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Influence of blockage effect on measurement by vane anemometers

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Abstract. The article deals with influence of blockage effect caused by vane anemometer in the wind tunnel by measurement via this anemometer. The influences will be represented by correction coefficient. The first part of this article is focused on the design of the impeller of vane anemometers. The impellers are printed on 3D printer with variable parameters. The anemometer is fixed in an open section of the wind tunnel with closed loop and the velocity profile is measured by Laser Doppler velocimetry (LDV) in front and behind it for all impellers. The experimental data are compared with the numerical simulation in OpenFOAM. The results are correction coefficients.

1 Introduction

Automatization in companies increases the claims on measurement, either operating measurement or testing measurement. This fact puts emphasis on accuracy of measurement and low uncertainty of measurement. The gauges of common units are on higher technical level than in old days. Now it is necessary to focus on the way how the gauges are used and on the measurement as a systematic process with many conditions. For example vane anemometers have significant differences between measurement inside the pipe with small diameter or in the open space. In the pipe a phenomena called blockage effect is created and the value on the gauge is not correct.

This article is focused on blockage effect created in wind tunnel during the calibration of anemometer. In this case testing gauge is putted in the measuring space and indicated value is compared with the value of primary standard. In fact the blockage effect is created in all cases but influence on the result is not significant in all cases. It depends on many conditions (diameter, blades, velocity, method of measurement etc.). For reducing the effect it is necessary to carry out the correction. The negligence of blockage effect may have significant influence on the result of calibration.

The aim of this article is to carry out the comparison of numerical simulation with experimental data. Validated numerical simulation will be used for calculation of correction factor for another design of anemometers (blades, diameter etc.).

2 The principle of calibration

The principle of calibration the anemometers is based on comparing the velocity of flow measured by testing gauge with velocity measured by primary standard. The calibration in CMI (Czech Metrology Institute) is carried out in close loop aerodynamics tunnel with open measuring space (Fig. 1). This tunnel was developed by Germany company Westenberg Engineering.

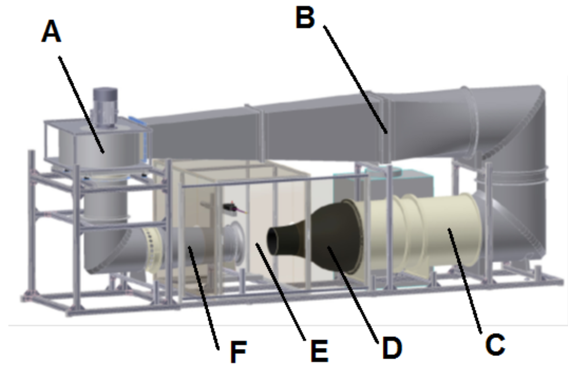

Fig. 1. Design of tunnel in CMI.

The legend of the elements (see figure 4) is the following: A – fan, B – heat exchanger, C – honeycomb, D – convergent nozzle, E – measuring space, F – diffuser.

The length of measuring space is 63 cm and the diameter of the nozzle is 45 cm. The area contraction of the nozzle is 6 times. The velocity profile on the outlet of nozzle is flat (like piston profile). The intensity of turbulence is maximal 3 % for the lowest speed and maximal 0.3 % for rest speed. The velocity of air can be set up in velocity range of (0.3 – 50) m/s. The expanded uncertainty type B of measurement in velocity range (0.3 – 5) m/s is (0.01 m/s + 0.3% of measured value) and in velocity range of (5 – 50) m/s is 0.5 % of measured value. The set-up of the velocity can be carried out in two ways. First way is manual mode (with fix rotation speed). The second way is automatic mode with

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feedback. The feedback is based on measuring the velocity by Prandtl tube which is also located in measuring space. The rotation speed is set up based on the comparison of measured value by Prandtl tube and velocity value in program for automatic mode.

The primary standard in this tunnel is LDA (Laser Doppler Anemometer). It is one direction Nd:YAG laser with wavelengths 532 nm and the laser power 75 mW. The focal length is 500 mm. As the particles for measurement DEHS (di-ethylhexyl-sebacate) were used.

For measurement of velocity profiles can be used traverser motion system in whole three axes.

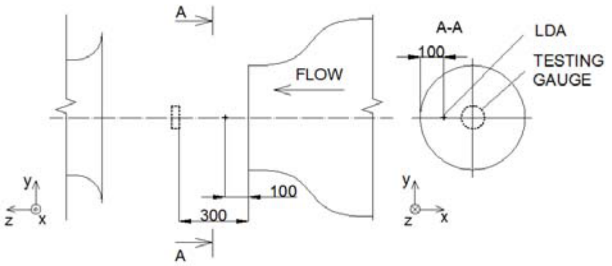

Fig. 2. The measuring space.

The testing gauge is fixed in the middle of the measuring space (Fig. 2) and the value of primary standard is measured 10 cm behind the nozzle through. This composition is necessary to minimalize the blockage effect. For this case it is important to know the correction factor for position (difference between the middle of the measuring space and place where the primary standard measures). Another necessary correction is the correction of influence of blockage effect (aim of this article).

Thermal probes, Prandtl tubes and vane anemometers are calibrated very often. The rest of the article is focused only on the vane anemometers which are suitable for studying of blockage effect due to their shape and proceeding.

3 Design and construction of the testing anemometer

The tested anemometer wasn't chosen from serial manufactured anemometers but it was made bespoke. For the construction a 3D printer was chosen which created product of good quality for testing blockage effect for good price. The advantage of the design of the anemometer is the possibility to change the shape of the impeller (shape of blades, diameter of the impeller, angle of pitch of the blades, width of impeller etc.).

The shape of main body was derived from the conception of the renowned manufacturers of anemometers. It consists of half ellipsoid with ball-bearing fasten inside. There are five arms coming out from the ellipsoid into the ring which creates cover of the impeller. The main body is divided into two halves which enables changing of the impeller. Both halves fit into each other due to indentations or mirror indentations. The main body is created by resistant ABS plastics. Bottom of the main body contains screw-thread for fixing of the monopod and hole for placement of optical sensor of rotations. The impeller is made of black PLA plastic which is more suitable for printing of difficult shaped parts. The impeller includes 6 blades. The impeller was made in three different variants with different angle of the blades of 20°, 30° a 40° (Fig. 3).

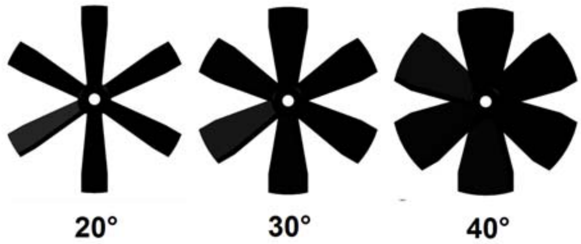

Fig. 3. The impeller variants.

Other versions of impellers were created with different diameters of 50 mm, 100 mm and 150 mm. Shaft was made of carbon rod which is tough enough and easy to machine. Detecting of the rotation of the impeller was carried out with optical part which was located in the main body of the anemometer. The optical part evaluated average value of frequency of rotation for 1 s, 5 s and 30 s. This was carried out with the help of the Arduino desk and the program which is based on the knowledge of the number of blades. Fig. 4 shows the assembly of the anemometer.

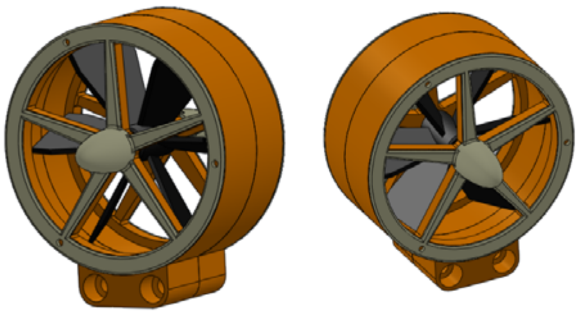

Fig. 4. The assembly of anemometer.

4 Experiment

4.1. Setup

The measurement was necessary to carry out with manual mode (set up fix rotation speed) of fan to avoid changes of rotation speed caused by blockage effect. In case of automatic mode this effect would change rotation speed because in space where the Prandtl tube is fixed is another velocity via blockage effect. This fact might devaluate the whole experiment.

The velocity was measured on grid points. The grid includes 10 points on x axis and 10 points on y axis. The distance between points was 50 mm (Fig. 5). This grid was measured in 5 surfaces beginning 100 mm from through of nozzle and distance between the surfaces was 100 mm.

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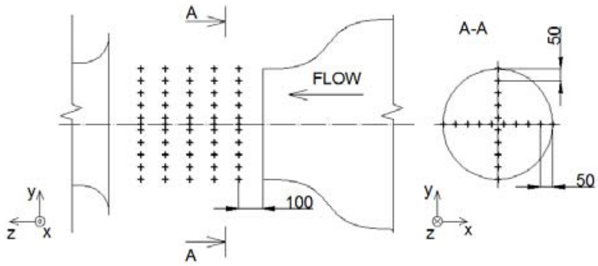

Fig. 5. The grid points for measurement.

The measurement began without anemometer to measure initial conditions (velocities of air). The measurement was repeated 10 times to determine uncertainty. The measurement continued with fixed anemometer. The result was difference between average velocities measured with and without anemometer.

4.2. The results

By the measurement in boundary points of grid high value of turbulence was indicated. This fact was caused by friction between stream of air from nozzle and claim air inside measuring box. These points were removed from results.

The difference of velocity profiles in each surface is shown on Fig. 6. In this case anemometer with diameter 50 mm and angle of blades 20° was used; velocity was 5 m/s. On the graph only left side of the velocity profiles is shown because monopod for fix anemometer was on the opposite side and velocity was affected.

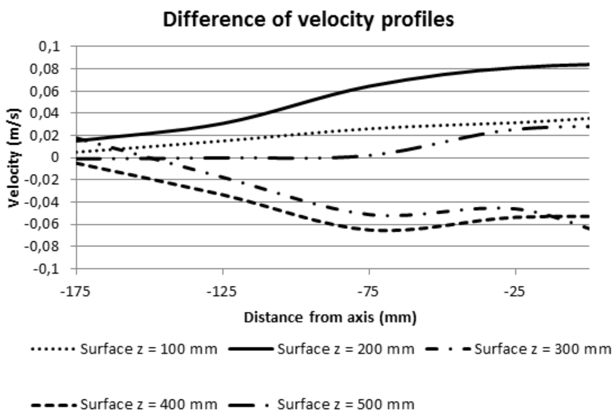

Fig. 6. Difference of velocity profiles in each surface.

Next graph shows the comparison between variable angle of blades for velocity of air 5 m/s and for diameter of anemometer 50 mm. The influence of angle of blades on the result is shown on the graph (Fig. 7). The angle of blades influences the magnitude of blockage effect and the size of space affected by blockage effect. This result was expected because the angle of blades influences permeability of air flow through the anemometer. Velocity difference between impeller 20° and impeller 40° in tracking point was 0.0035 m/s. It is necessary to take into account the influence of angle of blades on magnitude of correction of blockage effect or increase the uncertainty of measurement.

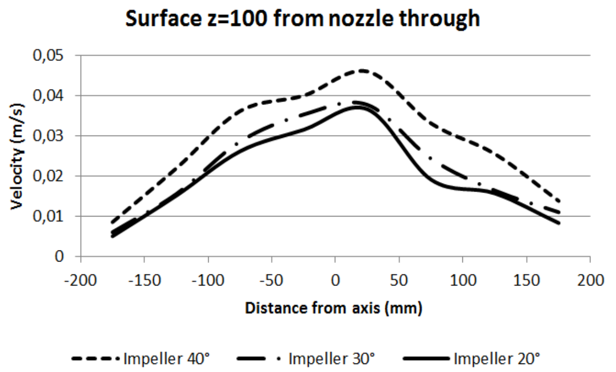

Fig. 7. Difference of velocity for all variables of angle of blades.

The correction and uncertainty is shown in tables bellow. The results are for anemometer with diameter 50 mm (Table 1), 100 mm (Table 2) and 150 mm (Table 3) and for variable velocities.

Table 1. Diameter of impeller 50 mm.

Velocity (m/s)	Correction (m/s)	Uncertainty (m/s)
1	0,002	0,002
3	0,000	0,002
5	0,001	0,002
10	0,001	0,003
20	0,001	0,006
30	0,005	0,009
40	0,002	0,012
50	0,000	0,015

Table 2. Diameter of impeller 100 mm.

Velocity (m/s)	Correction (m/s)	Uncertainty (m/s)
1	0,002	0,002
3	0,000	0,002
5	0,001	0,002
10	0,002	0,003
20	0,002	0,006
30	0,006	0,010
40	0,002	0,012
50	0,000	0,015

Table 3. Diameter of impeller 150 mm.

Velocity (m/s)	Correction (m/s)	Uncertainty (m/s)
1	0,002	0,002
3	0,000	0,002
5	0,001	0,002
10	0,002	0,003
20	0,003	0,007
30	0,007	0,011
40	0,003	0,013
50	0,000	0,017

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5 CFD simulation

5.1. Introduction and geometry

The aim of this part was to simulate the flow around the anemometer. The results were used for comparison between experimental data and simulation and will be used for the creation of the correction table for more variables of anemometers. The geometry is shown on Fig. 8. The air flows from left side to right side. On the inlet the velocity is pre-described as a constant value.

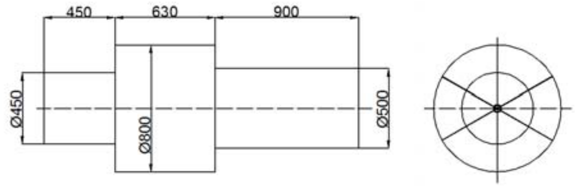

Fig. 8. Geometry of simulation.

5.1. The mesh, boundary condition, solver

Meshes have been realized by using a capability of OpenFOAM called blockMesh. The setup is more difficult than in commercial programs but the mesh is fully in the user's hands. The refinement of the mesh was carried out near the anemometer and inside the anemometer. Table 4 shows the details about the mesh.

Table 4. The mesh properties.

Mesh number	Cells
1 / 3D	2 431 904
2 / 3D	4 376 704
3 / 3D	8 041 728

The numerical problem was solved as a steady, viscous, turbulent, incompressible flow by a simpleFoam solver with k-ε and k-ω models of turbulence. Converged results were those results which had residuals lower than 10^{-10} for velocity in z axis and 10^{-8} for velocity in y and x axis.

5.2. Mesh convergence and turbulence model

As a final mesh the mesh number 3 was chosen because next refinement the mesh does not influence the result. Numerical simulation with two different turbulence models was carried out for this mesh. The result from surface 100 mm from nozzle through is shown on Fig. 9.

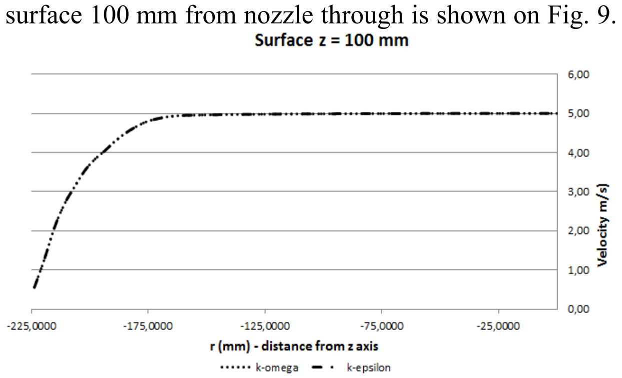

Fig. 9. Velocity profile (5 m/s), z = 100 mm from nozzle through.

The result is very similar for all surfaces.

5.3. The results

The simulations were carried out only for velocity 5 m/s. The boundary conditions and initial data were being changed in this case to get conformity between numerical model and experimental data. The conformity is received if the results from numerical simulation lay in area of uncertainty of measurement. The difference between numerical simulation and experimental data was 30 % (Table 5). In the table the difference between flow with and without the anemometer is stated.

Table 5. Comparison numerical simulation and experimental data.

Velocity (mm/s)	Numerical simulation (mm/s)	Experimental data (mm/s)
5 000	0,7	1,0

6 Conclusion

Phenomena called blockage effect and problems connected with this effect were explained in first part of the article. Integral part contains principle of calibration and testing facility for experiments.

In the next part the design of testing anemometer was shown. The design of anemometers was derived from the conception of the renowned manufacturers of anemometers but it is adjusted so that it enables usage of another impellers. It also contains part for detecting of the rotation. The values from the sensor will be used as boundary conditions for simulations.

Experimental part of this article shows the extent of area around anemometer influenced by blockage effect. The results from comparison of different types of impellers show that blockage effect depends on anemometer's permeability of air.

Final part of this chapter shows the correction table for one type of anemometer, including uncertainty which must be added to the measurement. The part dealing with the simulation is using only steady solver. This solver is faster for calculation but it does not reflect the processes inside of the case. The difference between the experiment and numerical simulation is 30 %. It is necessary to use unsteady solver with AMI interface in the future and add the rotation of impeller. This solver is time demanding because it needs dynamics mesh which is recalculated in each time step.