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The analysis of applicability of the refractive-index-matching method for flow investigation by LDA method in models of the fire chambers of complex geometry

Vitaly V. Rakhmanov[a] and Dmitry V. Kulikov

Institute of Thermophysics SB RAS, Novosibirsk, Russia

Abstract. Possibility of use of a refractive-index-matching method for flow investigation by LDA method in models of the fire chambers of complex geometry is shown. The technique of flows investigation by LDA method is developed. The given technique can be successfully applied in leading branches of a thermal and hydropower engineering, in case of need of flows diagnostics in models of devices with the complex geometry.

Up-to-date researches of aerodynamic flow structure in models of a fire chambers are usually executed by optical not destroying methods, such as LDA (Laser Doppler anemometry), PIV (Particle image velocimetry) and PTV (Particle tracking velocimetry). LDA methods in a problem solving of study of aerodynamic of fire chambers characteristics are especially perspective as they possess a low measuring error and do not create deflections in an explored flow [1]. It is necessary to have optical access to installation for flow investigation by means of LDA methods. The laser beams pass through the interface between media having different refractive indices, such as air-glass-air or air-glass-water, etc., depending on the experiment conditions. As refraction indexes for air, glasses and waters are various, the given transitions create an optical system in which measurements by means of LDA can be impeded. It is especially actual for cases when a normal line of a boundary air-glass is at an angle to LDA optical axis. Besides, models of fire chambers can be executed from glasses of unsatisfactory quality, with small cavities, curves and a rough surface, which causes additional deviations to a trajectory of the laser beams. As a consequence, this increases the error of measurement or this leads to the fact that it becomes impossible to measure the parameters of the object. These problems can be solved using the refractive-index-matching (RIM) method [2]. Models of fire chambers may have complex geometries, causing optical distortions occurs, leading to significant errors in the experimental data. This requires the development and application of methods for measuring flow, which would minimize the errors that occur.

In Fig. 1 the case of arrangement LDA at an angle θ to a normal line of a phase boundary air-glass-water at the left is displayed. Thick arrow shows the direction when moving LDA r from the starting point. When the rays **AB** and **CB** penetrate into the flow, then there is a path length difference between them. This case often occurs in experiments when a place to put the measuring device is limited. When $2\alpha = 5^\circ$ (from the geometry of the laser beams of LAD-05) and $\theta = 8^\circ$ divergence dependence

[a] Corresponding author: rahmanov@oit.itp.nsc.ru

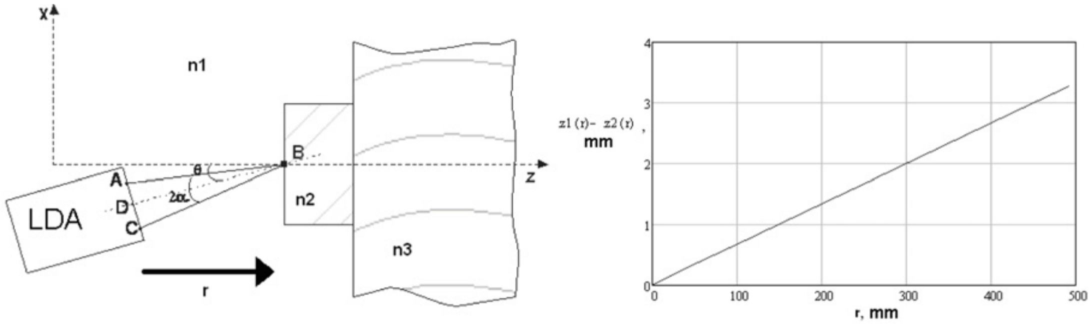

Figure 1. Passage of the laser beams through phase boundaries air-glass-water at an arbitrary angle θ between the normal line and the optical axis (left). Dependence of the difference coordinate constrictions from moving LDA for the angle $\theta = 8^\circ$ (right).

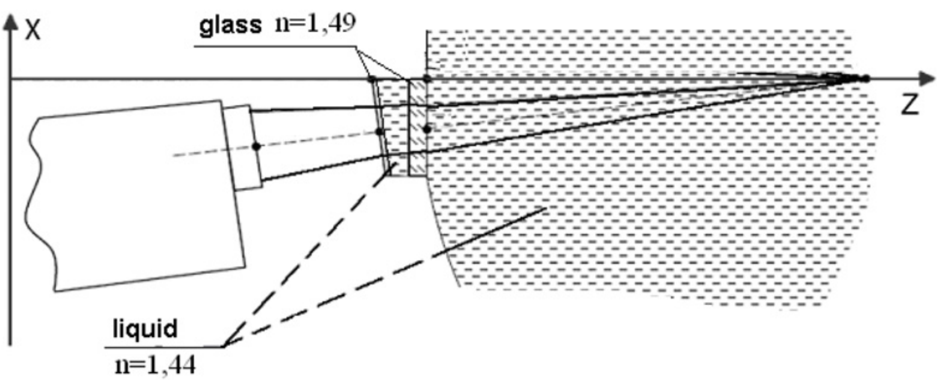

Figure 2. Arrangement LDA concerning the immersion container.

constrictions beams along the z-axis is shown in Fig. 1 on the right. z1 (r) and z2 (r) are coordinates of constrictions of beams in measuring volume depending on a depth r.

The constriction size in the z direction usually varies for different devices from 1 to 2.5 mm. Then at a discrepancy between the constrictions z1-z2 at a distance of about 1 mm the device or will cease to work, or the Doppler velocity conversion coefficient will be nonlinear, that will bring in an error in measurement. For the given angles the discrepancy on one millimeter is reached already at a depth in water on 150 mm.

The given problem is solved by means the RIM method. It is necessary, that the device optical axis placed on a normal line to the porthole plane. For this purpose the special immersion container (Fig. 2) has been developed. It consists of an external optical glass having a refractive index of 1.49 and a space filled with glycerol. As refraction indexes of a glass and glycerol differ not significantly (3.5%), the use of the RIM method successfully compensates a path difference of beams.

The optical axis of the device is located under the normal to the surface of the air-glass-glycerol in the horizontal and vertical planes. Thus, the laser rays emanating from the lens device tested same length in the air and intersect at a predetermined point in the water (in the area of constrictions rays).

Such a method of compensating of optical distortions can be effectively used for various forms of fireboxes and optically inhomogeneous surfaces. In case of quartz glass use in the porthole, in the capacity of the immersion fluid is recommended to use a solution of ammonium thiocyanate (NH CNS) and ammonium iodide (NH J) with a refraction index to relatives in 1.5. Application of the given the fluid

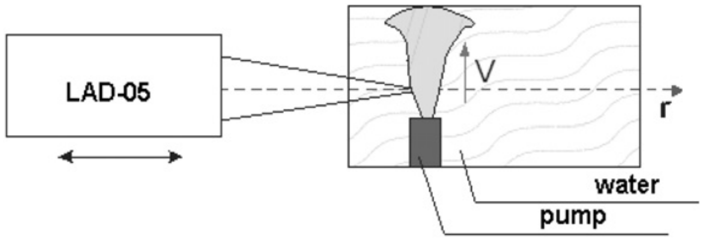

Figure 3. A schematic location of experimental installation (side view).

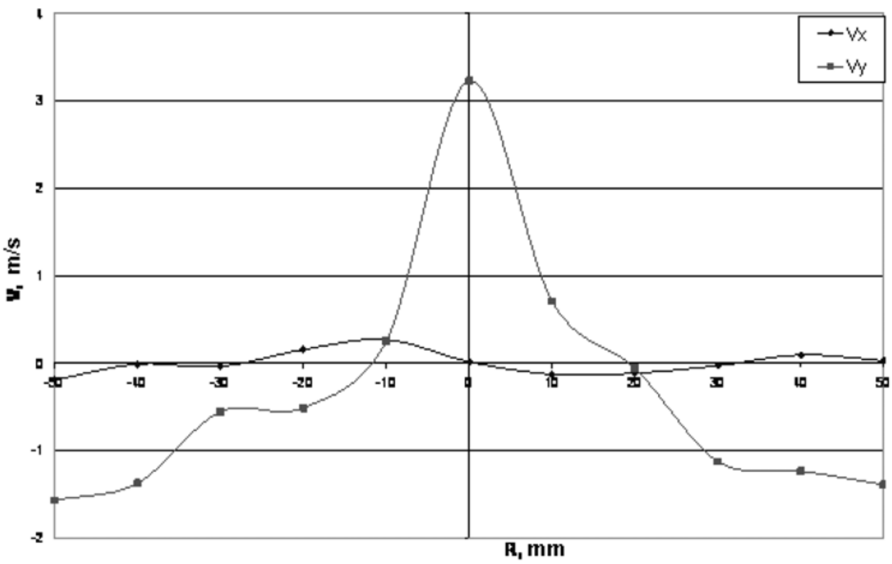

Figure 4. Flow velocity profiles in a container with a submersible pump: Vx – horizontal component of velocity, Vy – vertical.

allows to realize physical simulation of the flow inside the fireboxes taking into account arrangement of various feed pipes and other structures.

The laboratory setup consists of a rectangular container (sizes 300 × 500 × 300 mm) and two-component LDA installed on the traverse systems (Fig. 3).

As a source of water flow velocity was placed submersible aquarium pump. Flow rate measurements were performed at a distance of 20 mm vertically from the nozzle of the pump. The given installation imitates the behavior of gas flows behind the injector in a rectangular fire chamber.

As a result of application of the given immersion container two-dimensional velocity profiles in the glass container in the region of a pump nozzle (Fig. 4) for the angle of inclination of the optical axis of LDA $\theta = 8^{\circ}$ have been obtained. Maximum depth in this experiment was 300 mm. The axis of the nozzle of the pump was at a distance 250 mm from the front wall of the container. The velocity profile was measured along the axis **r** at a distance from 200 to 300 mm (Fig. 3). In Fig. 4 on the abscissa is the distance **R** from the nozzle axis of the submersible pump. Experimental results demonstrate the effectiveness of the RIM method for the flow investigation by LDA method in models of fire chambers with complex geometry.

As a result of this work it is shown that the RIM method can be successfully used for flow investigation by LDA method in models of fire chambers with complex geometry. The given method is differed by simplicity of implementation and provides a low measurement error over a wide range of optical surface properties. A feature of this method is the possibility of LDA flow diagnostics under difficult conditions of optical access to the investigated process.

Development of refractive-index-matching method will expand the area of application of optical measuring systems for various industries, will improve the quality of manufacture of fire chambers and will provide a significant contribution to the development of science and technology.

Performed analysis of the applicability of RIM method and the realized technique of LDA flow investigation can be successfully applied in leading branches of a thermal and hydropower engineering, nuclear industry, wherever a flow diagnostics in models of devices with the complex geometry is necessary.

Also, this method can be successfully used in the learning process of students and graduate students to work with the latest optical measurement systems in the framework of REC (Research and Education Center), and directly on the laboratory facilities at universities.

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