 0{,}44$ (fig.6b).

Temperature of gas practically is constant on whole volume of a circulating zone. The rectangular distribution of temperature is a result of high intensity of processes of turbulent exchange in a circulating zone. The latter is confirmed by outcomes of a measurement of intensity of processes of turbulent exchange.

4. Research blowout performances of rotational burners different construction

The experimental researches of blowout performances for swirler burners distinguished in design data are conducted.

On experimental installation (fig. 2) swirler burners was installed in tank, where the compressed air was overheated. From the tank through the burner the air followed in atmosphere. As fuel the petrol was used. The researches were conducted at the temperature of air $T \approx 300$ K. Significance α_{max} were determined on consumption of an air and fuel through the burner, the difference of pressure between tank and atmosphere was changed from 2 up to 8 kPa. The investigated burners differed from each other by some design data, and also by absolute sizes, which determine significance of bulkhead squares of swirlers (see tab.).

As a main parameters which determine remaining geometric performances of the burner were selected.

Parameter 0f rotation fuel-air swirler S_{fs}:

$S_{fs} = \pi\, r_{fs}^2\, (1 - (\mu_{fs}\, h_{fs}/2)\, /\, (\mu_{fs}\, F_{fs})$,

Where $h_{fs} = h_{fs}/r_{fs}$ - relative breadth of the intervened channel;

$F_{fs} = m_{fs}\, l_{fs}\, h_{fs}$ - bulkhead square of swirler;

μ_{fs} - flow coefficient of the channel.

The attitude of flow rate through swirlers, approximately is equal to the attitude of their effective squares:

$G_{fs}/\, G_{as} = (\mu_{fs}\, F_{fs})\, /\, (\mu_{as}\, F_{as})$.

Parameters describing sizes and the form of an exit pipe of the burner:

β - angle of declination forming of a cone;

$\underline{r}_K = r_K / r_{as}$ - a relative radius of a target cross section;

$\underline{l}_H = l_H / r_{as}$ - relative ring instrument length.

The modification of a parameter S_{fs} has a small influence on α_{max}. Only diminution of significance's $S_{fs} < 0{,}4$ results in some deterioration blowout performances. The parameter S_{fs} for constant ratio of consumption through swirlers $G_{fs}/\, G_{as}$ depends only on a radius of the twisting camera S_{fs} = const r_{fs}. The experiments have shown, that magnification S_{fs} more than 8,0... 8,5 does not call the extension of a range of stable burning, but in results it increase the diametrical sizes of the burner, that can be not desirable. Therefore maximum significance S_{fs} is expedient for selecting no more than 8,0.

The distribution of air consumption on swirlers G_{fs}/G_{as} poorly influences a range of failure of a flame. The magnification G_{fs}/G_{as} at the expense of a modification of a longitudinal size of swirler l_{fs} for constant meaning of a radius of the twisting camera r_{fs} calls an appropriate diminution of a parameter S_{fs} ($S_{fs} \sim Const / l_{fs}$), the whole range of which modification is within the limits of two ($S_{fs\ max} / S_{fs\ min}$ ($\approx 2{,}0$). Therefore exceeding of significance's G_{fs}/G_{as} more than 1,2... 1,4 it is not expedient. Thus, the rational range of a modification of these parameters is in limits S_{fs} = 4,0... 8,0; G_{fs}/G_{as} = 0,6... 1,4.

The exit pipe of the burner is expedient for executing as a direct cone. The angle of a cone β should not be less than 35... 40^0, because the lower β can inadmissible decrease volume of a circulating zone behind the burner. The increasing an angle β more than 50^0 results to noticeable deterioration of stable burning range for poor mixture.

For insure possible large significance's α_{max} it is necessary to have a cylindrical site on a shear of an exit pipe. Relative length of the given site l_H should be not less than 0,3... 0,4 to supply noticeable increase α_{max}. For want of significance's l_H = 1,5... 2,0 and the interaction of a circulating zone with jets of a secondary air in flame tube is more possible.

5. Influence of a construction of the front device to emission performances of the combustion chamber

The use of the front device with an opposite rotation of streams increases a degree of a turbulence of a stream. It results to intensification of fuel burning and diminution of length of a burning zone. As a result the residence time of reacting substances τ_r in a zone of high temperatures decreases from 2,5 ms up to 1,0 ms.

In a fig. 6 it is shown, that for of NO_x in products of combustion decreases approximately twice [1].

Using of combustion chambers with burners, which improve mixing and intensity the process in its initial part results in a diminution of harmful ejection's NO_x.

In a fig. 7 the outcomes of measurements of emission of combustion chambers of different aviation engines conducted by the company SNECMA are represented [2]. It is visible, that application of the burner with an increased turbulence of merging (the camera 2) essentially has improved ecological performances of combustion chambers. It is possible to expect that the application of front devices with an opposite rotating of streams will improve mixing and will ensure the uniform, homogeneous mixture. As a result the combustion will take place in narrow area. The residence time in this area will decrease up to 1 ms and the formation of NO_x will decrease on a comparison with outcomes obtained by the company SNECMA approximately on 15 %.

Conclusions

- The systematic researches of a structure of current, distribution of temperatures and intensity of turbulence in a trace behind single rotational burner are conducted, in which for intensification of a mixing the opposite twisted jets are used.
- The experimental researches of influence of main design data of single burner on blowout performance are executed, which gives the recommendations for rational designing of burners from the point of view of maintenance possibly best blowout performances for poor mixture.
- Is shown that the combustion chambers with rotational burners will have good emission performances.

The literature

1. Lefebra B. Gas Turbine Combustion, 1985.
2. Karadimas G. New Ways for the Design and the Development of Future Efficient Engine Components, XIII ISOABE, 1997, v. 1, pp. 51-57.

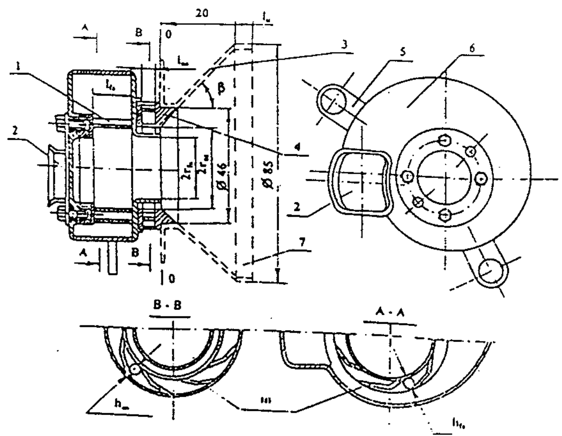

Fig. 1. Burners diagram № 0, 1, 2, 3, 4: 1 – air-fuel vane swirl; 2- inlet pipe; 3 – outlet cone; 4 – air vane swirl; 5 – mounting bracket; 6 – collector scroll; 7 – separable ring packing

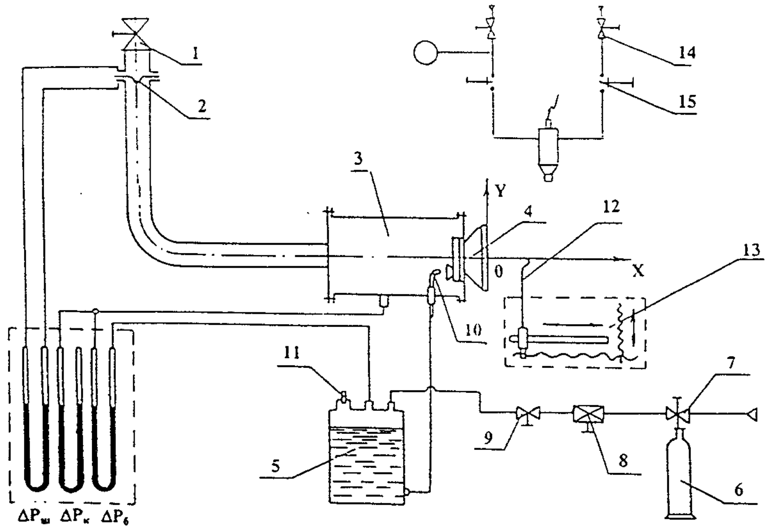

Fig. 2. Test-bench diagram

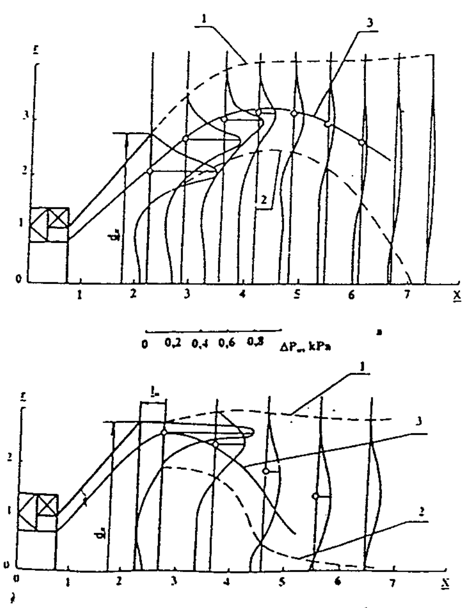

Fig. 3. Distribution of velocity head at various flow cross-sections behind the burner № 1 at $l_н = 0$ – (a) and behind the burner № 2 at $l_н = 0{,}44$ – (b) : 1 – flow edge; 2 – edge of back flow; 3 – calculated path

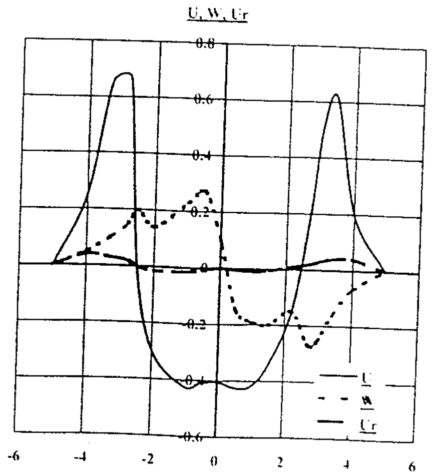

Fig. 4. Distribution of axis $\underline{U}$, circle $\underline{W}$, radial $\underline{U}_r$ velocity components at the cross-section $\underline{X}$ = 1.65 from the cross-section of outlet cone of the burner № 2 at $\Delta P_к$ = 8,6 kPa and V = 24 m/s

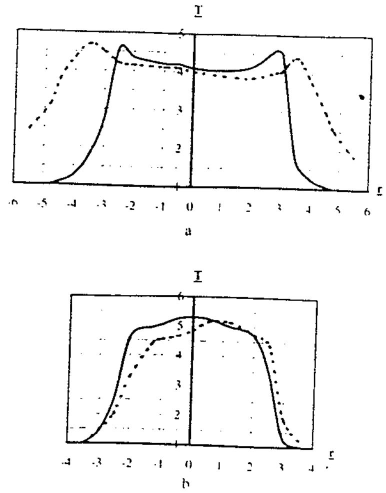

Fig. 5. Temperature fields behind the burner at α_0 = 0,6; $\underline{l}_н$ = 0 – (a) and α_0 = 1,2; $\underline{l}_н$ = 0,44 – (b) at various cross-sections at $\Delta P_к$ = 4.7 kPa:

———— $\underline{X}$ = 0   - - - $\underline{X}$ = 1,6

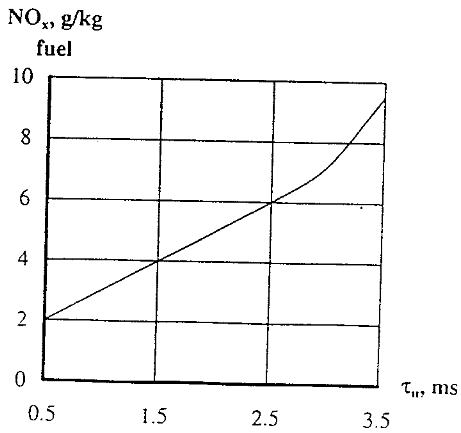

Fig. 6. Effect of residence time on NO_x emission in a premixed fuel-air mixture

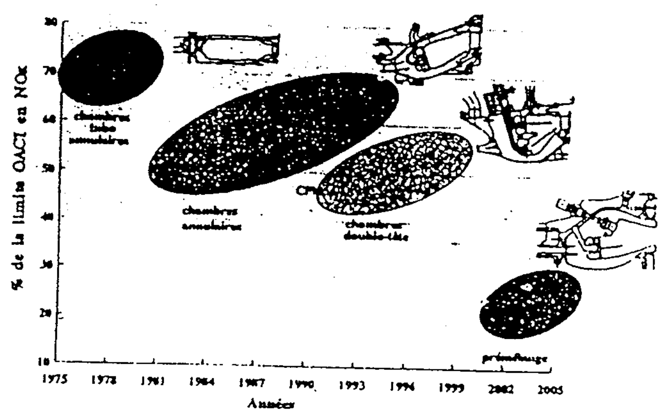

Fig. 7. NO_x evolution vs. combustor technology