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Experimental speed study of twirled gas pipe with precessing vortex nuclei

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Abstract. The results of an experimental study of a strongly wound free isothermal jet with a precessing vortex core are presented. It was found that the distribution of radial and tangential velocity components while moving away from the cut of the supply nozzle has a maximum that mirrors its position relatively to the central axis in step of 1 gauge due to the influence of vortex core on flow structure. It is shown that an axial component taken at different distances from the axis of the jet is characterized by the presence of positive and negative velocities in the initial section, separation of which corresponds to the outer and inner parts of the swirling jet, while velocity variation along the length of the jet has four distinct sections, that is caused by the existence of reverse currents zones, and change in the velocity along the axis of the stream indicates a nonlinear change in the shape of this zone.

1. Introduction

Achieving optimum heat dissipation in low-power heat generators (up to 300 kW) using existing control methods [1-3] is currently difficult from the economic point of view.

At the same time, rotating streams got widespread use, scope of which covers the processes of heat energy production, transmission and use of it, as well as processes associated with the use of heat in technological processes. In this case, the use of aerodynamics of rotating flows - centrifugal effect, occurrence of reverse currents in the central area, allows solving problems of intensification of production processes, optimizing equipment operation and its design parameters.

However, instability of the processes occurring during primary decay of a swirling flow (appearance of recurrent flow area), appearance and degeneration of a vortex precessing nucleus at certain values of flow twist degree causes considerable difficulties in applying twists in technological processes [1-5], which requires an analysis of reasons of low efficiency application of rotating streams in thermal processes.

2. Statement of subject objective

Development of new energy-saving methods and constructive decisions to reduce fuel consumption in decentralized heat supply systems, localization of low-power heat sources and dispersion of harmful substances in atmospheric air, along with theoretical researches, requires receiving experimental data on aerodynamics of interacting rotating flows. To solve this problem, based on recommendations [5-10], an experimental stand was designed and manufactured, general form of which is shown on Figure 1. Experimental setup consists of a nozzle with a diameter of 100 mm, with a tangential flow, flexible air ducts, a high-pressure fan, and valves for controlling air flow.

To perform speed measurements, unit is equipped with a thermoelectric anemometer determining velocity direction, ball probe and a coordinate grid for distribution of measurement points. Measurement of gas flow was carried out using a calibrated diaphragm by variable differential pressure method.

Before measurement was started, thermoelectric anemometer was connected to the network, instrument was checked and a nozzle was installed to create the studied type of swirling jet. Next, coordinate grid was set up along the cut of the nozzle or in the required section, and number of points to be measured was determined.

After the fan was turned on, axial, tangential and radial velocities were measured in this section, and then the grid was transferred to a distance corresponding to the next section with subsequent measurements.

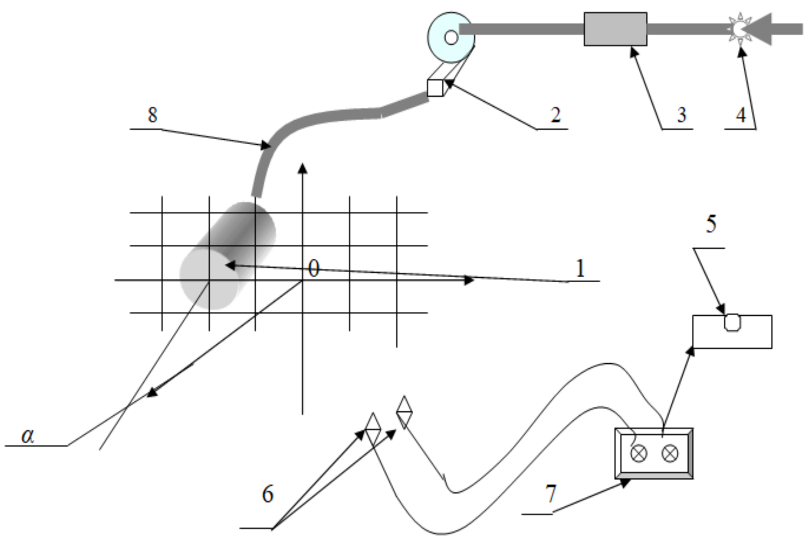

Figure 1. Scheme of the experimental stand for aerodynamic studies of a swirling jet: 1 - feed nozzle, ø 0.1 m; 2 - high-pressure fan no. 8; 3 - diaphragm; 4 - valve; 5 - chart recorder; 6 - probes; 7 - thermoelectric anemometer; 8 - flexible hoses.

3. Analysis of experimental results

Data obtained as a result of experimental studies, after evaluating their reliability, are presented in the form of graphical dependencies on Figures 2-6.

Distributions of radial and tangential velocity components on the branch cut (Figure 2) are similar to profiles for strongly twisted jets given in numerous papers [1-5,11-16], but it should be noted that distribution of tangential velocity, unlike more smoothed radial profile, has a clearly pronounced minimum, located at the boundary of the reverse currents, which is probably caused by a sharp expansion of the jet as it exits the nozzle and involves surrounding air mass in return flow on the axis of the jet, at the same time the difference in speed between central axis and boundary of the reverse currents region arises from inertia of ambient air mass and maximum of tangential velocity corresponding to the peripheral region.

Evolution of radial velocity distribution when moving away from the cut of the supply nozzle (Figure 3 (a)) shows that maximum of this velocity component mirrors its position relative to the central axis in steps of 0.1 m, and minimum (corresponding to the reverse currents region) expands, decreasing in absolute value as the distance from the source of the jet increases. This velocity behavior can be explained by unilateral tangential air supply, which results in an uneven distribution of rotating

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mass around the axis, however, this is possible with speed measurements with a time distribution equal to angular velocity of rotation, and in this case measurements were carried out in one time interval. That is, the most probable is influence of the vortex core, whose helical trajectory (in second section of this paper it was shown that vortex core is not rectilinear but curls about central axis of the swirling flow) and, obviously, has a step multiple to a branch pipe diameter.

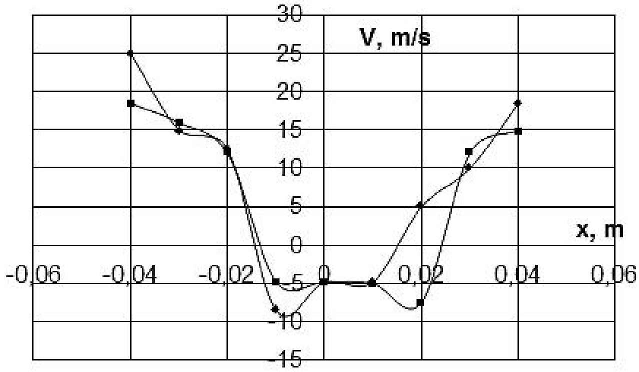
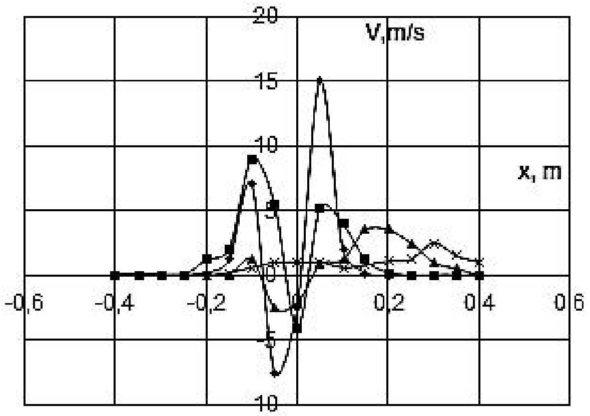
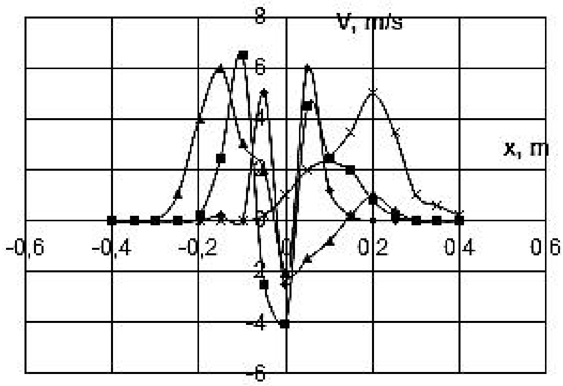


Figure 2. Speed distribution at branch pipe end: ♦ - radial velocity component, V_r, m/s; ■ - tangential velocity component, V_{φ}, m/s.



a) radial component



b) tangential component

Figure 3. Speed distribution in a single stream: ♦ - at a distance of 0.1 m from nozzle, ■ - at a distance of 0.2 m from nozzle; ▲ - at a distance of 0.3 m from nozzle; **x** - at a distance of 0.4 m from nozzle.

Profile of tangential velocity (Figure 3 (b)), shown at different distances from branch pipe, is also characterized by displacement of maximum relative to the axis, depending on considered cross section, which confirms the assumption that vortex core affects swirled flow rate, while region of reverse currents (a zone of negative velocities in central region) disappears, as in the case of radial velocity component at a distance of 3 gauges, and velocity profiles themselves are similar. However, in contrast to radial velocity, tangential component has a maximum not only at outlet of the jet from nozzle, but at a distance of 2 gauges, and further decreases in absolute magnitude. This effect is caused by rearrangement of velocity field of the initial section in the field of the main velocity, and also by effect of reduced pressure region (zone of reverse currents) due to a change in direction of axial velocity of the part of the flow located on the boundary with given region.

Analysis of axial velocity component taken at different distances from the jet axis (Figure 4) showed presence of positive and negative velocities in initial section, separation of which corresponds to outer and inner parts of the swirling jet, while velocity variation along the length of the jet has four distinct sections. Thus, peripheral layers of the jet in the initial section have a maximum, then, due to the expansion of reverse currents region, direction of motion decreases and changes, but at a distance of 2 gauges (on boundary of reverse currents zone), axial velocity again takes positive maximum values for given section, in the last section there is a smooth decrease in speed, which corresponds to damping of the jet in the main section. In central region of the jet at the initial section, axial velocity is negative (motion of gas flow is opposite to axis direction), but has maximum absolute value. At a distance of 1 gauge, maximum speed is also observed, but with the opposite sign, as the jet propagates further, analogous oscillations occur with a change in the speed direction through each gauge, while a decrease in absolute value is observed. This behavior of axial velocity component in the central region is explained by presence of reverse currents zone, and change in velocity along the axis of the jet indicates a non-rectilinear change in the shape of the given zone (in initial segment, its narrowing occurs, then, on the main, an increase in transverse dimension and, "collapse").

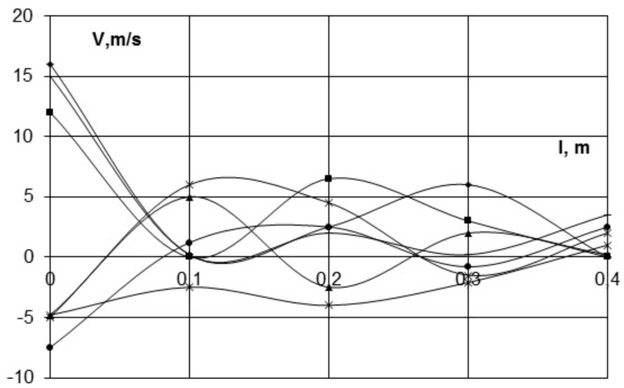


Figure 4. Axial velocity distribution: ♦ - at a distance Z = -0.15 m from axis of the jet; ■ - at a distance Z = -0.1 m from axis of the jet; ▲ - at a distance Z = -0.05 m from axis of the jet; **x** - on axis of the jet; **g** - at a distance Z = 0.05 m from axis of the jet; • - at a distance Z = 0.1 m from axis of the jet; + - at a distance Z = 0.15 m from axis of the jet.

Analysis of distribution of tangential velocity component in different sections along the length of a swirling jet represented in generalized coordinates V/V_{max} and $ln(x\ x_{max})$ (Figure 5), generally accepted for representation of such dependences [4,5,9,10] has shown that obtained dependences have the same profile for any cross section of the jet, but shift along the abscissa axis as the cross section is removed from the start of the jet. Comparison of these graphs with data from other authors [1-5,7,8] allows us to conclude that the results coincide with sufficient accuracy. However, such representation does not make it possible to analyze the processes occurring in rotating jets [10,11,17-20], although it is convenient for the development of engineering calculation techniques.

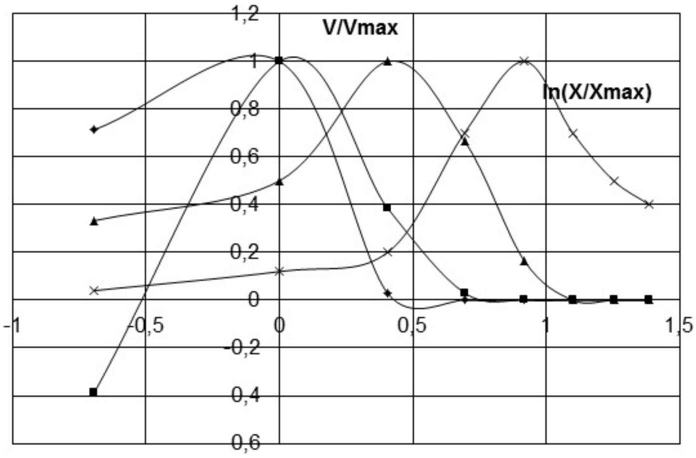


Figure 5. Distribution of the tangential velocity in dimensionless coordinates: ♦ - at a distance of 1 gauge from nozzle; ■ - at a distance of 2 gauges; ▲ - at a distance of 3 gauges; **x** - at a distance of 4 gauges.

4. Findings

Thus, experimental investigation of a strongly wound free isothermal jet with a precessing vortex core showed that distribution of radial and tangential velocity components when moving away from the cutoff of the delivery branch pipe has a maximum that mirrors its position relatively to the central axis in steps of 1 gauge due to the influence of the vortex core on flow structure. Axial component, taken at different distances from the axis of the jet, is characterized by presence of positive and negative velocities in the initial section, separation of which corresponds to outer and inner parts of the swirling jet, while change in velocity along the length of the jet has four distinct sections, which is due to presence of reverse currents zone, and change in velocity along the axis of the jet indicates a nonlinear change in the shape of this zone.

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