THE NATIONAL STANDARD FOR VELOCIMETRY AND POSSIBILITIES FOR IT IN SERBIA

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Abstract: Velocimetry has a long tradition in Serbia. Anyhow, constant improvement of the laboratories calibration and measurement capabilities (CMC) is an ongoing effort. Serbia, although it has good capabilities in this field, still doesn't have a national standard for velocimetry. Reliable velocimetry is a starting point in various sectors of energy production, numerous industrial branches, health, educational, business and sport centers, as well as in residential buildings, and etc. Realization of this national standard would influence and improve national industry capabilities, energy efficiency in general, health and environmental protection procedures, climate analysis, forecasts and hydrology. Various international and national standards treat velocimetry, especially, as a tool in determination of the flow rate in closed conduits and open channels. This opens a whole new area of validation of the volume flow rate calibration in laboratory, as well as in situ. In this paper will be presented novel velocimetry techniques and their capabilities implemented in the Laboratory for turbulence and velocimetry at the Faculty of Mechanical Engineering. Here are presented following measurement techniques: multihole probes, hot-wire anemometry, laser Doppler velocimetry (three-component) and image-based velocimetry techniques (particle image velocimetry (PIV) and micro PIV). In the Laboratory are implemented stereo PIV and high speed stereo PIV. In addition to this, constant upgrading of the existing systems is followed by the development of the new techniques and procedures. These complex measurement techniques are employed in research of various flow phenomena, what will be presented in short.

Keywords: velocimetry, national standard, calibration, turbulence.

1. INTRODUCTION

In Republic of Serbia exists only two accredited laboratories by the Accreditation body of Serbia after the international standard ISO 17025 [1] and ISO 17713-1 [2] in the field of velocimetry.

Standard ISO 17713-1 describes the wind tunnel test methods for rotating anemometer performances. It is for analogue and digital anemometers. One of these two laboratories is, also, accredited, after the international standard WMO No. 8:2017 [3]. The same laboratory has the accreditation after the international standard ISO 16622:2002 [4] for sonic anemometers. Ranges and calibration and measurement capabilities (CMC) are specified in the scope of accreditation sheets provided by the Accreditation body of Serbia for each laboratory.

However, capabilities of the velocimetry in Republic of Serbia are far beyond these two laboratories, because there exist a number of wind and water tunnels, as well as expensive equipment in the scientific laboratories.

Here will be discussed possibilities and competencies of the Laboratory for turbulence and velocimetry (Laboratory) at the Hydraulic Machinery and Energy Systems Department (HMESD), Faculty of Mechanical Engineering (FME), University of Belgrade (UB), Belgrade, Serbia.

2. WIND TUNNELS IN THE LABORATIRY

In the Laboratory exists numerous wind tunnels of the open type, but here will be presented three main wind tunnels, used for probes calibration. They are presented in [5-10].

Design of the first wind tunel with the profiled Witoshinsky nozzle with the outlet diameter 145 mm is presented in [5-8]. Maximum velocity is 60 m/s. It can be concluded that in the indicated measuring cross-section velocity profile is uniform in the central region [8]. This is derived on the basis of the standard [2] demand that the air flow uniformity should be ± 1 % across the test section. It was, also, shown, on the basis of the Laser Doppler anemometry measurements, that the turbulence levels are below 2%.

The second wind tunnel is presented in details in [9-11]. It is designed and manufactured by the Lečić [9]. It is, again, of the open type with the profiled outlet nozzle with the outlet diameter of 30 mm [9-11]. The maximum air axial velocity is 38 m/s. “Speed uniformity in the calibration section is in the limit of satisfyingly 1%, which is experimentally proved. Average turbulence intensity in this section is around 0.5%.“ [11].

The third wind tunnel is, also, of the open type. It is Mini wind tunnel, by Testo, Germany, part No. 0554 0450. It is described in [12]. Three velocities can be set and that are: 2.5, 5 and 10 m/s. In [12] is presented a procedure for calculation of the uncertainty of a measurement.

The second and the third wind tunnels could be, also, used for in situ probes' calibration.

3. ORIGINAL CLASSICAL PROBES FOR 2D AND 3D VELOCITY FIELDS AND PRESSURE FIELD MEASUREMENTS

Original classical probes for measurement of the 1D up to 3D velocity fields and pressure fields are developed in the Laboratory for HMES and presented in numerous papers [5-11].

A set of original probes is developed by Benišek with the aim to determine the velocity and pressure fields [5, 6, 13]. Angle probe is used to determine the total velocity vector direction in swirl flow when the flow is considered to be quasy 2D dimensional and afterwards the is used the combined probe. It is directed in the angle, determined by the angle probe, and it measures the total velocity. Afterwards, the closed sleeve is attached, so the static pressure is measured. In this way is measured the two velocity components and the static pressure. In Figure 1a are presented total and static pressure distributions determined in the turbulent swirl flow in pipe.

a) b)

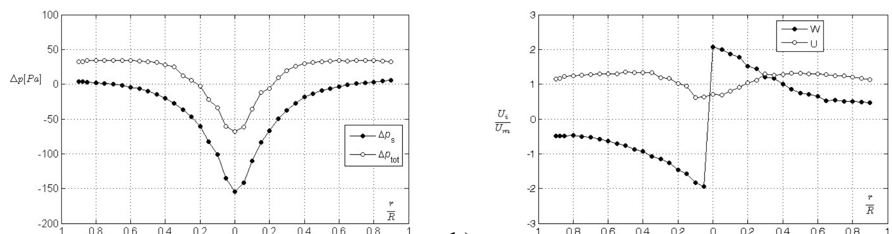


Figure 1: a) Total and static pressure distributions and b) Calculated axial and circumferential velocity components [14]

In Figure 1b are presented axial (U) and circumferential (W) velocity components distributions, calculated on the basis of pressure distributions, presented in Figure 1a.

More complex probe geometry – a Conrad probe is developed and manufactured in the Laboratory for HMES FME UB by Benišek. Authors Benišek M. and Čantrak S. have realized that Reynolds number influences probe calibration characteristics [15]. Universal calibration characteristic for measurement of the 3D velocity field and pressure field by use of the Cobra probe is developed [15,16]. This probe is very useful in investigations in complex turbulent flows generated by the turbomachinery.

In the Laboratory is recently introduced the new five hole fast response probe for measurement of the 3D velocity and pressure fields, presented in Figure 2. It has, also, complex geometry and pitch-yaw calibration procedure, but it could be used in the measurements of the nonstationary fluid flows, which widely occur in the technical systems. It has fast response sensors, up to 10 kHz, which enable good sampling rate, necessary for turbulence study.

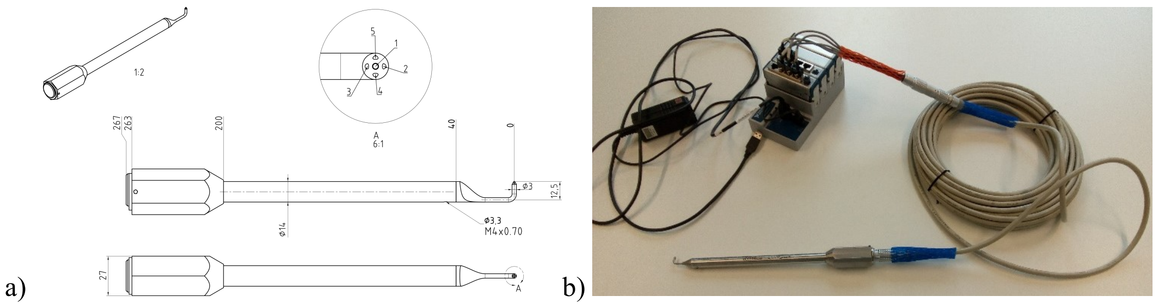


Figure 2: a) Five holes probe geometry and b) Probe connected with the data acquisition system [17]

4. HOT-WIRE ANEMOMETRY

Various types of hot-wire anemometry (HWA) probes are developed by Vukoslavčević for turbulent swirl flow investigations in the Laboratory. Their geometry, calibration and application is presented in [9, 10, 11, 18, 19]. HWA probe, named VP-NP, has three sensors and is presented in Figure 3a. Probe prongs are made of the stainless steel sharpen at the top to the size of 40 µm. Sensor of platinum alloy with diameter of 2.5µm is attached to their top.

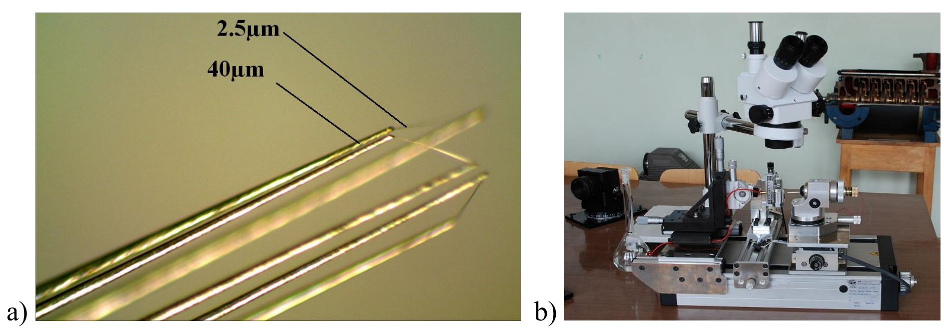


Figure 3: a) VP-NP probe under the stereo microscope and b) Patented HWA probe reparation device [19]

HWA probe reparation device is developed in the Laboratory and it is presented, in the operation mode, under the stereo microscope, in Figure 3b. It has 15 degress of freedom. It is used to attach the sensor to the prong top by welding with electrode [19, 20]. Welding generator for HWA probes by Dantec is used. So, various geometries of HWA probes could be repaired, from the industrial ones up to the specific, scientific ones.

In Laboratory exist, also, various geometries of the Dantec HWA probes, equipped with the adequate anemometry system.

5. LASER DOPPLER VELOCIMETRY

In Laboratory are applied two laser Doppler velocimetry (LDV) systems and they work in backscatter mode. The first one is the Flow Explorer Mini LDA, by Dantec, Denmark. It is one-component LDV system, with the following main characteristics: 1) signal processor BSA F60, 2) laser power: 30 mW, 3) laser wavelength: 660 nm, 4) focus: 300 mm and 750 mm, 5) beam diameter: 5 mm, 6) beam distance: 60 mm, 7) maximum speed: 100 m/s and 8) measurement uncertainty: 0.1%. It has Bragg's cell and uses BSA Flow Software for data acqusition and processing. This one is flexible and could be employed, also in situ. The Flow Explorer Mini LDA is well described in [12, 19].

The second LDV system is more complex three-component LDV system, by TSI, USA, with 1D, 2D and 3D velocity probes. The last one has five beams. It has laser Innova 70C-5, water cooled. FlowSizer 64 is used for data acqusition and processing. The whole system is explained in details in [21]. Sources of the measurement uncertainty for the performed measurements are explained and quantified in [21, 22]. It is in the interval 0.1 to 0.5%.

System is equipped with the three-axis traversing system by ISEL, with the travelling length: in x- and y-direction: 1090 mm and in z-direction: 1590 mm. It is, also, described in details in [21].

LDV and Particle image velocimetry systems use the following seeding systems in the Laboratory: 1) Fog generator model Z-3000II by Antari and 2) Six-jet atomizer 9306. The first one uses INVISION Dense Smoke Fluid, based on the water, while olive oil is used in the second case. Both systems are described in details in [12, 19, 21].

In order to illustrate some LDV measurement results in the turbulent swirl flow in pipe behind the axial fan, following diagrams are presented. In Figure 4a are presented time averaged velocities (U-axial, V-radial and W-circumferential) distributions. Characteristic distributions for the Rankine type vortex, generated by the axial fan with the twisted blades, are obtained (Figure 4a).

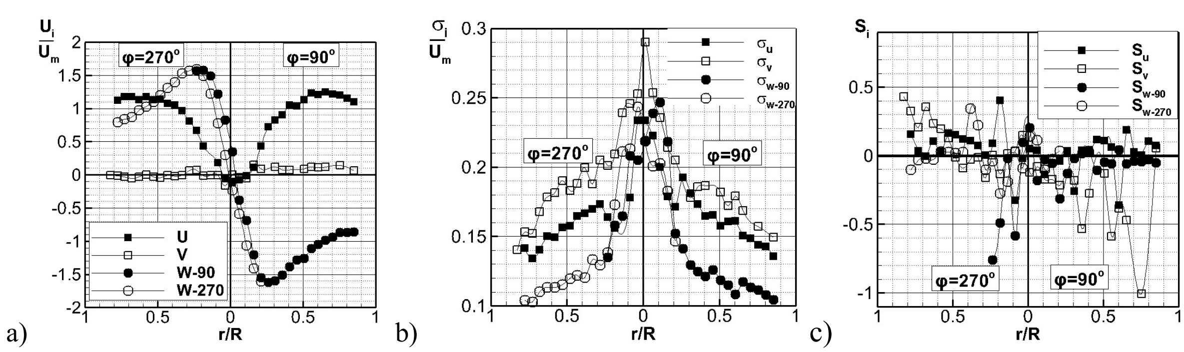


Figure 4: LDV results a) Time averaged velocities, b) Turbulence levels and c) Skewness factors for all velocities [23]

On the basis of the high sampling rate, obtained by the LDV system, various statistical characteristics of the turbulent swirl flow could be obtained. In Figure 4b are presented turbulence levels experimentally obtained for the same velocity filed presented in Figure 4a. The highest levels of turbulence are achieved in the vortex core region. Statistical moments of the higher order could be, also, obtained on the basis of the LDV results. In Figure 4c are presented skewness factors for all fluctuating velocities. "It is obvious that all distributions are very non-uniform and skewness factors differ from adequate values for normal, i.e. Gaussian probability distribution, where $S_u=S_v=S_w=0$." [23].

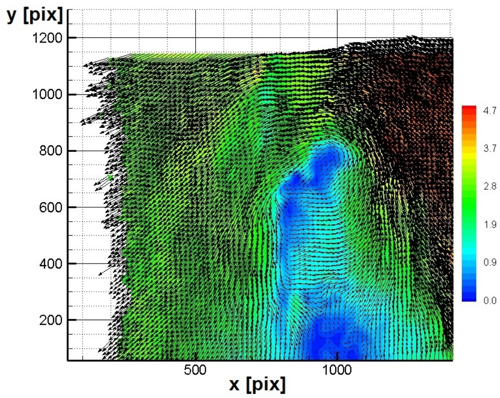
Problems of dislocation are, also, thoroughly discussed in [19, 24, 25] and this should have in mind while performing LDV measurements through the transparent walls. The more careful one should be if performing measurements in the water flows. The example of these measurements in the pump system is presented in [26].

6. PARTICLE IMAGE VELOCIMETRY

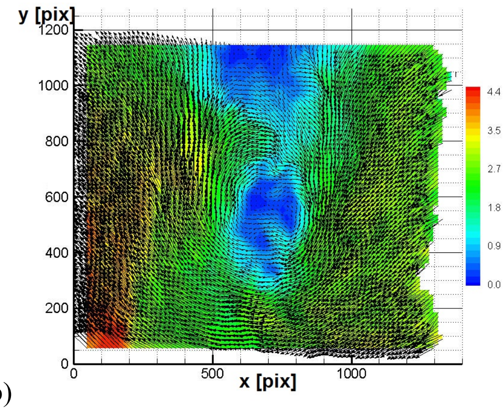
Particle image velocimetry (PIV) is introduced in Republic of Serbia, and widely, in region, in 2007. by official installation of the first stereo PIV system in the Laboratory. The first stereo PIV system, by TSI, USA has the following components and characteristics: 1) laser Nd:YAG, model Laser Pulse Solo Mini Dual Nd:YAG, by New Wave, model YAG30-15, maximum power 30 mJ/pulse, laser wave length 532 nm, and operating frequency 15 Hz; 2) Laser pulse computer controlled synchronizer model 610034. Its time resolution is 200 ns; 3) spherical lenses with focal lengths of 500 and 1000 mm, as well as cylindrical lenses with the focal lengths -25 and -15 mm; 4) two cameras with CCD (charge-coupled device) sensors, model Power View Pulse 2MP, No. 630057, with resolution 1660 x 1200 pixels, low noise level, 12-bits exit, 32 fps, lens 50 mm/F1.8 and 64-bits interface; 5) calibratiom target; 6) data acquisitions and processing software INSIGHT 3G; 7) Tecplot software for data postprocessing and 8) Scheimpflug mechanism for cameras for stereo measurements. This systems is described in details in [12, 19, 27].

The second system, employed in the Laboratory, is the Stereo high frame rate (time-resolved) PIV system (TR PIV) or High speed stereo PIV system (HSS PIV). It is, again, by the TSI, USA and has the following main components: 1) impulse laser Nd:YAG with high working frequency up to 40 kHz, model Hawk-Duo 532-120, by Quantronix, with guaranteed min power of 120 W at 10 kHz, laser wave length is 532 nm, water cooled, with adequate optics and light arm; 2) two cameras model FASTCAM SA1.1, by Photron, USA, with high sampling rate, internal memory of 8 GB, adequate lenses and mechanism for Scheimpflug arrangement; 3) synchronizer; 4) calibration target with dimensions 300 x 300 mm; 5) software INSIGHT 4G for data acquisition, processing and postprocessing. This system is, also described in [12].

SPIV measurement uncertainty for turbulent swirl flow in pipe is discussed in [12, 19, 27]. After gathering the data of good quality and by applying the adequate algorithms, and if the number of interpolated velocity vectors is lower than 5% than the experimental resulst are acceptable. This is repeated for each pair of photos. Photo processing in pixels lead to the results presented in Figure 5.



a)



b)

Figure 5: Velocity vectors in pixels for the a) left and b) right camera [12, 19]

In the vortex core region both cameras provide small movement and it is approximately 0.4 pix, while in the rest of the cross-section it is about 4 pix. Used correlation techniques [28] could estimate movements up to 0.1 pix, or even to 0.05 pix, due to hardware. So it could be calculated that in this case, measurement error is in the interval from 0.05/4·100=1.25% in the outer region (more precisely, shear layer and sound flow regions) up to the 0.05/0.4·100=12.5% in the vortex core region. This is the consequence of recording the whole (pretty big) region with the same time distance between the laser pulses. So, it could be concluded that particle movement error is dominant. The total measurement uncertainty is derived by taking into account all influences [19, 28]. This issue occupies attention of researchers worldwide and a progress is introduced in new versions of software [29].

All these issues, make a focus on the fact that only well educated researchers with the adequate equipment could provide experimental results of high quality.

In Laboratory is, also, made a progress in introducing the Micro PIV and development of the low cost PIV systems, of micro and regular size [30, 31].

7. CONCLUSIONS

On the basis of the facts presented in the text, the following conclusions could be derived in supporting the idea of establishing the Serbian national standard and Designated institute for velocimetry:

- Laboratory for turbulence and velocimetry has established numerous velocimetry techniques, from classical probes, up to the newest generations of the fast responsive multihole probes, and modern optical velocimetry techniques, such as LDV and PIV,
- Constant scientific progress is made in the Laboratory, what is followed by numerous important scientific references,
- Well trained persons work and collaborate with the Laboratory,
- It has expensive and well used equipment,
- Research in the Laboratory is supported through the scientific projects by the Ministry of Education, Science, and Technological Development, Republic of Serbia and the Science Fund of the Republic of Serbia,
- It has good collaboration with other national and international laboratories in the fields of turbulence and velocimetry,
- Laboratory has a good collaboration, also, with industry, and etc.

ACKNOWLEDGEMENT

This research was supported by the Science Fund of the Republic of Serbia, Program DIASPORA, Project “Flow investigation within innovative designed regulative element of the control valve”, #6385782, acronym FIDE and by the Ministry of Education, Science, and Technological Development, Republic of Serbia, grant number 451-03-68/2022-14/200105, subproject TR35046, what is gratefully acknowledged.

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