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Processes of Precession and Nutation in Swirling Interacting Gas Jets

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Abstract. The results of experimental studies of the oscillations of the velocity of a free isothermal swirling jet with a precessing vortex core are presented. They showed that in the initial section where there is a developed zone of reverse currents, the oscillations of the radial and tangential velocity components are observed in the regions of maximum values in the peripheral layers of the jet, which is explained by the nutation of the precessing vortex core. The most unstable region in a free twisted jet corresponding to the revealed maximum of the amplitude of the oscillations of the axial velocity component at a distance of 3-4 diameters is determined. It is shown that in the main part an increase in the relative amplitude of the radial and tangential velocities is observed throughout the section, the maximum values occurring in the region located outside the back current zone.

1. Introduction

Analysis of the current state of the theory of interacting rotating flows has shown that free single swirling flows are rarely used, mainly in heat-power engineering, the interacting swirling flows [1-6] are used, while the same and oppositely twisted flows at the same time are investigated under coaxial, parallel and counter interaction [11-16].

The mathematical description of the resultant motion in these studies was based on the Navier-Stokes equations and the Prandtl theory on the mixing path, but the influence of the precession structure of the vortex nuclei of the rotating streams, ie the region of existence of the precessing vortex core, determined by the Reynolds numbers Re> 18000) [1, 11-20], when the flow is unstable, has not been studied in practice and requires studies in this field for colliding, horizontally displaced of active rotating jets.

In addition, taking into account the data obtained in [3, 4, 9, 10], which testify to the significant influence of the precessing vortex core on the stability of a single swirling flow and the proposed concept of the appearance, development and destruction of a vortex core in it with a developed backward current zone [10], it is necessary to consider the problems associated with superimposing oscillations of the vortex nuclei against one another and on the resulting gas flow during the interaction of rotating jets and to reveal the conditions for the appearance of resonant phenomena, and also to ensure the stability of vortices in the cases of nutation of the precessing vortex core [11-20].
Since it is not possible to obtain such data theoretically with an allowable practical accuracy, it was not possible to obtain the velocity field by interacting two counter-rotating horizontal jets of free rotating jets, experimental studies of the velocity oscillations were carried out on the laboratory stand when the axes of counter-whose form was given in [10], the center of coordinates was located at an equal distance from the axes of the jets.

The purpose of this paper is to experimentally study the oscillatory processes that arise in the resultant velocity fields in the interaction of oppositely directed free rotating jets displaced in the horizontal plane.

2. Results of the study

The results of studies on the radial component of the velocity are shown in Fig. 1-2 with a variation in the displacement of the axes of the delivery nozzles from 0.05 m to 0.4 m in steps of 0.05 m.

An analysis of the obtained data showed that radial velocity oscillations are observed in the peripheral layers of the resulting flow, that is, in the non-interacting part of the jets, with the amplitude of the oscillations of this component of the velocity being shorter than when moving single or parallel rotating streams.

As the distance between the horizontal axes increases, the analogy of the distribution of the radial velocity field remains, up to a displacement of 4 diameters (0.4 m), when the pulsations are uniformly distributed over the entire section and have an almost equal amplitude, although the velocity profile itself indicates that the interactions between the jets are already there is practically no and in this case it is the oscillations of individual rotating jets.

![Fig.1. Distribution of radial velocity at a distance of 0.2 m (displacement of axes 0.2 m): ♦ — 10 s.; ■ — 30 s.; ▲ — 60 s.; x — 90 s.; ж — 120 s.](image)

![Fig.2. Distribution of radial velocity at a distance of 0.2 m (displacement of axes 0.4 m): ♦ — 10 s.; ■ — 30 s.; ▲ — 60 s.; x — 90 s.; ж — 120 s.](image)
When considering the tangential velocity component, oscillations occur in the central part (along the horizontal axis) (Fig. 3-4) already when the axes are shifted by 1 diameter. In the future, there is a tendency of increasing tangential velocity oscillations with increasing interaxial distance.

This distribution is explained by the collision of interacting layers in the lower part of the resulting flow and, accordingly, by the addition of oscillations in the regions adjacent to them. The amplitude of the oscillations for a given component is less than in other types of interaction of rotating flows considered earlier.

![Graph](image1.png)

**Fig.3.** Distribution of tangential velocity at a distance of 0.2 m (displacement of axes 0.2 m): ♦ — 10 s.; ■ — 30 s.; ▲ — 60 s.; x — 90 s.; ж — 120 s.

![Graph](image2.png)

**Fig.4.** Distribution of tangential velocity at a distance of 0.2 m (displacement of axes 0.4 m): ♦ — 10 s.; ■ — 30 s.; ▲ — 60 s.; x — 90 s.; ж — 120 s.

Comparison of the magnitude of the oscillations of the axial velocity component [10] with the oscillations arising in the other considered types of interaction of rotating jets has shown that in this case their amplitude is much smaller, while the location of the velocity profile can indicate the occurrence of rotational motion in the vertical plane between the jets.

The displacement of the phases of the oscillation amplitude of the layers arranged symmetrically with respect to the horizontal axis is revealed. Also clearly visible is the region of interaction of rotating jets (Fig. 5-6) - an increase in the axial velocity from 1 to 3 gauges and a further decrease.
3. Acknowledgments

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4. Conclusions

1. Restructuring of the velocity field in the main portion of a free swirling jet, after the zone of reverse currents, increases the amplitude of velocity oscillations relative to its average values, but the constancy of the absolute value of the oscillations confirms the assumption of nutation of the precessing vortex core as a mechanism for excitation of oscillations.

2. The results of experimental studies of velocity oscillations in counter-rotating horizontally displaced jets have shown that in the radial velocity component there are oscillations in the peripheral layers of the resulting flow, with the amplitude of the oscillations of this component of the velocity being shorter than when moving single or parallel rotating streams.

3. Oscillations of the tangential component of the velocity when moving counter-rotating rotating jets in the horizontal plane appear in the central part already when the axes move by 1 diameter and increase with increasing interaxial distance, which is explained by the collision of interacting layers in the lower part of the resulting flow and the addition of oscillations in the adjacent areas.

4. The amplitude of the oscillations of the axial velocity component in counter-rotating horizontal jets is considerably less than for other types of interaction of rotating streams, although the period of oscillations remains practically constant and is equal to 60 s, with a rotational movement in the vertical plane between jets.

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