

6-22-2018

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Recommended Citation

Isatayev, M. S.; Seydulla, Zh. K.; Dosanova, A.; and Tolen, Zh. (2018) "Study of integral characteristics of the turbulent jet elements of power plants," *Eurasian Journal of Physics and Functional Materials*: Vol. 2: No. 2, Article 9.

DOI: <https://doi.org/10.29317/ejpfm.2018020209>

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Study of integral characteristics of the turbulent jet elements of power plants

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DOI: 10.29317/ejpfm.2018020209
Received: 01.05.2018

The work represents the results of experimental research of aerodynamics of three-dimensional turbulent jets flowing from nozzles with rectangle outflow face. The results of measurements of average and pulse flow characteristics of three-dimensional jets are given. The data on axis speed and turbulence intensity are given and an attempt to reveal their interrelation is made. The results of experimental data comparison on axis speed attenuation of three-dimensional jets with the data for axis symmetric stream are presented.

Keywords: dynamic and thermal flow characteristics; turbulent jet; three-dimensional jet.

Introduction

When testing gas turbine power plants, questions arise about the study of the average characteristics of products. This article is devoted to problems of finding the average integral characteristics under conditions of a complex three-dimensional turbulent flow. As an example of such a current - the flow in and behind the main units of the plants (compressor, turbine, etc.). At the same time, the further the section under investigation along the path, the more complex the flow becomes. For power plants (for both projected and converted), the issue of measurement is even more acute - the gas-air path at the outlet should create a minimum hydraulic resistance in the entire range of operation. Therefore, the quality of measurements and the accuracy of determining the integral characteristics of the flow depends on the amount of irretrievable losses and, ultimately, the economy of the power plant. In this case, it is important (critical) to measure the fields of the average characteristics of a turbulent jet.

In the experimental studies of recent years [1-3] it was noted that when the jet flows from a rectangular nozzle, the velocity and temperature profiles develop with sharp irregularities, despite the fact that the velocity and temperature profiles were uniform in the exit section of the nozzle. Further studies have shown that these irregularities are due to the influence of the structure of large-scale vortices developing in the initial part of the jet.

The purpose of this paper is to experimentally study the average dynamic and thermal flow characteristics in a three-dimensional jet over a wide range of changes in the aspect ratio and the initial velocity in the presence and absence of acoustic action, to study the coherent structure of turbulence in a three-

dimensional jet and to determine the influence of such structures on the dynamics and heat transfer of the jet. The experiments were carried out on the setup schematically shown in Figure 1.

The air from the fan (1) passed through the vibration-damping transition (2) into the soothing chamber (3), then through the grids (4) and (5) flowed from the nozzle (6) with a rectangular shape of the outlet section.

The main part of the jet was located in the working part of the shadow device IAB-451, equipped so that it was possible to observe an instantaneous shadow flow pattern.

The jet was subjected to the action of the speaker (7) with a power of 50 W, placed in the soothing chamber in front of the outlet section of the jet.

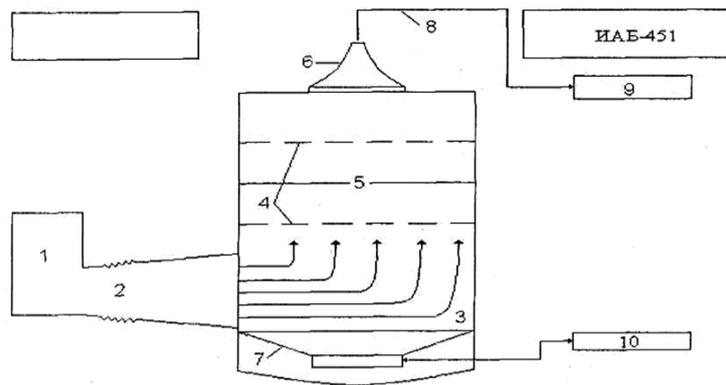


Figure 1. Diagram of the experimental setup. 1 is a fan; 2 is a vibration damping transition; 3 is a soothing chamber; 4 are leveling grids; 5 is a heated mesh; 6 is a nozzle; 7 is a speaker; 8 is a Pito tube; 9 is a micromanometer; 10 is a sound generator.

When a sine signal from the speaker is sent to the sound generator (10), sinusoidal oscillations of the speed of selected frequency are created in the output section of the jet.

To measure the average speed and dynamic pressure, a Pito tube (8) and a MMN-240 micromanometer (9) were used.

The Pito tube and sensors moved along the three axes of symmetry of the nozzle by a three-dimensional co-ordinator.

To form three-dimensional jets, replaceable nozzles with different elongations were used. The nozzle extension (hereinafter referred to as the nozzle aspect ratio) is the ratio of the long side a , to the short side b on the nozzle cut ($\lambda = a/b$).

The four sides of the nozzle, formed according to Vitoshinsky's formula, were first mounted to each other with special clamps, then carefully welded together. Rectangular nozzles had the same length of 90 mm, with the degrees of compression $c \approx 10$ ($c = F_1 / F_2$), where F_1 is the area of the entrance section of the confuser; F_2 is the area of the output section of the confuser), and the values of the output cut-off areas for all nozzles were approximately equal and equal in area to the round nozzle, whose diameter would be $d_{cr} = 22.57$ mm. Accordingly, the effective diameter of each rectangular nozzle d_e was approximately the same as that of the circular nozzle.

$$d_e = \sqrt{2ab/\pi}, \quad (1)$$

The main measurements were made for $\lambda = 2.66, 11$ and 25 .

The flow velocity during the experiment varied from 6 to 40 m/s. The main measurements were carried out at the outlet velocity from the nozzle $U_0 = 6$ m/s, which corresponded to the Reynolds number $Re \approx 0.97 \times 10^4$, calculated from the effective diameter.

The jet was subjected to the action of the sound radiator placed in the soothing chamber frontal to the exit section of the nozzle. The experiments were mainly carried out in the absence of an external action, and in the presence of an impact corresponding to the Strouhal number:

$$Sh = \frac{f_b b}{U_0} = \frac{f_a a}{U_0} = \frac{f_{d_e} d_e}{U_0} = 0.48, \quad (2)$$

where f_b , f_a and f_{d_e} are frequencies calculated on the short and long sides of the nozzle and the effective diameter of these nozzles.

An experimental study of heat transfer processes in three-dimensional jets was carried out in the same experimental setup, the scheme of which was shown in Figure 1. The air entering the soothing chamber through the equalizing grids went out from the rectangular nozzle. The jet was heated by a heater mounted in the inlet section of the nozzle.

To measure the temperature distribution in the jet, a copper-constantan thermocouple was used, the "hot" junction of which was placed in the flow, and the other, the so-called "cold" junction, was at room temperature. The emf of the thermocouple was measured by a digital voltmeter. The thermocouple signal was also sent to a two-coordinate recorder, where continuous recordings of temperature changes along the axis of the jet and in cross sections were made.

The flow temperature ranged from room temperature to 60° C, and the flow rate was in the range (6-15) m/s.

The following excess temperatures are introduced:

a) the difference between the temperature at a given point of the jet and in the environment $\Delta T = T - T_{average}$;

b) the difference between the temperature on the jet axis and in the environment $\Delta T_m = T_m - T_{average}$;

c) the difference between the temperature in the initial section of the jet (at the mouth of the nozzle) and in the environment $\Delta T_0 = T_0 - T_{average}$.

When studying nonisothermal three-dimensional jets, difficulties arose in obtaining a uniform temperature profile in the exit section of the jet. They were overcome by the reconstruction of replaceable nozzles used to study dynamic characteristics. In their input section, nickel fine-meshed meshes, heated by current, were mounted.

Figure 2 shows an example of temperature distribution along the axis of a nonisothermal jet for $\lambda = 2.66$ and 11. It is not difficult to see that the temperature distribution curve in the transition section contains a flat section coinciding by its location with a similar section in the velocity distribution. This means the existence of processes that delay the rate of temperature reduction upstream.

In order to establish the influence of the number Re on the decay of the axial velocity, experimental studies were carried out with a variation of the parameter Re .

The measurements were carried out at flow rates from the nozzle 6.03, 20 and

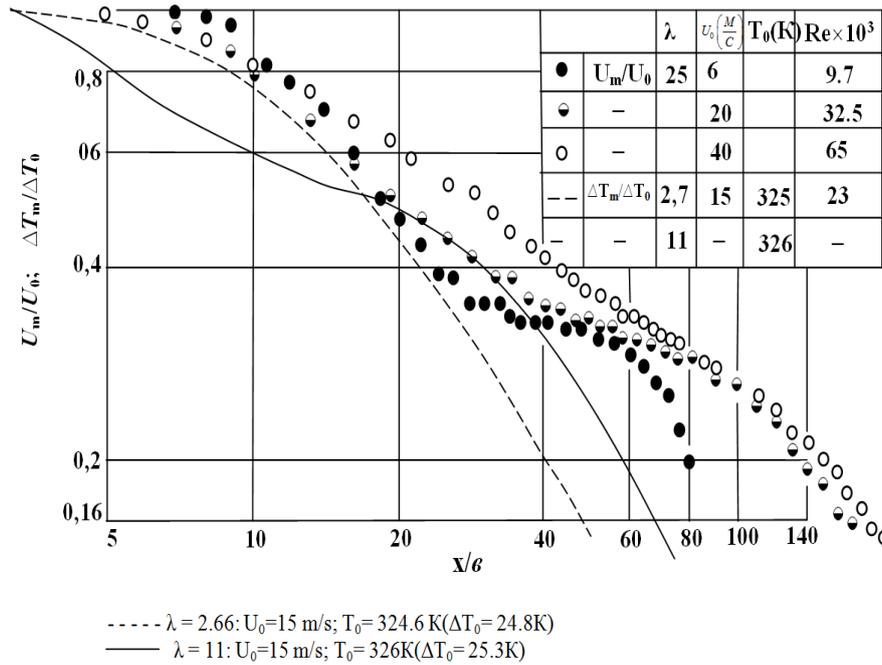


Figure 2. Distribution of velocity and excess temperature along the axis of the three-dimensional jet at different values of the elongation parameter.

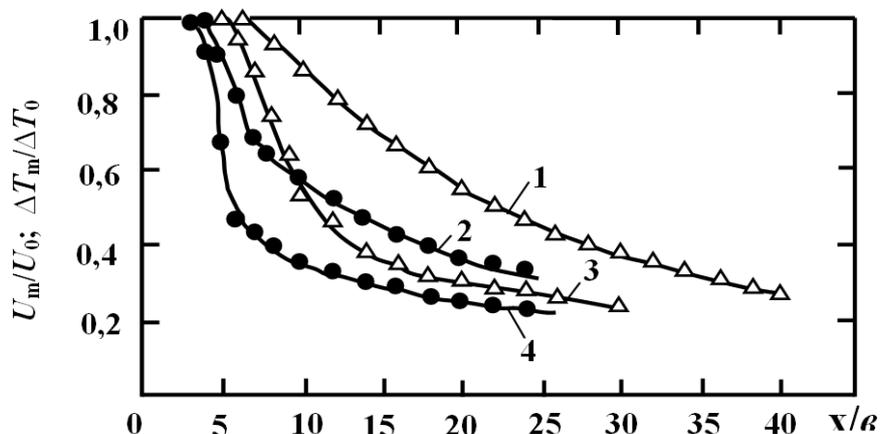
40 m/s, which corresponded to Reynolds numbers $Re=0.97 \times 10^4$, 3.25×10^4 and 6.5×10^4 calculated from the effective diameter. The results of these experiments are also shown in Figure 2. As can be seen from the figure, the number Re basically affects the patterns of the change in the speed in the transition section, and with an increase in speed, a gradual straightening of the shape of the curve occurs, which corresponds to the flow region in which the rate of decrease in the velocity previously slowed down. This is well illustrated in the figure. It can also be noted that as the Re value increases, the beginning of the region in which the rate of decrease in the velocity is proportional to x^{-1} , gradually moves further away from the nozzle.

Figure 3 shows the velocity and temperature distributions in the jet for $\lambda = 2.66$ with natural development and the effect of a low-frequency sound equal to the frequency of periodicity of the flow in the region of deformation of the cross section of the jet. It can be noted that, in comparison with the rate of change in the axial temperature, it occurs more sharply both in the absence of acoustic impact and in its presence. These changes occur in the transition area. A significant effect of f_a on the rate of decrease of the axial velocity is explained by an increase in the intensification of the turbulent exchange. As for the axial temperature, this same process is the reason for a faster rate of its decrease.

In order to determine the external influence on the thermal characteristics of the three-dimensional flow, transverse profiles of the mean temperature in different sections of the jets were measured.

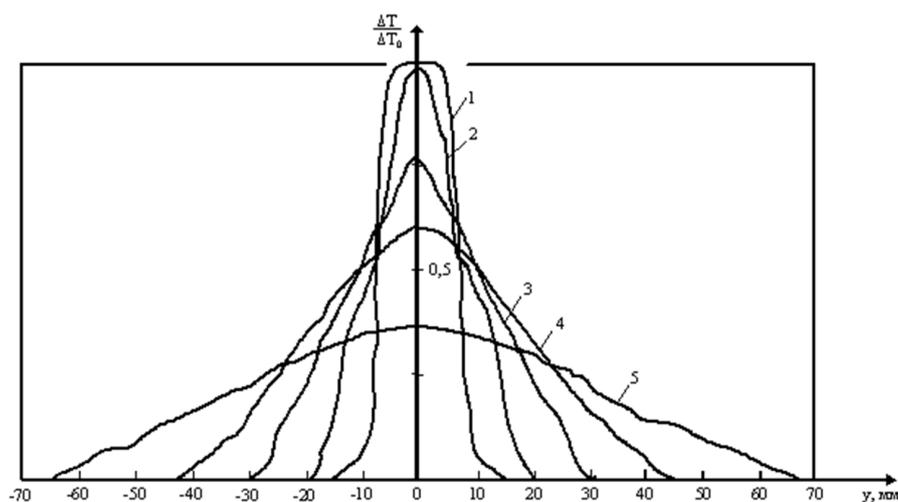
Examples of transverse temperature distributions in the presence and absence of the external impact are shown in Figures 4 and 5. The appearance of additional maxima relative to the jet axis under the external impact is caused by bifurcation of the vortex structures generated by the external impact. Less noticeable than in the previous case, but easily detected in the temperature profiles (the initial section), lateral protrusions also occur in the case when the impact is absent. In

both cases the reason for appearance of such nonmonotonous temperature distributions is the formation and further evolution of large-scale vortices. It should be noted that, from a certain distance from the nozzle cut, the jet in the shape of the temperature profiles becomes axially symmetric.



$$\lambda = 2.66; U_0 = 6.03 \text{ m/s}; T_0 = 323 \text{ K } (\Delta T_0 = 23 \text{ K}); Sh_a = 0.48. \Delta - U_m/U_0; \\ \bullet - \Delta T_m/\Delta T_0; 1.2 - f = 0; 3.4 - f_a = 89 \text{ Hz}$$

Figure 3. Variations in velocity and excess temperature along the axis of the jet with and without external action.



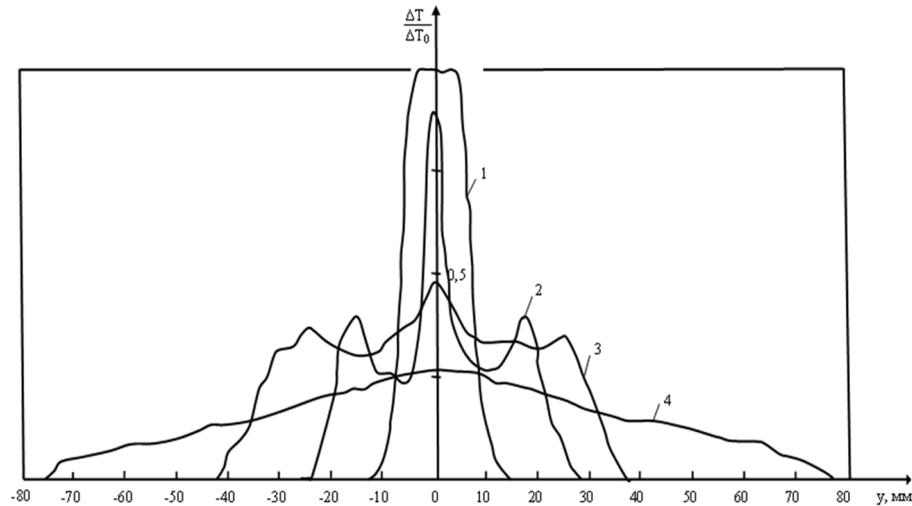
$$\lambda = 2.66; U_0 = 6.03 \text{ m/s}; T_0 = 323 \text{ K } (\Delta T_0 = 22 \text{ K}). 1 - x/b = 0; 2 - x/b = 4; 3 - x/b = 6; 4 - x/b = 10; 5 - x/b = 20$$

Figure 4. Transverse profiles of the excess temperature in the three-dimensional jet along the axis parallel to the short side of the rectangular nozzle without external impact.

It is possible to detect lateral projections ($x/b = 4, 6$) in the temperature profiles (Figure 4), which arise when the action is absent, while similar nonmonotonicity in the velocity profiles is not observed. The appearance of such nonmonotonicity in the temperature profiles is insignificant and they are quickly smoothed away with the distance from the cutoff of the nozzle, which does not occur when an external action is imposed on the jet (Figure 5).

If there is a sound field, such lateral, with respect to the axis of the jet, maxima are even stronger and manifest themselves in a more pronounced form.

The nature of the appearance of nonmonotonicity in the profiles of the excess temperature of the jet can be explained by the dynamics of large-scale vortices.



$$\lambda=2.66; U_0=6.03 \text{ m/s}; T_0=324 \text{ K } (\Delta T_0=23.3 \text{ K}); f=89 \text{ Hz. } 1-x/b=0; 2-x/b=4; 3-x/b=6; 4-x/b=20$$

Figure 5. Transverse profiles of the excess temperature in the three-dimensional jet along an axis parallel to the short side of a rectangular nozzle in the presence of an impact.

In the case of translational rotational transfer of an inert mass, as it occurs in large vortices, nearby parts of the stationary surrounding cold liquid are transported by circulation into the inside of the heated jet and change the temperature distribution in the transverse direction. With acoustic action, the vortices become larger in size, further strengthen this process and, as a result, lead to the appearance of sharp nonmonotonicities in the profiles of excess temperature.

The temperature sensor, moving across the jet, registers a higher temperature in its central part, less high at the foci of large eddies, and minimum values between the foci of the outer torus. The minimum excess temperature corresponds to the region of the jet formed by the transfer of colder air layers.

Conclusion

With the help of these methods of experimental investigation, a series of experiments was carried out to study the integral characteristics of a three-dimensional turbulent jet as the main element of flows in power installations. The results of the influence of the number Re on the decay of the axial velocity, on the velocity distribution and the excess temperature along the axis of the three-dimensional jet were obtained for different values of the elongation parameter. The influence of external influence on the thermal characteristics of the three-dimensional flow is studied.

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