Mean and turbulent experimental airflow inside a vane separator

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Abstract - An experimental study of the mean and turbulent experimental air flow inside a vane separator is made. Experimental techniques are used in air velocity evaluation.

Two different inlet air velocity values are used in order to evaluate the airflow topology inside a vane separator. The experimental study is done inside a vane separator system constituted by zigzag and semi-circular deflectors, built in stainless steel, placed inside an experimental module built in Perspex.

Air velocity fluctuations, for two different airflow values, are measured. The air velocity fluctuations, using hot-wire anemometry, are measured inside the zigzag and semi-circular deflectors. The air velocity fluctuations is used to evaluate the mean air velocity, the air velocity root mean square, the air turbulence intensity, the air velocity fluctuation equivalent frequencies and the air velocity fluctuations frequencies. In the air velocity equivalent frequencies the power spectra is used.

Keywords— Experimental methods; Internal airflow; Vane separator; Air velocity fluctuations; Hot-wire anemometry.

I. INTRODUCTION

Vane mist eliminators are among the most effective devices used to separate liquid from a gas flow. Separation efficiency of these devices is largely dependent on the gas velocity, vane spacing and vane turning angles [1].

Vane mist eliminators are the devices that can effectively remove entrained liquid from a gas flow, usually by inertial impingement [2]. In these eliminators, the wavy vanes (zigzag shaped plates) cause the gas to move in a zigzag manner between pairs of them. The liquid drops cannot follow these changes in the direction due to their higher inertia. Thus they impinge, adhere on the solid surfaces, coalesce and, when the amount of liquid is sufficiently high, form a film which drains away under gravity [1], [2], [3] and [4].

The drops inertia and the gas drag control the drops motion through zigzag passages. The efficiency is dependent of the gas turning that could centrifuge drops out of the stream. Drop size, plate spacing and bend angle as well as fluid properties are important [2].

The vane's design is crucial for the separation efficiency, and the vane may contain "pockets" where the fluid can drain without influence of flow pressure from the passing gas [5].

This paper presents the experimental study that is developed on a system for treating waste gas with a centrifugal vane mist eliminator made with stainless steel deflectors (made with a zigzag and semi-circular system).

The mean air velocity, the air velocity root mean square, the air turbulence intensity, the air velocity fluctuations equivalent frequencies and the air velocity fluctuations frequencies, inside the vane separator zigzag and semi-circular deflectors, influences the separation of the liquid from the gas flow. Thus, in this work, the study of these field variables inside the vane separator zigzag and semi-circular deflectors is detailed analyzed. In the air velocity fluctuations equivalent frequencies the analytical numerical expression [6] and [7] is used, while in the air velocity fluctuations frequencies the power spectra is used.

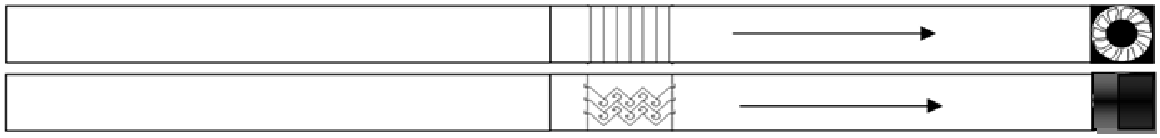
In the experimental tests is used a hot-wire anemometry sensor to measure the air velocity fluctuations. The application of this technique is very common in this type of measurements. Some examples of application of hot-wire anemometry techniques are described in [8], [9], [10] and [11].

In [8], it is used to measure the vortices in the trailing edge of the central turbine blade. In [9], it is used to measure the flow on the boundary layer on turbomachines blades. In [10], it is used to measure the synthetic jet velocity distributions to evaluate its power density spectra. In [11], it is used to obtain averaged velocity and turbulence intensity in order to recognize the separate effects of the blowing and the suction phases of the jet as a part of the jet effects analysis on the transition and separation processes taking place within the boundary layer.

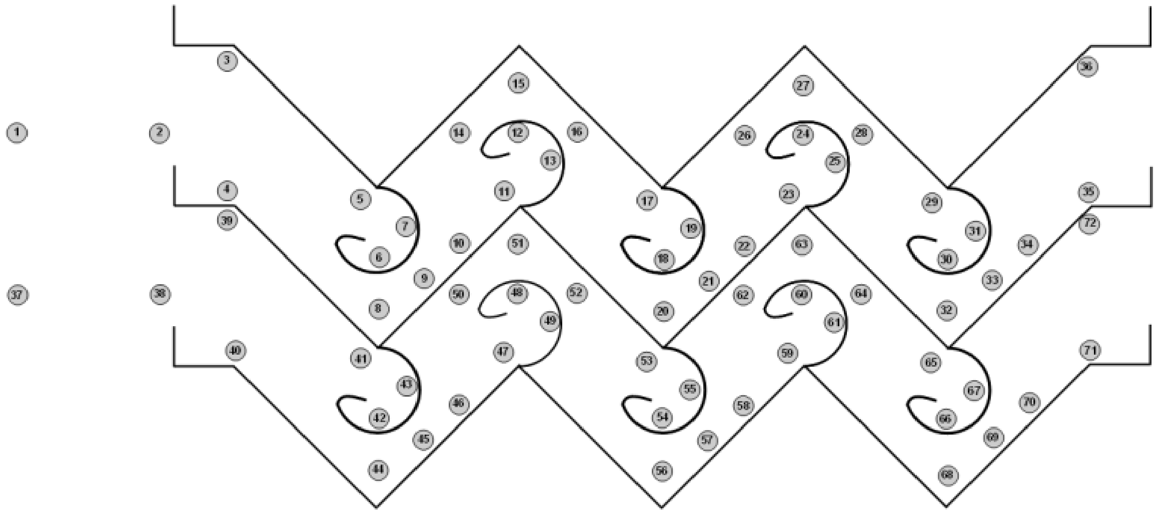
II. EXPERIMENTAL SETUP

The experimental setup, used in this test, consider a fan, a system of deflectors and a experimental module built in Perspex (see fig. 1a). In the experimental tests, an inlet air velocity of 0.7 m/s and 1.546 m/s are considered and 72 points are measured (see fig. 1b).

In the experimental test a hot-wire anemometry sensor connected to a data acquisition system PXI from National instruments measurements, with a 1000 points for second sample rate, is used.



a)



b)

Fig. 1 – Experimental setup used in the measurements. a) Location of the deflectors in the experimental setup and b) location of 72 measurement points along the treatment system (scheme based in US Patent Design n.º 373,625).

The air fluctuations are measured:

- at the inlet (1, 2, 37 and 38);
- between the zigzag deflectors (3, 4, 8, 9, 10, 14, 15, 16, 20, 21, 22, 26, 27, 28, 32, 33, 34, 39, 40, 44, 45, 46, 50, 51, 52, 56, 57, 58, 62, 63, 64, 68, 69 and 70);
- inside the semi-circular deflectors (5, 6, 7, 11, 12, 13, 17, 18, 19, 23, 24, 25, 29, 30, 31, 41, 42, 43, 47, 48, 49, 53, 54, 55, 59, 60, 61, 65, 66 and 67);
- at the exit (35, 36, 71 and 72).

In table I, the inlet environmental conditions, namely the air velocity, the air temperature and air relative humidity, for the experimental tests are presented.

Table I - Inlet environmental conditions observed in experimental tests carried out to obtain the evolution of the fluid flow after vane mist eliminators treatment system.

Test	I	II
Air Velocity	0,7 m/s	1,546 m/s
Air temperature	22,2 ºC	
Air relative humidity	47 %	

In this work, only the information associated with the vane separator zigzag and semi-circular deflectors is presented.

III. Results and Discussion

In this section the air velocity field, the air velocity root mean square field, the air turbulence intensity field, the air velocity fluctuations equivalent frequencies field, and the air velocity fluctuations frequencies field are presented.

Air Velocity field

In fig. 2 and 3 are presented the air velocity field values, inside a deflectors system, calculated experimentally at 72 different points, for inlet air velocities of 0.7 m/s and 1.546 m/s, respectively. These figures include the air velocity fluctuations.

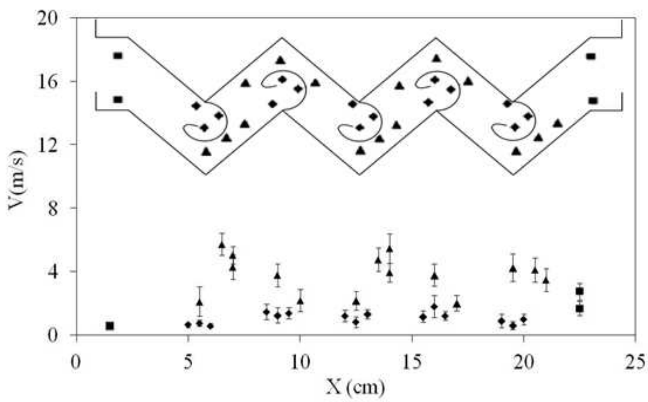


Fig. 2 – Air velocity field values inside the zigzag and semi-circular deflectors, for an inlet air velocity of 0.7 m/s.

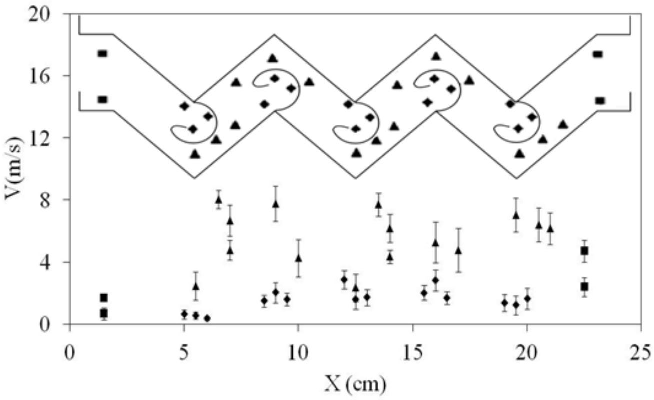


Fig. 3 – Air velocity field values inside the zigzag and semi-circular deflectors, for an inlet air velocity of 1.546 m/s.

In accordance with the obtained results is possible to conclude that:

- The air velocity is higher inside the zigzag deflectors than inside the semi-circular deflectors;
- The air velocity values inside the semi-circular deflectors increase from the first to the third deflector and decrease after;
- The air velocity values inside the deflectors system are slightly higher for 1.546 m/s air velocity inlet than for 0.7 m/s air velocity inlet. However, the increase is more evident in the zigzag deflectors;
- In general, the air velocity fluctuations are slightly higher for the inlet air velocity of 1.546 m/s than for the inlet air velocity of 0.7 m/s.

Air velocity Root Mean Square field

Fig. 4 and 5 show the evolution of the air velocity root mean square (RMS) values, inside the deflectors system, calculated experimentally for inlet air velocities of 0.7 m/s and 1.546 m/s, respectively.

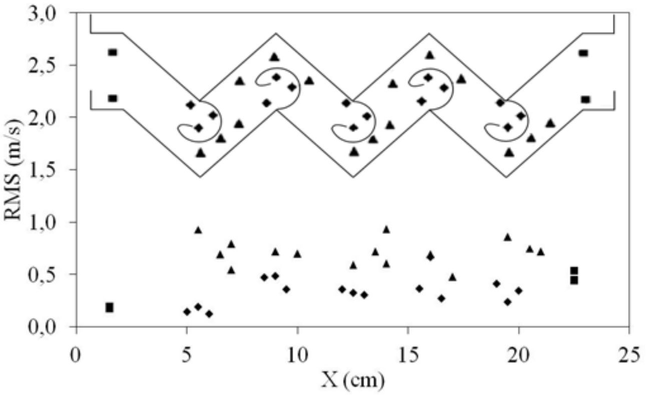


Fig. 4 – Air velocity root mean square values inside the zigzag and semi-circular deflectors, for an inlet air velocity of 0.7 m/s.

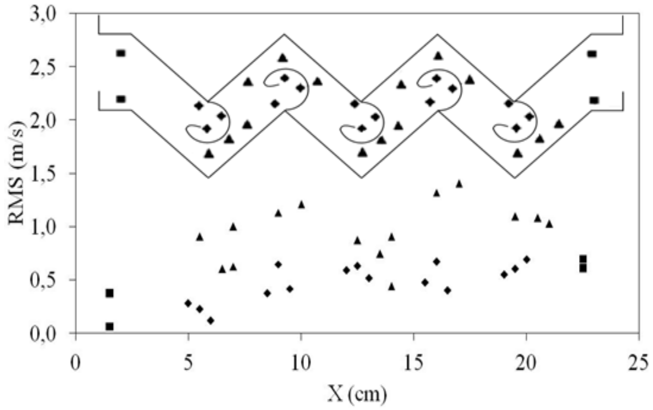


Fig. 5 – Air velocity root mean square values inside the zigzag and semi-circular deflectors, for an inlet air velocity of 1.546 m/s.

In accordance with the obtained results is possible to conclude that:

- The air velocity root mean square values are higher inside the zigzag deflectors than inside the semi-circular deflectors;
- The air velocity root mean square values inside the semi-circular deflectors increase from the first to the third deflector and decrease after the fourth;
- The air velocity root mean square values inside the deflectors system are slightly higher for 1.546 m/s air velocity inlet than for 0.7 m/s air velocity inlet. However, the increase is more evident in the zigzag deflector.

Air turbulence intensity field

Fig. 6 and 7 show the evolution of air velocity turbulence intensity (Ti) field values inside the deflectors system, calculated experimentally for inlet air velocities of 0.7 m/s and 1.546 m/s, respectively.

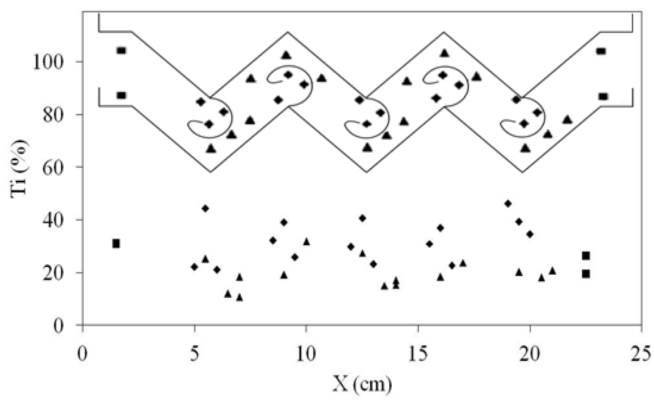


Fig. 6 – Air velocity turbulence intensity field values inside the zigzag and semi-circular deflectors, for an inlet air velocity of 0.7 m/s.

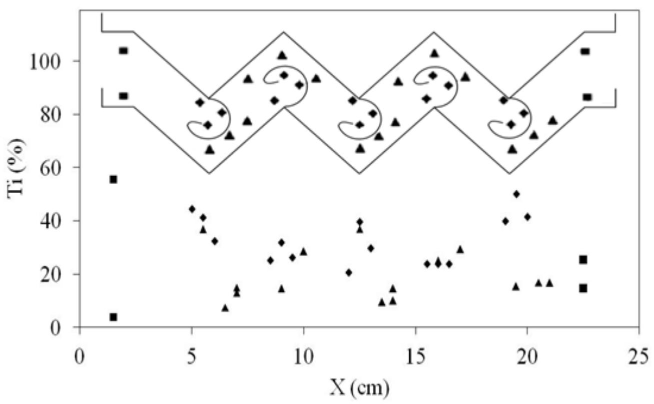


Fig. 7 – Air velocity turbulence intensity field values inside the zigzag and semi-circular deflectors, for an inlet air velocity of 1.546 m/s.

In accordance with the obtained results is possible to conclude that:

- The air velocity turbulence intensity values, in general, are higher inside the semi-circular deflectors than inside the zigzag deflectors;
- The influence of the air velocity turbulence intensity in the deflectors system with the distance is not evident. However, in general, when the distance increases the air velocity turbulence intensity values increase, mainly in the semi-circular deflector;
- The influence of the air velocity turbulence intensity in the deflectors system with the inlet air velocity is, also, not evident.

Air velocity fluctuations equivalent frequencies field

Fig. 8 and 9 show the evolution of the air velocity fluctuations equivalent frequencies (EF) field values, inside the deflectors system, calculated experimentally for inlet air velocities of 0.7 m/s and 1.546 m/s, respectively.

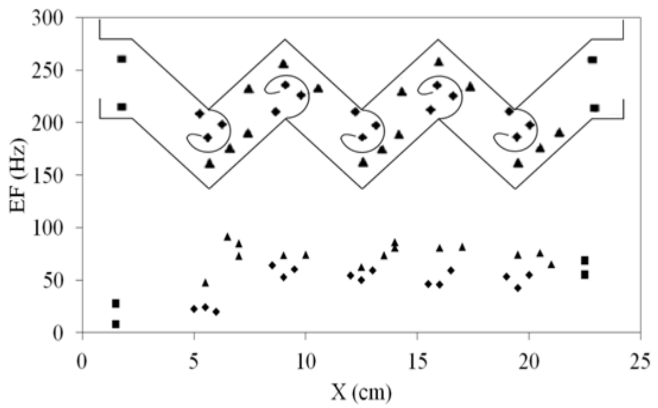


Fig. 8 – Air velocity fluctuations equivalent frequencies field values inside the zigzag and the semi-circular deflectors, for an inlet air velocity of 0.7 m/s.

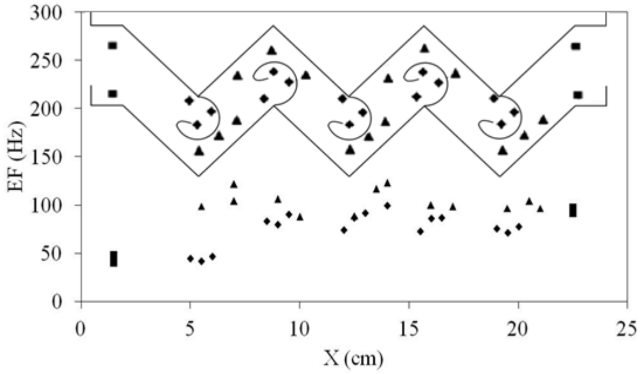


Fig. 9 – Air velocity fluctuations equivalent frequencies field values inside the zigzag and semi-circular deflectors, for an inlet air velocity of 1.546 m/s.

In accordance with the obtained results is possible to conclude that:

- The air velocity fluctuations equivalent frequencies values are smaller inside the semi-circular deflectors than inside the zigzag deflectors;
- In general, the air velocity fluctuations equivalent frequencies values are lowest at the inlet and increase with the distance from the first semi-circular deflectors to the third semi-circular deflectors and are constant for the others deflectors;
- The air velocity fluctuations equivalent frequencies values are slightly higher for the inlet air velocity of 1.546 m/s than for the inlet air velocity of 0.7 m/s.

Air velocity fluctuation frequencies field

In this section the power spectra is evaluated in all measurement points for the inlet air velocity of 0.7 m/s and 1.546 m/s.

From fig. 10 to 15 the air velocity fluctuations frequencies field are presented for an inlet air velocity of 0.7 m/s. Fig. 10 is associated to the inlet and outlet area, fig. 11 (first downstairs zigzag deflector) and 13 (third downstairs zigzag deflectors) are associated to the downstairs zigzag deflectors, fig. 12 (first upstairs zigzag deflector) and fig. 14 (fourth upstairs zigzag deflector) are associated with the upstairs zigzag deflectors and fig. 15 are associated with the semi-circular deflectors.

In the presented figures, the abscissa axis represents the air fluctuations frequencies f, in Hz, and the coordinate axis represents the dimensionless energy, φ.

From fig. 16 to 21 the air velocity fluctuations frequencies are presented for an inlet air velocity of 1.546 m/s. Fig. 16 is associated to the inlet and outlet area, fig. 17 (first downstairs zigzag deflector) and 19 (third downstairs zigzag deflectors) are associated to the downstairs zigzag deflectors, fig. 18 (first upstairs zigzag deflector) and fig. 20 (fourth upstairs zigzag deflector) are associated with the upstairs zigzag deflectors and fig. 21 are associated with the semi-circular deflectors.

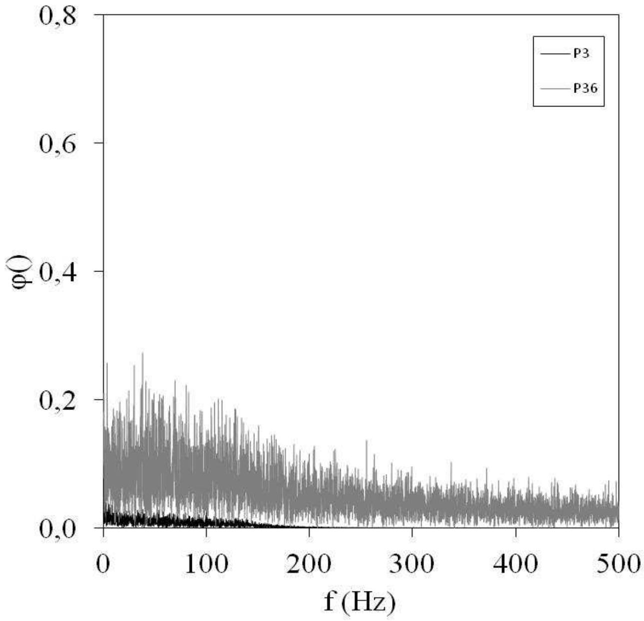


Fig. 10 - Power spectra values obtained at the points 3 (inlet) and 36 (outlet), for inlet air velocity of 0.7 m/s.

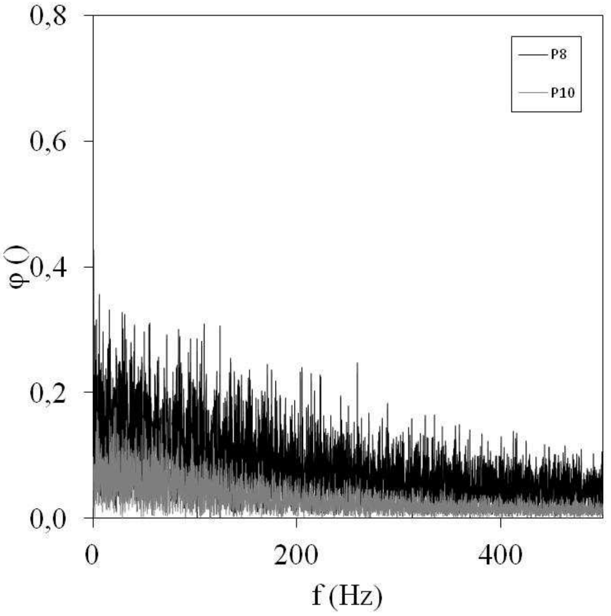


Fig. 11 - Power spectra values obtained in first downstairs zigzag deflectors at the points 8 (corner) and 10 (after the corner), for inlet air velocity of 0.7 m/s.

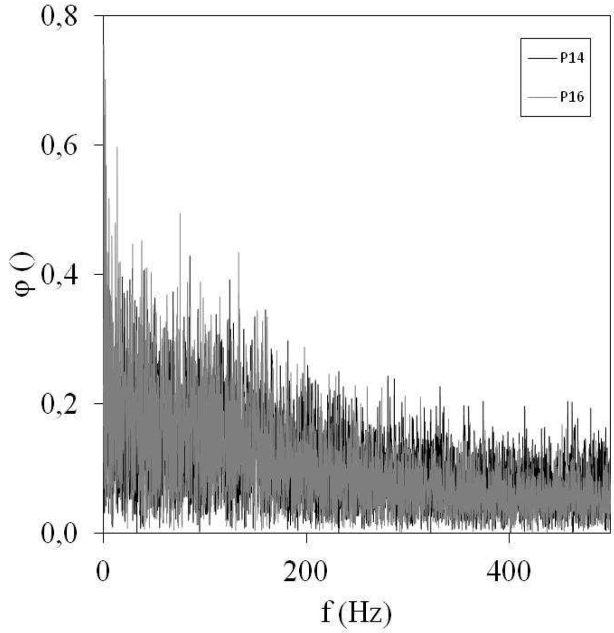


Fig. 12 - Power spectra values obtained in first upstairs zigzag deflectors at the points 14 (before the corner) and 16 (after the corner), for inlet air velocity of 0.7 m/s.

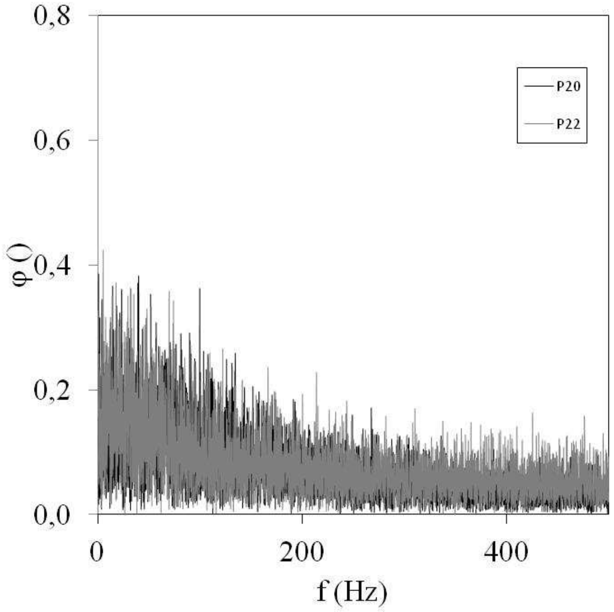


Fig. 13 - Power spectra values obtained in third downstairs zigzag deflectors at the points 20 (corner) and 22 (after the corner), for inlet air velocity of 0.7 m/s.

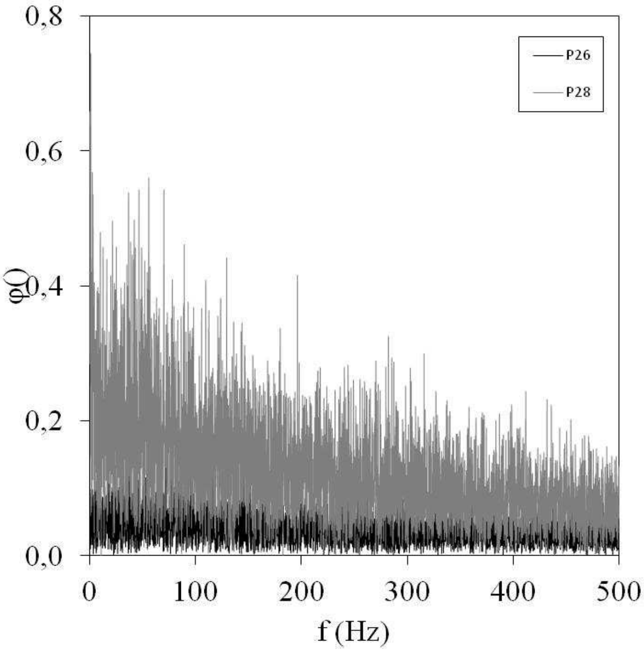


Fig. 14 - Power spectra values obtained in fourth upstairs zigzag deflectors corner at the points 26 (before the corner) and 28 (after the corner), for inlet air velocity of 0.7 m/s.

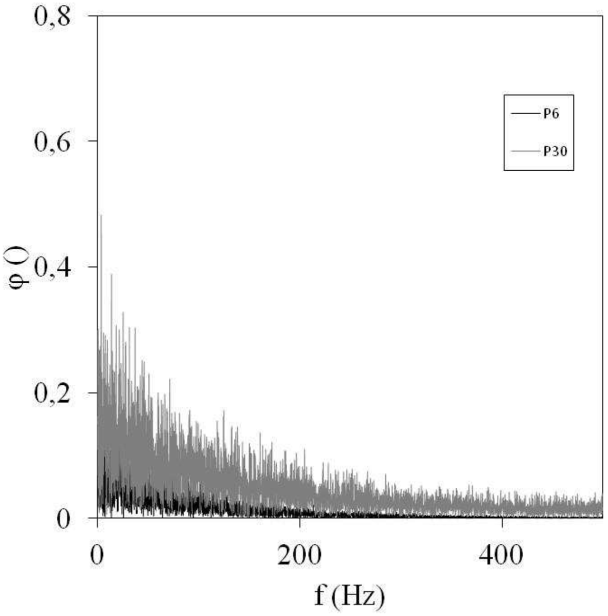


Fig. 15 - Power spectra values obtained at the points 6 (first semi-circular deflector) and 30 (fifth semi-circular deflector), for inlet air velocity of 0.7 m/s.

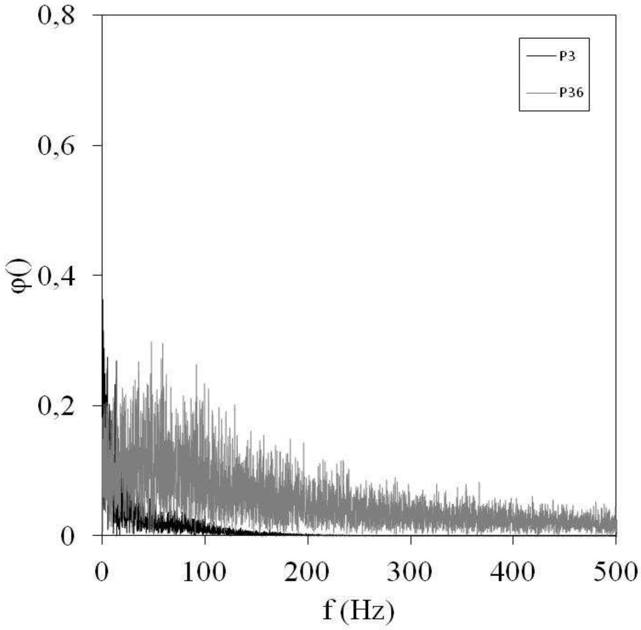


Fig. 16 – Power spectra values obtained at the points 3 (inlet) and 36 (outlet), for inlet air velocity of 1.546 m/s.

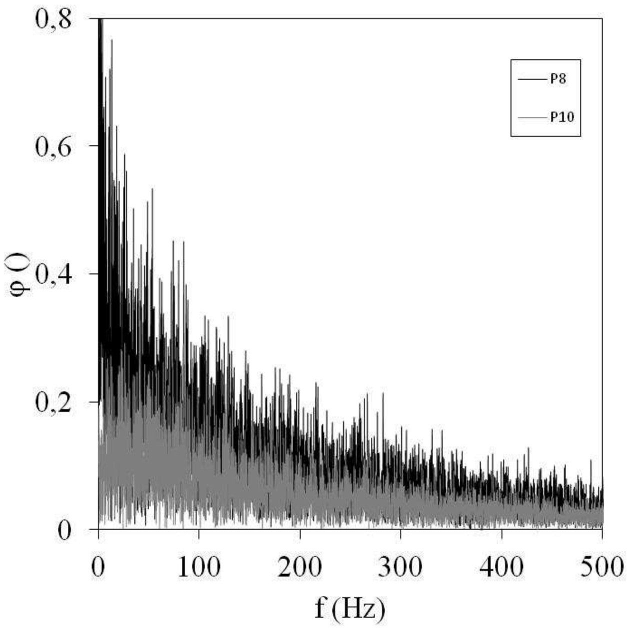


Fig. 17 – Power spectra values obtained in first downstairs zigzag deflectors at the points 8 (corner) and 10 (after the corner), for inlet air velocity of 1.546 m/s.

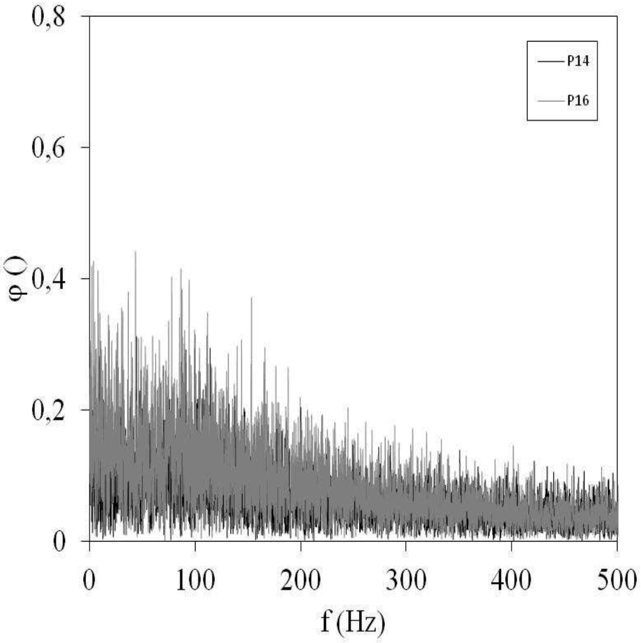


Fig. 18 - Power spectra values obtained in first upstairs zigzag deflectors at the points 14 (before the corner) and 16 (after the corner), for inlet air velocity of 1.546 m/s.

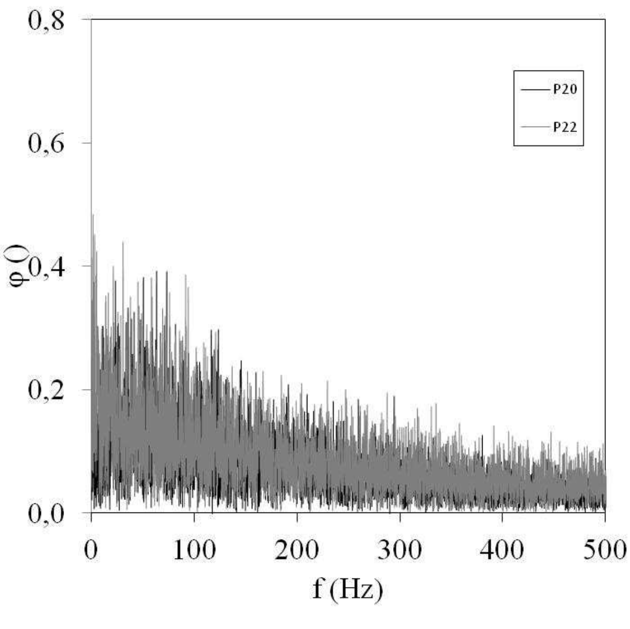


Fig. 19 – Power spectra values obtained in third downstairs zigzag deflectors at the points 20 (corner) and 22 (after the corner), for inlet air velocity of 1.546 m/s.

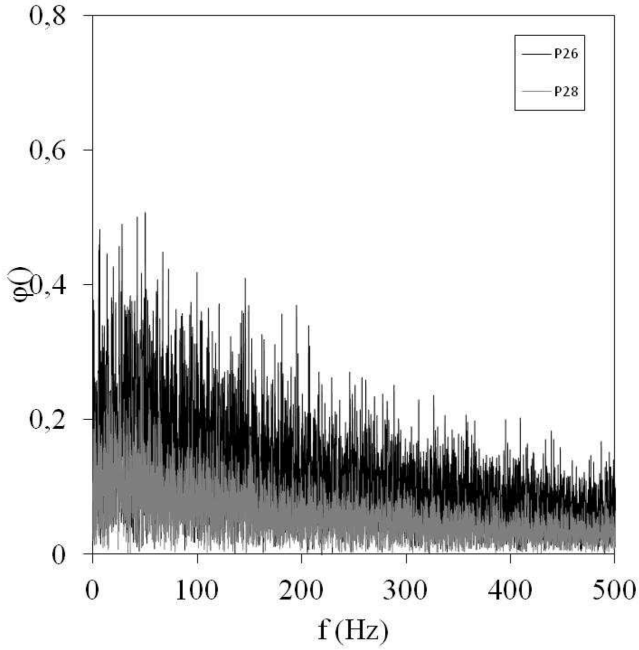


Fig. 20 – Power spectra values obtained in fourth upstairs zigzag deflectors corner at the points 26 (before the corner) and 28 (after the corner), for inlet air velocity of 1.546 m/s.

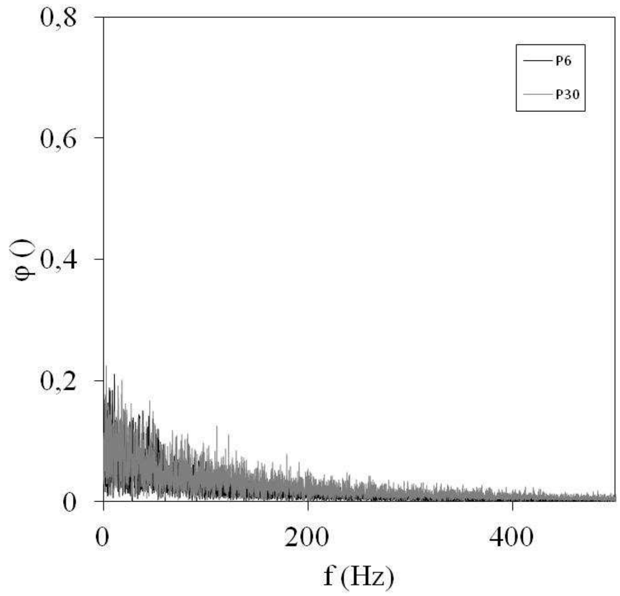


Fig. 21 – Power spectra values obtained at the points 6 (first semi-circular deflector) and 30 (fifth semi-circular deflector), for inlet air velocity of 1.546 m/s.

In accordance with the obtained results is possible to conclude that:

- The airflow inside the entrance is lower energetic than in the exit;
- The airflow inside the semi-circular deflectors are lower energetic than inside the zigzag deflectors;
- The airflow in the first zigzag deflectors are lower energetic than in the last zigzag deflectors;
- The airflow in the upstairs zigzag deflectors is most energetic after the corner than before the corner and the airflow in the last upstairs zigzag deflectors are most energetic than the first upstairs zigzag deflectors;
- The airflow in the downstairs zigzag deflectors is most energetic in the corner than after the corner, and the airflow in the downstairs zigzag deflectors is most energetic in the last deflectors than in the first deflectors;
- The airflow inside the semi-circular deflectors is most energetic in its interior area than in its entrance area;
- The airflow inside the semi-circular deflector is most energetic in the last deflectors than in the first deflectors;
- The airflow inside the semi-circular deflectors is more energetic for an inlet air velocity of 0.7 m/s, than for inlet air velocity of 1.546 m/s.

IV. Conclusions

The mean air velocity, the air velocity root mean square, the air turbulence intensity, the air velocity fluctuations equivalent frequencies and the air velocity fluctuations frequencies, inside the vane separator zigzag and semi-circular deflectors are detailed analyzed. In the air velocity fluctuations equivalent frequencies the analytical numerical expression is used, while in the air velocity fluctuations frequencies the power spectra is used.

In accordance with the obtained results is possible to conclude that the air velocity in the zigzag deflectors is higher than in the semi-circular deflectors, the airflow inside the semi-circular deflectors are lower energetic than inside the zigzag deflectors, the influence of air velocity intensity in the deflectors' system with the distance is not evident and the inlet air velocity doesn't significantly influence the deflectors' system behaviour.

The difference between the beginning and the end of the deflectors system is higher for higher air velocity than for the lower air velocity.

V. Acknowledgment

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