ANALYSIS OF FLUID FLOWS IN TUBES OF VARIABLE CROSS-SECTION BY LDA

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***KEYWORDS**: measurement, flow velocity, Doppler efect, light refraction*

1. INTRODUCTION

Further development of gas and fluid dynamics results from the improvement of measuring systems and is concerned with reliable information on fluid flow parameters. There are various methods for fluid flow velocity measurement such as hot wire, hot film and laser Doppler anemometry (LDA). These methods are of particular interest for the analysis of flow of some cryogenic and non-Newtonian fluids whose flow characteristics are much different of those in usual fluids. The best are contactless methods among which are those optical. They have been successfully used in experimental gas and hydrodynamics for a long time. The advent of laser made possible the expansion of possibilities of the classical optical methods and also gave raise of new ones.

Optical methods, in their essence, are founded on scattering effects on microparticles within a measured flow and interference of coherent and scattered laser light. This means that their investigation involves many disciplines. Among these are the scattering theory of laser light, dynamic scattering, and theories of laminar and turbulent fluid flows...

In the first approach the scattering centre velocity is detected irrespective of the nature of its motion, which might br Brownian or turbulent, or of the speed, which might be of the order of μm/s or in the range of shock waves and velocities of several Machs.

As implied by the name, LDA is based on the detection of Doppler effect in the scattered light spectrum. The flow velocity in one point is measured. Simultaneous flow velocity measurement for different points can be made by using several probe beams, subject to the limits of the measuring method itself as well as by the financial means at disposal.

Apart from these there are other optical methods based on the time of flight measuring at the microscopic scale. Then, there are speckle techniques, high speed micro-holografic techniques of multiexposed holograms, techniques that use visualisation of flow...[1,2]

Every technique requires fine and complex devices, which are by rule even more complex if the Doppler frequency shift is smaller (it can be several Hz to over MHz)

The main advantage of these methods is that they are contactless, distant measurement methods. This may include the application of lidars with their many possibilities (measurement of wind velocity vector, temperature, pressure). Since the first commercial laser Doppler anemometers (1970.) the method is accepted as a useful measurement technique with numerous advantages compared to the conventional methods.

The method is proved at measuring of gas flow in tubes[3]. Then it manifested itself as quite appropriate for investigation of distant atmospheric flows[4]. Significant field of LDA application is the investigation of turbulence in flame. By specially adjusted LDA system, particle sizes in flames or in aerosols are measured[5,6]. Laser Doppler velocimetry has also found its application in investigations of liquid flows, especially those more complex. Thus, for example, LDA measuring systems are developed for analyzing the distribution of water velocity around the model of vessel working propeller[7]. In some problems of fluid mechanics it is necessary to know the flow velocities and turbulence levels in thin channels. This is the case with filtration systems and water distillation systems research. When the width of a channel approaches the millimetres standard velocimetres considerably disturbe the flow, and then the solution is laser Doppler velocimetry[8]. Particularly significant applications of laser Doppler velocimetry are biomedical investigations in vitro and in vivo, such as cells, cell organelles and alive world liquids movement research. In that field laser Doppler spectroscopy is developed[9].

Commercial LDA systems are designed for velocity measurements in the flows behind flat and very thin walls. However, due to finite thickness of walls disloca-

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tion of measuring volume occurs. Furthermore, the bending of walls, apart from measuring volume dislocation, leads to decalibration of the system. This paper deals with the corrections that are to be made in cases of flows through tubes of complicated form, as well as examples of application of such corrections.

2. MEASURING VOLUME DISLOCATION AND DECALIBRATION OF THE SYSTEM

In many applications of laser Doppler velocimetry, flows in tubes of circular cross sections are investigated. Those tubes are made of glass, commercial plastic glasses or some other transparent material. The position of the measuring volume (the cross section of two laser beams), calibration constant or even the direction of the measured component of velocity could be changed in the course of traversing, and could be nonlinearly connected with shifts of the measuring system due to the difference in indices of refraction of air, tubes and liquid. The placing of such a tube into a rectangular transparent box with immersion materials could compensate some effects of light refraction [10].

In order to get correct results, the LDA system should have computer controlled traversing which automatically takes into consideration corrections of measuring volume positioning. Errors due to the change of the angle between beam axes and change of the direction of sensitivity vector could be compensated by correcting the output data for velocity intensities. In the measurements presented in this paper, all corrections are made at output data for velocity intensities.

The axial component of velocity measurement in cylindrical tubes (out of widening and bending tube parts), along the diameter of the cross section of the tube can be analyzed by the help of figure 1.

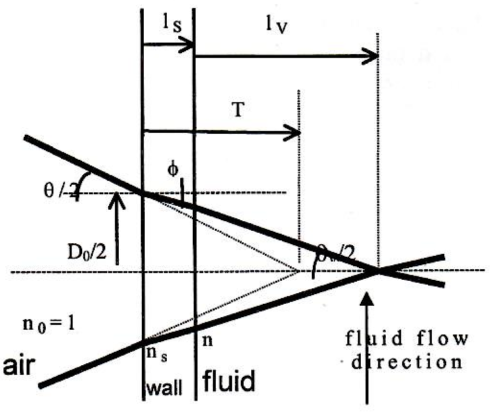


Fig.1.: The path of light beams in the cylindrical part of the tube. Beams are in the axial plane of the tube.

The calibration constant in this case is:

$$C_1=\frac{\frac{\lambda_0}{n}}{2\sin\frac{\theta_V}{2}}$$

where λ_0 is the wavelength of the laser beam in the vacuum (air). Since according to the Decartes-Snelius law we have

$$n_0\sin\theta/2=n_S\sin\phi=n\sin\theta_V/2$$

the new calibration constant is

$$C_1=\frac{\lambda_0}{2\sin\frac{\theta}{2}}=C$$

where C is the calibration constant in air. The change of the cross section angle is entirely compensated by the change of wavelength of the laser light, which means that the decalibration does not occur.

On the other hand, the changes of the position of the measuring volume are not equal to the changes of position of the emitting lens. The connection between the real distance of the measuring distance from the tube wall l_v and the apparent one T, deduced from the emitting lens movement, is given by the following expression:

$$T\text{tg}(\theta/2)=l_s\text{tg}\phi+l_v\text{tg}(\theta_V/2)$$

The apparent distance of the measuring volume from the tube wall appears here as the distance of the emitting lens from its position when the measuring volume is at the very tube wall. When the angle values are calculated according to the Decartes-Snelius law and tube dimensions used in the experiment the dependence shown in the diagram in Figure 2. is obtained.

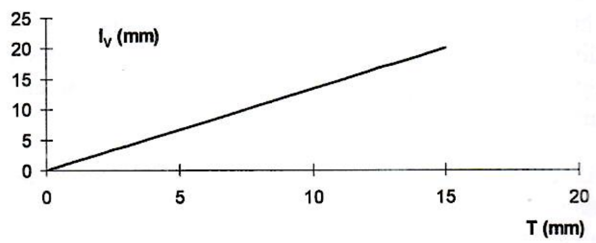


Figure 2.: The shift of the measuring volume l_v versus the shift of the emmiting lens T

From the diagram it can be seen that for the shift of the emitting lens of 12mm, the shift of the measuring volume exeeds 15 mm.

When one measures the axial component of the velocity along the diameter of the largest cross section of the tube widening, the real position of the measuring volume and the value of the calibration constant is determined using Fig. 3.

The calculation of the real position of the measuring volume (Fig. 4.) shows relatively small deviations of the real position of the measuring volume from the apparent one in the domain between the tube axes and the emitting lens (the focus distance of 350mm). In this domain the shifts of the emitting lens are approximately equal to the corresponding shifts of the measuring volume. In the domain on the other side of the tube axes,

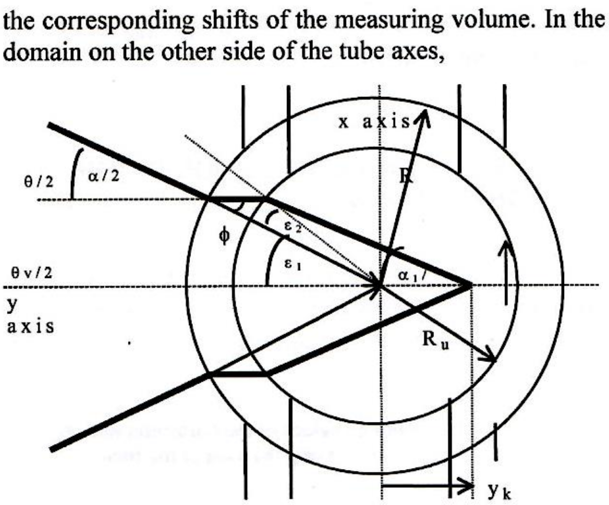
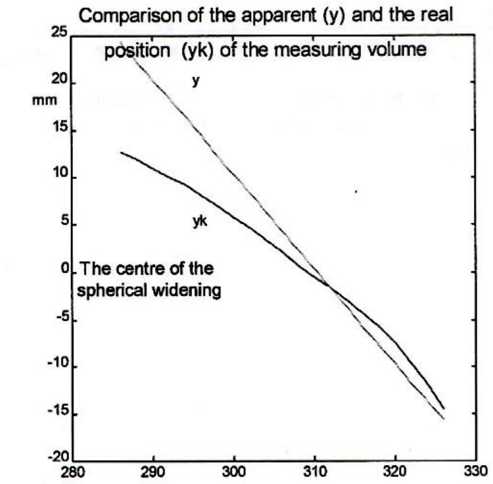
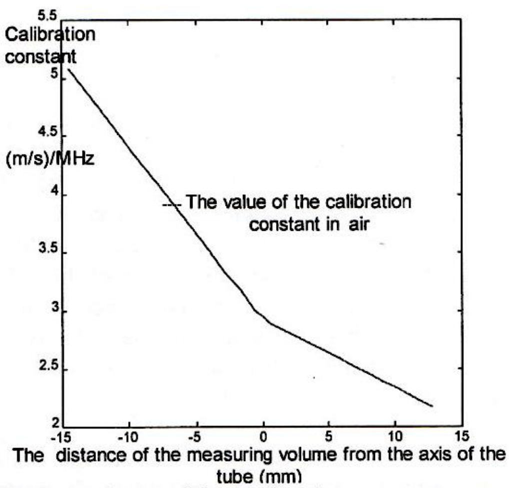


Fig. 3.: The path of the laser beam in measuring the horizontal component of the velocity along the cross section.

for constant shifts of the emitting lens the shifts of the measuring volume positions become increasingly smaller if they are at the greater distance from the tube axes.



a)

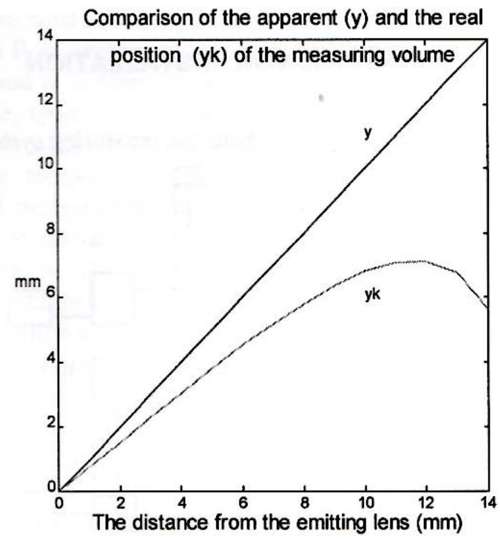


b) The dependence of the calibration constant versus the distance of the measuring volume from the tube axes

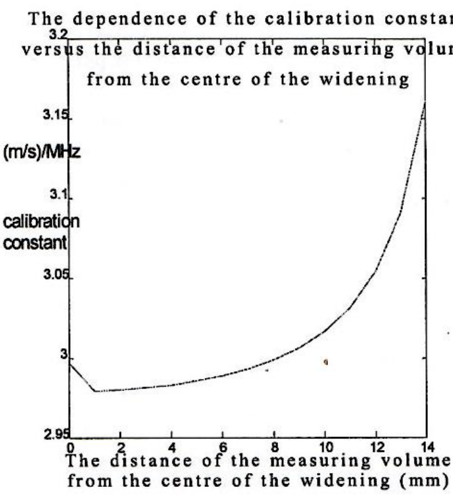
Figure 4.

Unlike the measurement through the flat wall, the values of the beam crossing angle, i.e. calibration constants, change considerably with the the position of the measuring volume (Fig. 4.b). This is why the values of the velocity shown by the LDA system should be corrected.

The previous calculation considered the shift of the emitting lens along the radial direction. For the case of the shift of the measuring volume along the tube axis within the spherical widening of the tube, the principle of the calculation of the position of the measuring volume is similar but more complex, because the two laser beams fall under different angles to the tube surface. That is why the direction of the measured velocity component is changed, too. The calculation results are shown on diagrams in Fig.5.



a)



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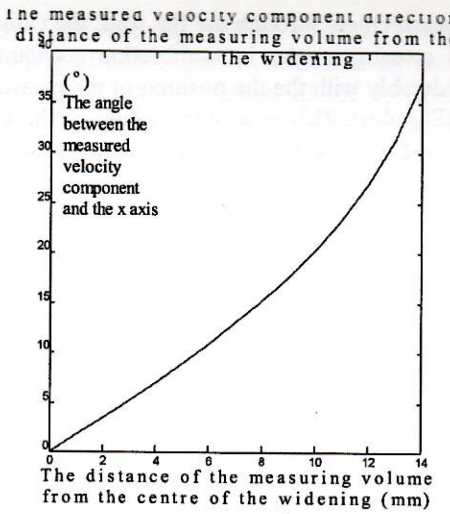

c)

Figure 5.

3. THE EXPERIMENTAL INSTALLATION

Block diagram in Fig.6. presents the measuring system.

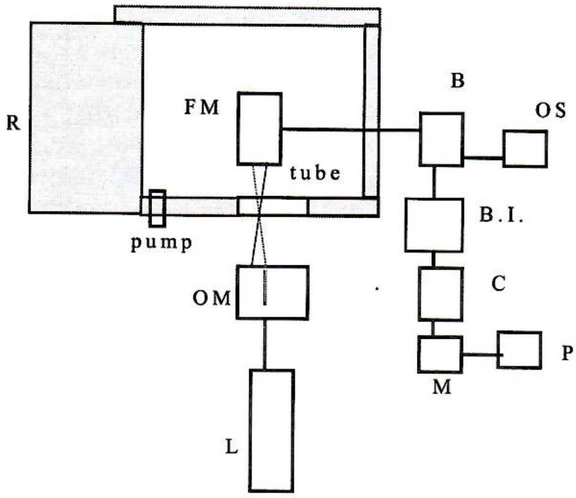

Figure 6.: Block diagram of the LDA system used in the measurement described in this paper.

The fluid flow is set up by pumps from a reservoir R with a capacity of 50l and pumps. L is the HeNe laser emmiting a coherent beam of the wavelength of 633nm. The optical module divides the light beam into two parts of equal intensity and directs them so that they intersect at the point of the measuring volume. The scattered light is detected by the photo-multiplier FM. Then, the signal from the FM is amplified and led to counter B, where the primary processing of the signal is performed. From the counter the signal is led, through the buffer interface (B.I.), to the oscilloscope OS and the computer C, where final data processing is performed. The measuring results are shown on the monitor M or are printed on the printer P.

The flow parameters were investigated in glass tubes, blown from factory cylindrical tubes of exterior diameter of 18mm. Two tubes have a widening with exterior diameters of 32mm to 34mm. Two tubes are bent (single or double curve). The measurements are made in such a way that the radii of their curves are in the vertical plane.

4. RESULTS AND APPLICATION OF THE CORRECTIONS

The tubes with widening represent a problem, due to the complexity of the flow and due to the complications in determining the exact position of the measuring volume and calibration constant.

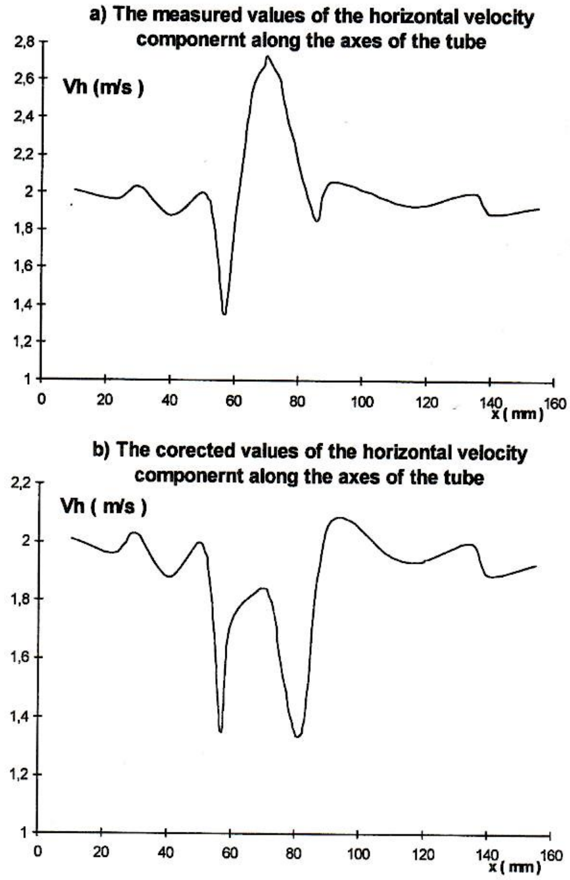

Figure7.

Fig. 7.a) shows the change of the measured velocity value along the tube axis. According to that diagram at the widening spot an unexpected rise of the velocity intensity occurs, as if the effective diameter of the flow were decreased. However, when the correction of the measured values of the velocity intensity is carried out, the diagram from Fig. 7.b) is obtained. The diagram shows that the values of axial component of the velocity at the widening ends have, as expected since the diverging of the flow, a sharp minimum, and the velocity in the centre of the widening is smaller than that in the tube axis out of the widening.

The profile of the horizontal component of the velocity, along the diameter of the cross section out of the widening, is uniform, which is shown in Fig.8.a). The Reynolds number at this cross section is close to 1500. In fig.8.b) we plot the measured dependence of the turbulence level versus the distance from the tube axes.

The measurement of the horizontal component of velocity along the diameter of the largest cross section in

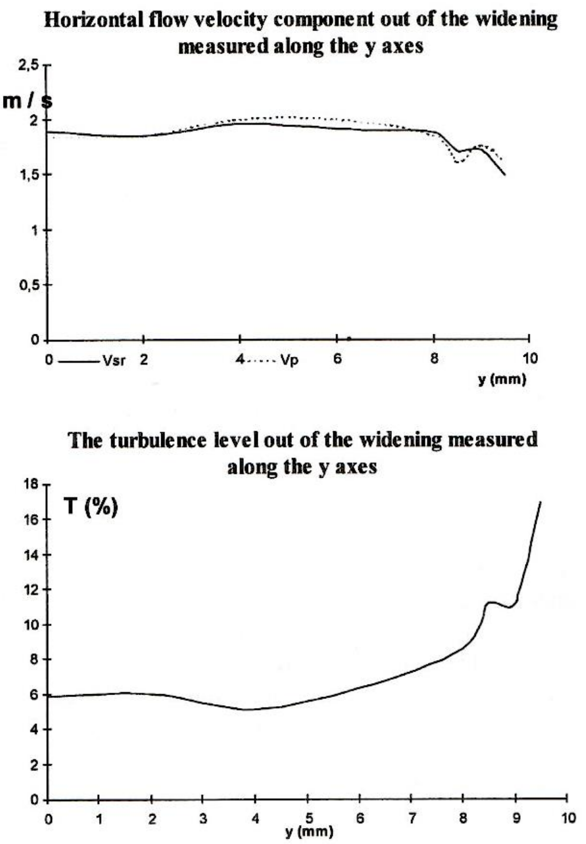

Figure 8.

the widening yielded the values presented on the diagram-Fig.9. by a dashed line. If the change of the angle under which the beams intersect is taken into account and upon taking into account the real positions of the measuring volume the values shown by the crosses on the diagram are obtained. In order to stress the regularity of that line, the distribution of the velocity according to Poiseuille's law is shown by a full line in the same diagram. This confirms that, the flow, which is turbulent in the narrow portion of the tube converts to laminar in the widening, as demonstrated by the applicability Poiseuille's distribution.

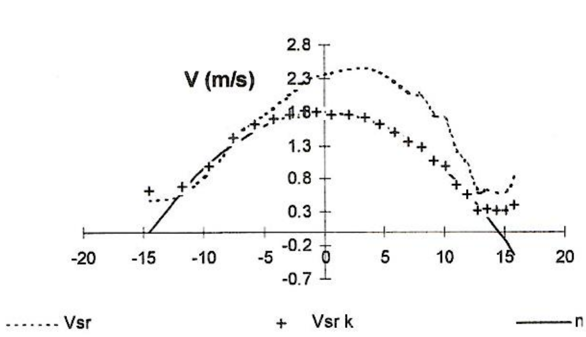

Figure 9. Horizontal velocity component values along the diameter of the largest cross section

Finally, the accuracy of the corrected values of the velocity is confirmed by the equation of continuity applied to the widest and narrowest cross sections.

In the vicinity of the tube wall the velocity does not fall to zero as expected, but rather tends to a constant value. In this region the level of turbulence rises at first, and then drops abruptely in the closest proximity of the wall.

5. CONCLUSIONS

By applying the LDA system the values of the flow velocity at a particular points, and through them the other characteristics of the flow field are obtained. The method requires specific conditions in order to secure standard accuracy of measurement. However, the absence of probes in the measuring volume and the very nature of the phenomenon in the basis of this method recommend it mostly because it does not disturbe the fluid flow neither mechanically nor thermally. The LDA method is suitable for work in turbulent flow fields, because, apart from the mean velocity it can determine the values of RMS of the velocity, i.e. the level of turbulence, temporal as well as spatial. The accuracy of the LDA measurements depends on many factors: the selection of particles serving as scattering centres, the configuration of the system, arrangement of receiving-transmitting equipment, adjustment of the system for the acquisition and processing of data. This paper deals with the refraction of applied laser beams, by tube walls, which can, in some configurations, significantly distort the measuring results, because it dislocates the measuring volume, change the calibration constant and measured velocity component. The causes of these distortions are explained and the principles of compensation, are given. Compensation made by the correction of the output data, is also presented. The corrected results agree with the expectations and thus confirm the exactness of the applied correction method.

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ANALIZA TOKA FLUIDA KROZ CEVI PROMENLJIVOG POPREČNOG PRESEKA POMOĆU LDA

S. Ristić, M. Srećković, J. Ilić

U radu su navedene mogućnosti laser Dopler anemometrije (LDA). Objašnjeni su problemi, koji se javljaju u primeni LDA kod cevi kružnog poprečnog preseka 1) stalnog i 2) promenljivog prečnika, usled prelamanja laserskog snopa. Izloženi su proračuni grešaka merenja, koje se javljaju zbog pomenutih problema i postupci korekcije rezultata merenja. Na kraju su predstavljeni rezultati primene tih korekcija.

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In this paper, the possibilities of laser Doppler anemometry (LDA) are stated. Problems, that appear in LDA application on circular cross section tubes of 1) constant and 2)varying diameter, due to refraction of laser beam. Calculations of measurement errors, for mentioned problems, and methods for the correction of the measurement results are exposed. Finally, the results of application of those corrections are presented.

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