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NUMERICAL AND EXPERIMENTAL DETERMINATION OF FLOW UNIFORMITY AND TURBULENCE INTENSITY IN AN OPEN LOW-SPEED WIND TUNNEL WITH A CLOSED TEST SECTION

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ABSTRACT

Cup and propeller anemometers are the most frequently used meteorological instruments for the measurement of mean wind speed in the near surface layer. These general purpose anemometers are used extensively for meteorology, aviation, air pollution, wind energy and numerous other applications. In order to have a worldwide uniform set of test methods to define the characteristics of cup and propeller anemometers standard ISO 17713-1 was developed.
This test method requires a wind tunnel with a relatively flat velocity profile. The air flow in the wind tunnel shall be uniform to within ± 1 % across the test section volume occupied by the cups or propeller of the anemometer under test. At air speeds greater than 10 m/s, the wind tunnel shall have an axial turbulence intensity level of less than 2 % as measured at the anemometer test location.
The paper describes the procedures of numerical and experimental determination of flow uniformity and turbulence intensity in an open low-speed wind tunnel with a closed test section at Faculty of Mechanical Engineering in Zenica.
Keywords: wind speed, anemometer, wind tunnel, flow uniformity, turbulence intensity

1. INTRODUCTION

One of the renewable energy sources that has a large available energy potential is wind. Wind is the air masses flow in the atmosphere that is result of uneven Earth's surface warming by solar radiation. The fact which tells that exploiting only one percent of the available energy potential of the wind meets the energy needs of the entire planet, clearly indicates why so much resources are being invested in researching new and more efficient ways to exploit wind power. The power which can be extracted from a free-stream airflow by an energy converter increases with the third power of the wind velocity. Therefore, it is very important to have reliable information about the wind speed at a particular location. Wind resource assessment is the process by which wind power developers estimate the future energy production of a wind farm. To estimate the energy production of a wind farm, developers must first measure the wind on site.
Cup and propeller anemometers are the most frequently used meteorological instruments for the measurement of mean wind speed in the near surface layer. These general purpose anemometers are used extensively for meteorology, aviation, air pollution, wind energy and numerous other applications. In order to have a worldwide uniform set of test methods to define the characteristics of cup and propeller anemometers standard ISO 17713-1 was developed.

2. WIND TUNNEL PROPERTIES ACCORDING TO ISO 17713

Part 1 of ISO 17713 describes wind tunnel test methods for determining performance characteristics of rotating anemometers, specifically cup anemometers and propeller anemometers. These test methods require a wind tunnel with a relatively flat velocity profile. The air flow in the wind tunnel shall be uniform to within ±1% across the test section volume occupied by the cups or propeller of the anemometer under test. At air speeds greater than 10 m/s, the wind tunnel shall have an axial turbulence intensity level, measured at the anemometer test location, less than 2% for averaging period up to 1 minute [2]. The axial turbulence intensity level is equal to the standard deviation of the mean wind tunnel air speed divided by the mean wind tunnel air speed. Flow uniformity and turbulence intensity can be measured by a hot wire anemometer, a laser Doppler anemometer or other equally sensitive air flow measurement instrument [1].

2.1 Classification of wind tunnels

The basic air tunnels selection is according to the speed of air flow around the model. According to this criterion, there are subsonic and supersonic tunnels. There are two basic types of subsonic air tunnels (open and closed) and two basic configurations of work sections (open and closed work sections). An open low-speed wind tunnel with a closed test section at the Mechanical Engineering Faculty in Zenica is shown on Figure 1. In these tunnels, the air follows the straight line path from the input section (1), through the convergent nozzle (2) to the working section (3), passes through the diffuser (4) and exits from the air tunnel through the drive section (5).

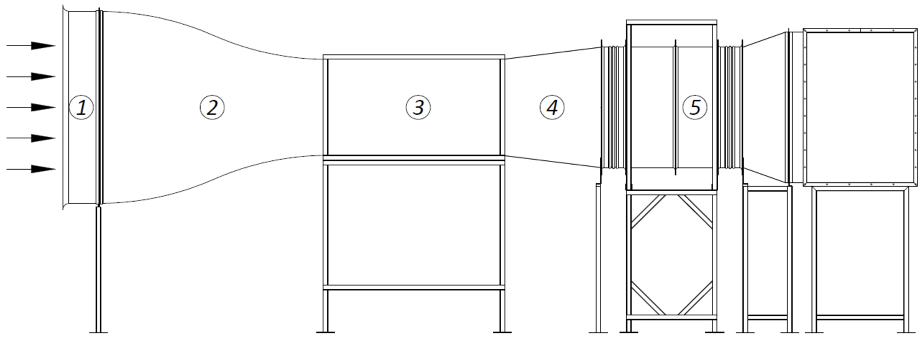

Figure 1. An open low-speed wind tunnel with a closed test section.

The drive section consists of the axial fan CC 1004 T 11kW VS-10-27 manufactured by Dynair. The nominal diameter of this fan is 1 m. The fan is capable to produce a volume flow of 50,000 m3/h and provides an output air velocity of 18.85 m/s. The engine powered by the fan is integrated into the fan itself and its maximum power is 11.00 kW. Variable frequency converter with a step of 0.01 Hz in the range of 0-50 Hz control the speed of the engine, and therefore the speed of the air at the exit of the fan. The working section is a square cross sectioned, dimensions of 800x800mm and its 1500mm long.

3. NUMERICAL DETERMINATION OF FLOW UNIFORMITY

Dimensions of the test section volume occupied by the cups of the anemometer under test (Figure 2) are 180x180x30 mm. According to determine the flow uniformity in observed volume, air flow analyzes are performed in SolidWorks Flow Simulation.

Figure 2. Three-cup anemometer.

Figure 3. Hot wire anemometer.

SWFW allows us to simulate a fan as an ideal device creating a volume (or mass) flow rate. In this case, option ***Internal Fan*** is used. This type of fan simulates an internal fan within the model, with one selected set of faces acting as the inlet and other set acting as the outlet. Since both sides of an Internal Fan are in contact with the fluid within the computational domain, the fluid static pressure difference between the sides governs fluid passage through the fan in accordance with characteristics of the selected fan. The user can either select an existing fan from the Engineering Database, or create a user-defined fan by specifying its parameters. In our case, as a fan type, an axial fan is selected, which characteristics are determined by a fan curve that represents the volume or mass flow dependence of the pressure difference at the inlet and outlet of the fan. In addition, this type of boundary condition allows that the size and speed of the fan rotor be defined. In this way, it is possible to simulate the swirl flow caused by the fan.

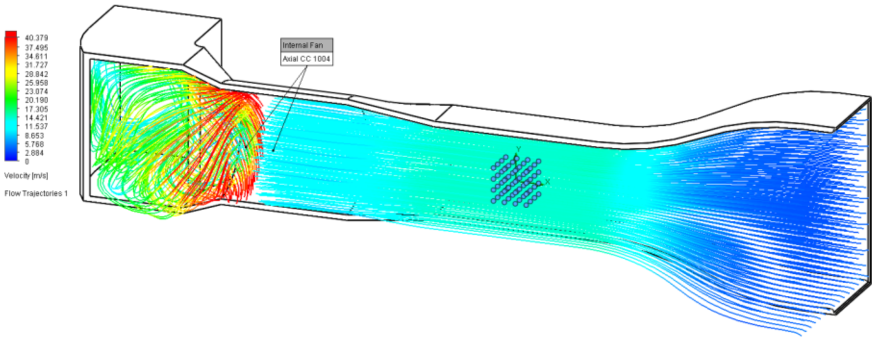

Figure 4. Flow trajectories and specified points inside the Computational Domain.

Four analyzes with different volume flow at the input section were performed. The inlet volume flow is determined based on the speed that is desired in the working section of the air tunnel. Using the Point Parameters option, 64-point speed values were analyzed in the central part of the work section. With these 64 points, a volume of 300x300x300 mm is covered. Table 1 shows the maximum and minimum values of the calculated speeds in the observed points for the four different boundary conditions. On the basis of the obtained results, it can be concluded that all calculated speed values do not deviate from more than 1% of the calculated average value of the velocity.

Table 1. Results of the computed numerical simulations.

Simulation	1	2	3	4
Inlet volume flow [m^3/s]	7,68	8,96	10,24	11,52
Mean air speed [m/s]	12,008499	14,015018	16,016284	18,021824
Maximum air speed [m/s]	12,035400	14,046173	16,049520	18,059757
Deviation from the mean value [%]	0,224	0,222	0,207	0,210
Minimum air speed [m/s]	11,979204	13,981968	15,979648	17,982694
Deviation from the mean value [%]	-0,245	-0,236	-0,229	-0,218
Total deviation [%]	0,469	0,458	0,436	0,428

4. EXPERIMENTAL DETERMINATION OF TURBULENCE INTENSITY

Hot wire anemometer was used to measure the flow velocity in a 300x300x100 mm volume in the central part of the working section. Measurements were performed at 32 points for four different speed values. The variable frequency converter is set to four frequency values: 30, 35, 40 and 45 Hz.

At each control point, at each air flow velocity, measurements were performed for a one minute period of time. Table 2 shows the results obtained for experiments conducted at 40 Hz frequency. A graphic representation of the turbulence intensity for all four air flow speeds is given in Figure 5. It can be seen that the turbulence intensity at any control point does not exceed the value of 2%. According to this, it can be concluded that the analyzed air tunnel meets the standard criterion related to turbulence intensity.

Table 3 shows the maximum deviations of the measured speed values in relation to the average value. It can be seen that the measured values deviate by more than ± 1% and that the flow is not uniform within the limits specified by the standard in the observed zone.

Table 2. Computed results at the 40 Hz frequency.

	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8
Standard deviation	0,090976	0,037324	0,100165	0,086554	0,107711	0,094769	0,079683	0,085137
Mean air speed [m/s]	16,488783	16,433033	16,612117	16,584683	16,167117	16,267550	16,212217	16,376900
Turbulence intensity	0,55%	0,23%	0,60%	0,52%	0,67%	0,58%	0,49%	0,52%
	Point 9	**Point 10**	**Point 11**	**Point 12**	**Point 13**	**Point 14**	**Point 15**	**Point 16**
Standard deviation	0,159495	0,213723	0,142190	0,129387	0,095179	0,165435	0,146169	0,119337
Mean air speed [m/s]	16,727650	16,730233	16,427550	16,255883	16,787350	16,791400	16,424467	16,380883
Turbulence intensity	0,95%	1,28%	0,87%	0,80%	0,57%	0,99%	0,89%	0,73%
	Point 17	**Point 18**	**Point 19**	**Point 20**	**Point 21**	**Point 22**	**Point 23**	**Point 24**
Standard deviation	0,134281	0,157191	0,086768	0,093354	0,149174	0,146667	0,124743	0,094311
Mean air speed [m/s]	16,463600	16,612467	16,433917	16,433750	16,280683	16,323983	16,235800	16,168983
Turbulence intensity	0,82%	0,95%	0,53%	0,57%	0,92%	0,90%	0,77%	0,58%
	Point 25	**Point 26**	**Point 27**	**Point 28**	**Point 29**	**Point 30**	**Point 31**	**Point 32**
Standard deviation	0,225655	0,193296	0,193444	0,286854	0,325406	0,189815	0,177225	0,221004
Mean air speed [m/s]	16,095000	16,255567	16,320800	16,635117	16,495633	16,331250	16,306517	16,182733
Turbulence intensity	1,40%	1,19%	1,19%	1,72%	1,97%	1,16%	1,09%	1,37%

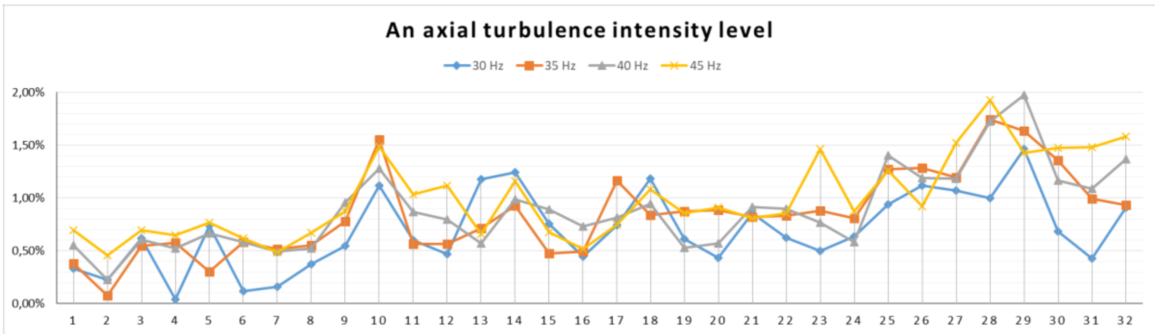

Figure 5. Graphic representation of the turbulence intensity of four air flow speeds

Table 5. Maximum deviations of the computed speeds in relation to the average speed.

Frequency [Hz]	30	35	40	45
Mean air speed [m/s]	12,305938	14,329090	16,413863	18,536647
Maximum air speed [m/s]	12,683933	14,828650	16,791400	19,080500
Minimum air speed [m/s]	12,055167	14,027750	16,095000	18,066783
Total deviation [%]	5,11%	5,59%	4,24%	5,47%

5. CONCLUSIONS

This paper describes the procedure of numerical and experimental determination of flow uniformity and turbulence intensity in an open low-speed wind tunnel with a closed test section at the Mechanical Engineering Faculty in Zenica. The results of the computed numerical simulations, in order to determine the uniformity of the flow, deviate in relation to the values obtained by the experimental path. The reason for this may be found in the fact that time independent numerical simulations were conducted while experimental tests were performed within a one-minute period of time. Uniformity of flow in the central zone of the working section is not within the allowed limits and in the zone of 300x300x100 the tested air tunnel does not meet the requirements of the standard. It is necessary to repeat measurements in a narrow zone corresponding to the volume occupied by the cups of the anemometer under test and determine the uniformity of the flow in that area. The turbulence intensity is less than 2% in the tested zone, which means that the air tunnel meets this standard defined criterion.

6. REFERENCES

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