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THE INFLUENCE OF INTERNAL VANE ON UNIFORM VELOCITY DISTRIBUTION IN THE CROSS-FLOW FAN

In this paper the authors present the test carried out to obtain the uniform velocity distribution at the outlet cross section of flow fan. In the investigations the inner flat vane mounted inside of the impeller has been applied. For various angular position of the inner vane , one obtained different flow structures as well as different velocity distributions. The analysis of the obtained results is presented in form of graphs shown in 10 figures, juxtaposing flow phenomena with velocity distributions. Numerical flow simulation with the use of Flo++ program based on the Finite Volume Method was carried out.

1. Introduction

Cross-flow fans are not so widely applied as other types of fans, for example axial or centrifugal ones, due to their rather low efficiency. For several years, the cross flow fans often used in place of other types in industrial applications, because they are able to produce higher discharge flow rate than axial or centrifugal fans having the same diameters. The interest in this kind of fan has grown from year to year not only in the industrial applications i.e. in ventilating, cooling or drying systems but also in household appliances as an element of air conditioners or air curtains where their silent operation seems to be particularly suitable. The dynamic development of electronic engineering has enlarged application of cross-flow fan in computers and other electronic devices where such a very compact cooling element is required.

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Cross-flow fan, Fig. 1, has an impeller with forward curved blades and a casing profiled in such way as to assure the air flow over whole length of impeller.

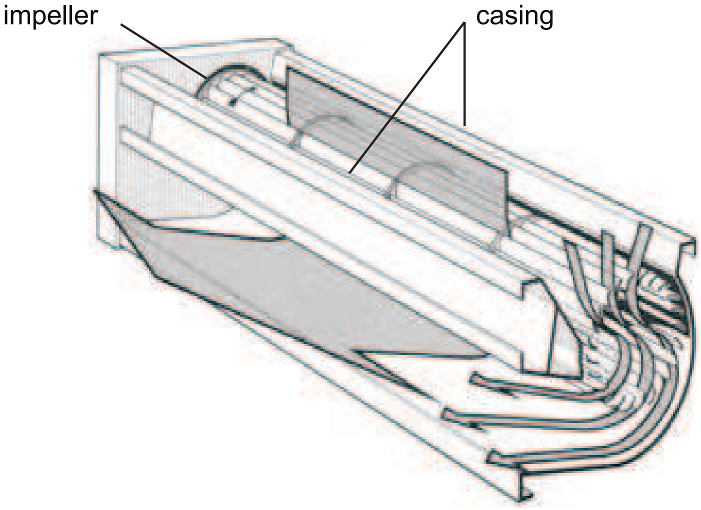

Fig. 1. Cross-flow fan [1]

The realization of an air flow across full inflow section of the cooperating device improves the efficiency of the whole system in spite of relatively low efficiency of the cross flow fan. The parallel air stream generated by air curtains makes it possible to separate rooms with different temperatures, Fig. 2. In particular the clean rooms and laboratories for high- technology industries require air properties, which could be assured by the use of a special apparatus where the cross-flow fan generating uniform flow are applied. For example in hospital operating room cross-flow fans find application in separating the places which require special conditions of clean air free of microorganisms from one side and for generating laminar flows from the other side [3]. The most popular application of cross-flow fans is in the flow heat exchangers, where the dimensions of rectangular outlet cross section of the fan can be adapted to rectangular inlet cross section of the heat exchanger, Fig. 3, reducing the local pressure losses.

From this point of view, a uniform velocity of the air stream leaving the discharge zone of cross-flow fan seems to be expected. The lack of theoretical considerations or experimental results dealing with the problem of uniform velocity distribution at an outlet cross section, given in catalogues of the producers as one of the specific properties of cross-flow fans, has encouraged the authors to examine this property using numerical calculations. In work [5] the authors have only discussed the identification of some flow phenomena

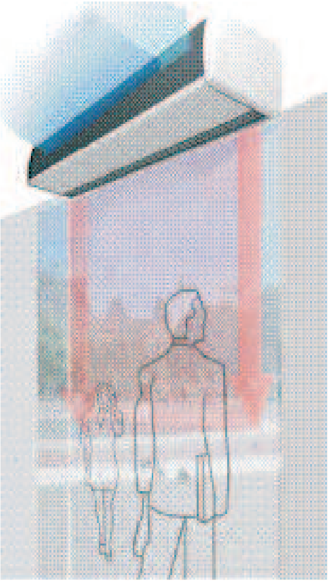

Fig. 2. Air curtain [2]

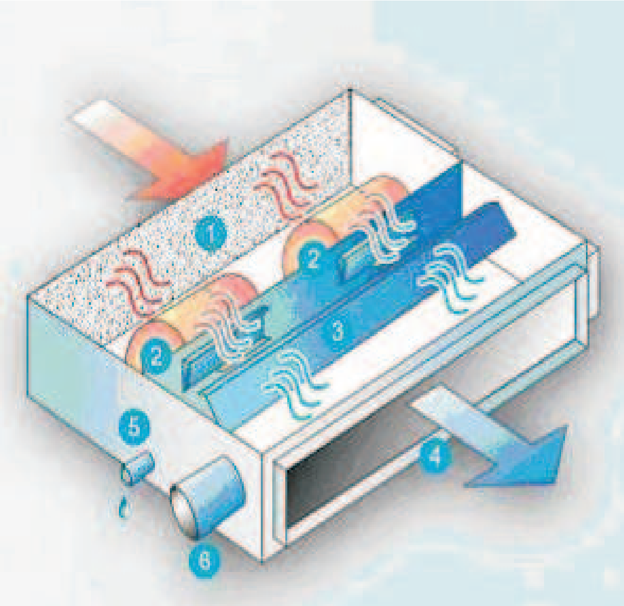

Fig. 3. Convector [4]: 1 filter, 2 fan, 3 coil pipe, 4 outlet, 5 release mechanism from high pressure zone, 6 inlet zone

and their effects on cross-flow fan performance based on the flow structure analysis.

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2. Flow simulation in the cross-flow fan

2.1. Numerical model of the flow

Two-dimensional geometry of cross flow fan based on the functional fan model tested experimentally earlier by the authors [6] consisted of the casing block (with 18 smaller blocks) and the impeller block which was created in Microstation/J program [7]. The numerical model with one sliding edge between immobile casing and the moving impeller (Fig. 4a), was written as IGES file and implemented to Flo++. The block of blade passage with uniform grid (Fig. 4b) was copied around the centre of the impeller, which covers with polar co-ordinates system, in number equal to the number of blades. The impeller block was created by joining adequate nodes in contact areas.

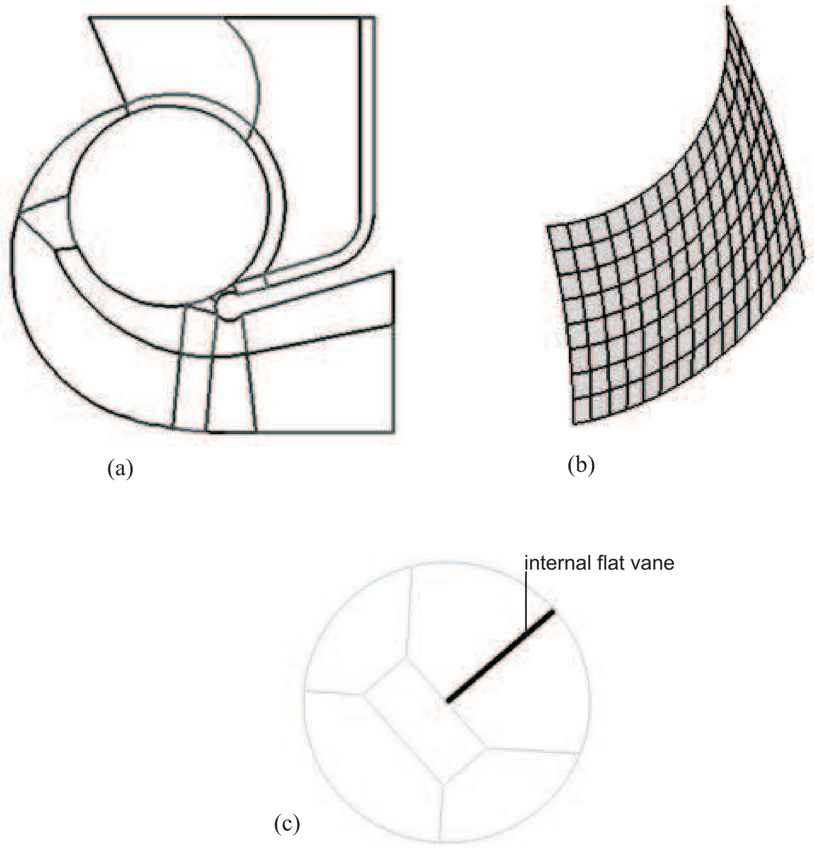
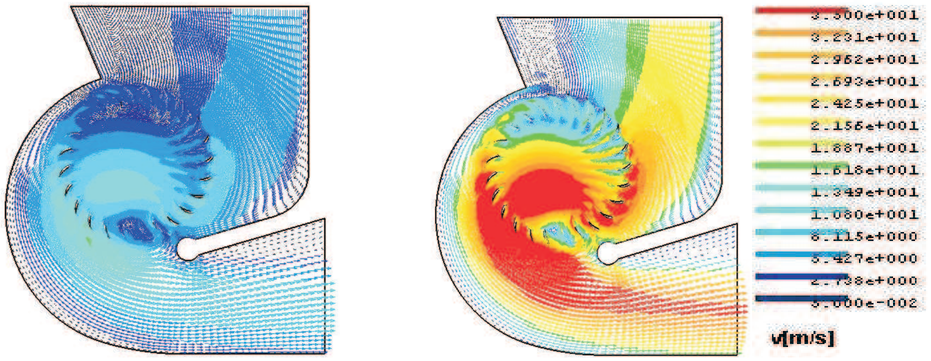


Fig. 4. Numerical model of cross-flow fan , (a) section of flow area, (b) grid of blade passage , (c) impeller with internal flat vane

The numerical simulation of flow in the cross-flow fan was performed using the Flo++ program based on Finite Volume Methods (full package CFD). We also applied the algorithms of conjugate gradient, k-ε turbulence and Transient PISO implemented in Flo++ [8]. An unsteady incompressible flow (flow with small velocities) was assumed [8] as well as constant values of: fluid density (ρ = 1.207 kg m^{-3}), dynamic viscosity (η = 1.787 10 $^{-5}$ Nsm^{-2}), atmospheric pressure (p_a = 101325 Pa), temperature (T = 293.15 K) and constant total pressure at inlet (suction) and constant static pressure at outlet (discharge) zones. It means that the cross-flow fan was considered without inlet and outlet channels. The applied method and the construction of numerical model is described in detail [9].

2.2 Analysis of flow structure in the cross flow fan

Two graphs of vector velocity derived for different rotational speeds of the impeller: n = 12.5 s^{-1}, n = 41.67 s^{-1} presented in Fig. 5, show the influence of rotational speed or the Reynolds number (Re = (ρ u_2 c)/η , u_2 – peripheral speed at outer diameter, c- chord blade) on the flow structure. The character of flow is similar in both considered cases but differences in velocity fields must be noticed. The main vortex centre is located almost at the same place of blading and the dimensions of vortex at two different rotational speeds do not differ from one another. The increase of the Reynolds number does not effect the velocity distribution at the outlet cross section. (In all figures presented in this paper dark blue colour means the lowest values and red denotes the highest values of velocity).



(a) (b)

Fig. 5. Vector velocity field for n = 12.5 s^{-1} (a) and n = 41.67 s^{-1}(b)

The analysis of vector velocity graphs (Fig. 5) shows that the velocity distribution at outlet cross section of cross-flow fan is not uniform in either case. The higher values of volume flow rate produced by higher rotational speeds are untypical in the ventilation systems and particularly in air conditional devices, which require rather lower outlet velocities generated by fan, with regard to maintain the thermal comfort conditions (average flow velocity in the range of v_{av} = 0.3-0.5 m s^{-1}).

In order to achieve the uniform velocity distribution at discharge zone, we considered the use of internal element in the shape of flat vane mounted in the centre of the impeller has been considered. Its influence on the flow structure and velocity distribution was analyzed.

The tested cross-flow fan with the internal flat vane located inside the impeller is shown in Fig. 6. The change of internal vane position measured by the angle α and the cross section of the outlet zone where the velocity distributions were examined, are presented in the same figure.

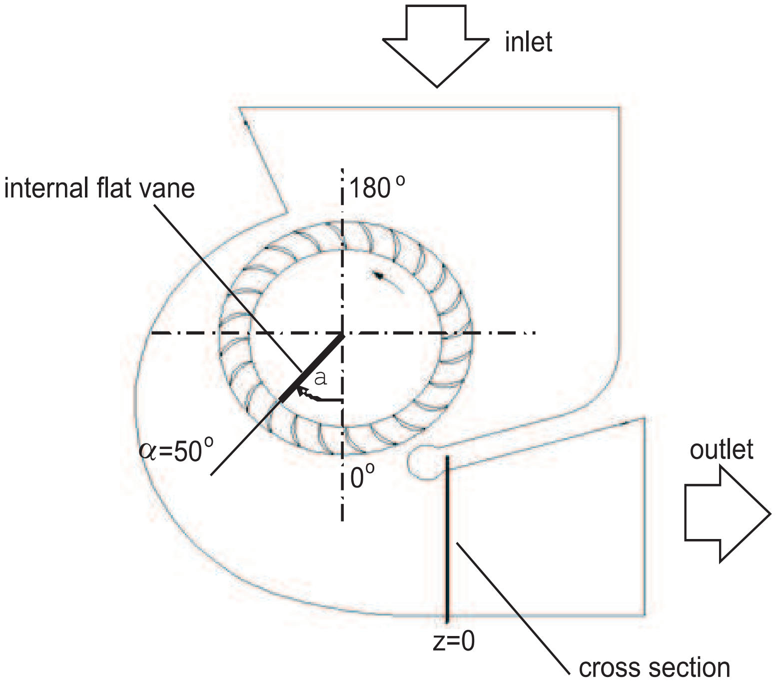
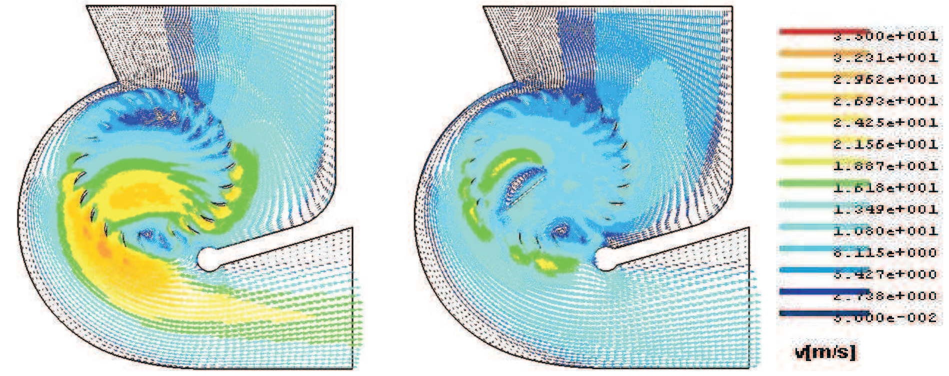


Fig. 6. The tested cross-flow fan with internal flat vane

Fig. 7 presents the vector velocity graphs obtained for two different cases: without (a) and with internal vane (b) located at the angle position α = 50°, made at the same rotational speed n = 24.67 s^{-1}.

The comparison of results obtained for the two cases has shown some differences in flow structure. The most important changes of flow structure



(a) (b)

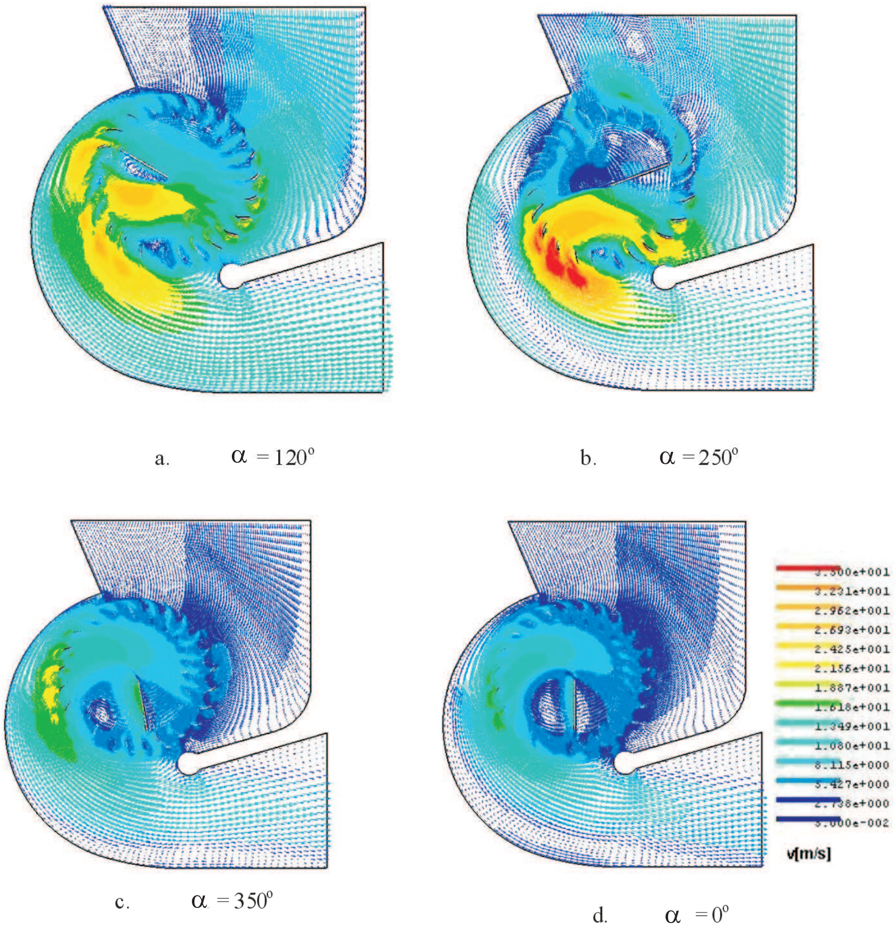
Fig. 7. Vector velocity fields for cross-flow fan with empty impeller (a), and with flat vane, $\alpha = 50°$(b)

were noticed inside the impeller, where the internal vane divided the throughflow into two streams. Close to the vane one could observe the considerable decrease of flow velocity and the appearance of a second vortex of elongated shape. The use of internal vane resulted in the decrease of flow velocity inside the impeller and at the discharge zone (Fig.7b) and it reduced the shedded vortices which were located at the suction arc of blading in the case without vane (Fig.7a). The eccentric vortex had a slightly greater dimension in the case with internal vane and its centre was moved towards the vortex wall – casing tongue (about 15°-20°). It is true than that the decrease of flow velocity is noticeable at the discharge zone in the case with internal vane but the velocity distribution at the outlet cross section is much more uniform.

The main changes of flow structure resulting from various angular positions of the internal vane: $\alpha = 0°$, $\alpha = 120°\alpha = 250°$ and $\alpha = 350°$ were indicated on the basis of the vector velocity graphs presented in Fig. 8.

Let us start the analysis from the flow structure obtained for $\alpha = 120°$ (Fig. 8a), where the main eccentric vortex reduced in dimension, allows a rather greater arc of blading to take part in active work. In consequence, a relatively high velocity of the throughflow and a higher flow rate at the discharge zone were obtained.

The position of the internal vane determined by $\alpha = 250°$ (Fig. 8b) creates a very special flow structure, where the dead zone appears at the centre of impeller. This angle position of the vane results in several recirculation zones located at the suction area and inside the impeller. The centre of the main vortex is located at the same place as in the case of $\alpha = 120°$, so the flow pattern at the discharge zone of cross-flow fan seems to be similar, but the



a. $\alpha = 120^\circ$

b. $\alpha = 250^\circ$

c. $\alpha = 350^\circ$

d. $\alpha = 0^\circ$

Fig. 8. Vector velocity fields for various angle positions of internal vane

disturbed throughflow is not enough strong to generate a similar value of flow rate at the discharge zone of impeller.

Analyzing the flow structure obtained for the angle position of internal vane $\alpha = 350^\circ$ (Fig. 8c), one can notice that the centre of the eccentric vortex moves in the direction of the leading wall by about 40° (in comparison with its location in the case without internal vane at the same rotational speed) and it eliminates a substantial great part of the impeller blading from active work which results in the significant decrease of the flow velocity.

The change of vane position from $\alpha = 350^\circ$ to $\alpha = 0^\circ$ results in a noticeable difference in flow structure (Fig. 8d). The main eccentric vortex changes its location towards the centre of the impeller and is placed on the left side of internal vane while flow recirculation appears on the right side close to the vane. The result of increase of dimension of the main vortex and the recirculation zone is that the throughflow is realized on a relatively small arc of discharge. The greatest values of velocity appear at this part of blading which is not responsible for generation of flow rate.

3. Influence of angular position of the internal vane on uniformity of velocity distribution at the outlet zone of cross-flow fan

The uniform velocity distribution at the outlet zone of cross-flow fan, which is one of its advantages, gives the possibility of constructing units that require a homogenous inflow. Numerical simulation of flow in cross flow fan with internal vane made it possible to identify some differences in flow structure caused by the existence of flow phenomena such as: vortexes, recirculation regions, zones with very small velocities or dead zones, movements of the eccentric vortex centre and the changes of its dimension, which appear or disappear depending on the flow conditions or geometry of the tested model.

The existence of the flow phenomena mentioned above significantly influence velocity distribution at the outlet cross section, which could be seen in the graphs presented earlier.

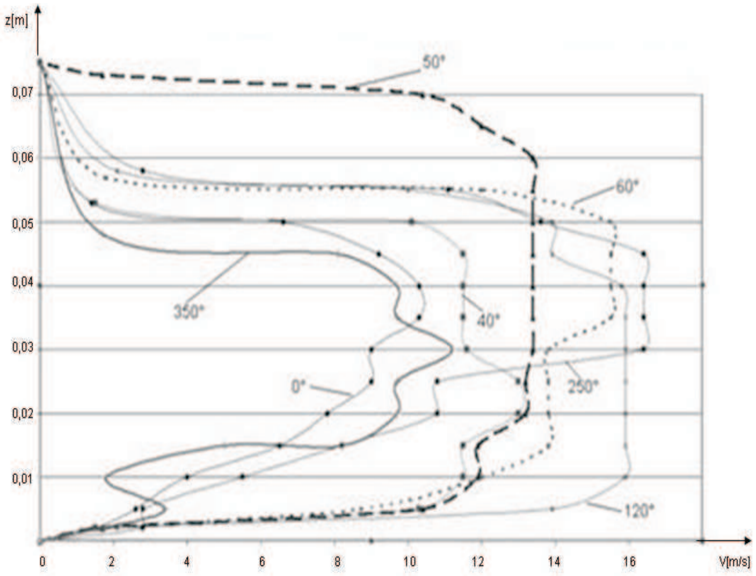


Fig. 9. Velocity distributions at the outlet cross section for the different angles α

Fig. 9 presents a selection of some velocity distributions at the outlet cross section obtained for the various angular positions of the internal vane made at the same rotational speed, n = 24.67$s^{-1.}$ It is worth noticing that various angles give the different courses of the curves as well as different values of local velocity.

The analysis of curves presented in Fig. 9 shows that, for vane position $\alpha = 50^\circ$ one obtains the most uniform velocity distribution at the outlet cross section of the tested fan.

The maximum local values of velocity are also obtained in the cases of other angular positions: $\alpha = 60^\circ$, $\alpha = 120^\circ$ or $\alpha = 250^\circ$ but these values exist only in narrow range of outlet cross section area**.**

Analyzing the structure of flow obtained at angular position of internal vane $\alpha = 50^\circ$ shown in Fig. 7b one can notice that the centre of eccentric vortex is shifted to the tongue casing. Neither its location nor its dimension disturb the air flow at the discharge zone. The outflow can be realized in almost full cross section with the same velocity. This situation is shown in Fig. 10, which presents the comparison between velocity distributions at the cross section made for the empty impeller, and for that with the internal vane at angular position $\alpha = 50^\circ$.

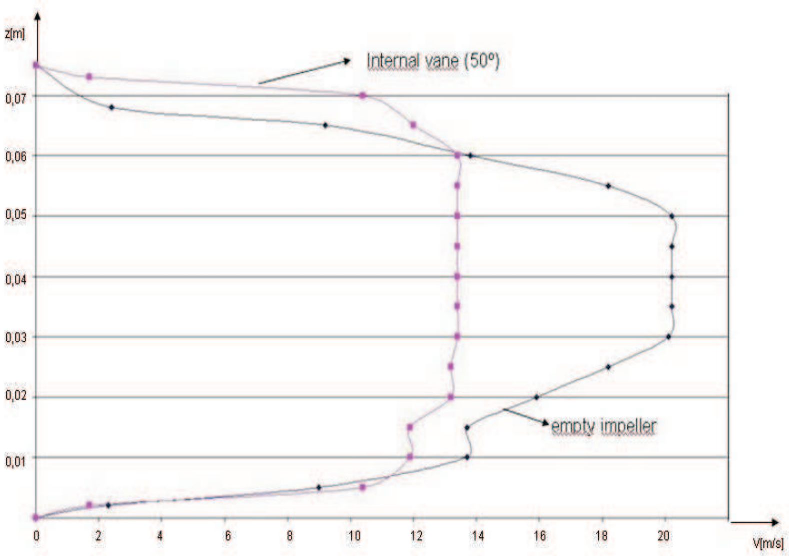


Fig. 10. Velocity distributions at the outlet cross section for the empty impeller and with the vane ($\alpha = 50^\circ$)

Fig. 11 shows the comparison between the vector velocity fields at outlet zone of cross- flow fan obtained for two different angular position of internal vane $\alpha = 350^\circ$ and $\alpha = 50^\circ$.

Velocity field at the outlet section presented in Fig. 11b is recommended particularly in the situation, when constructional and economic reasons require that the inflow at a heated surface should be uniform.

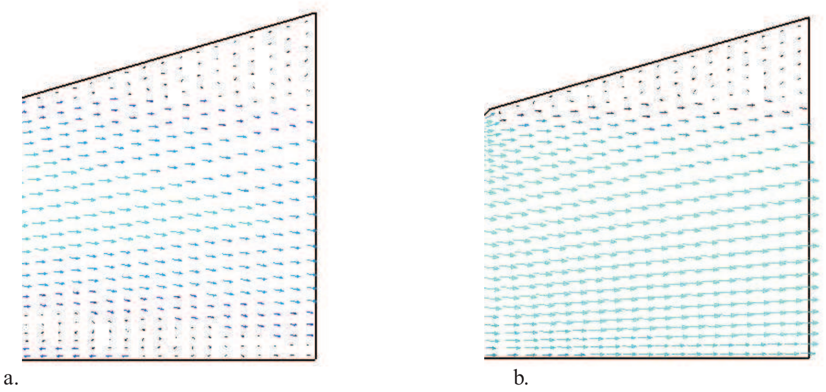


Fig. 11. Vector velocity field at the outlet zone (a) $\alpha = 350°$, (b) $\alpha = 50°$

4. Conclusions

The attempt of numerical prediction of the velocity distribution in the cross-flow fan made by using the Flo++ program based on the Finite Volume Methods, gave rather positive results. The internal element having the shape of a flat vane mounted in the centre of impeller was used for obtaining a uniform velocity distribution at the discharge zone. For various angular positions of internal vane, it was possible to achieve different velocity distributions at the same rotational speed. Moreover, the authors have shown the influence of the angular position of the internal vane on flow structure as well as the interaction between flow phenomena and velocity distribution were shown.

It seems to us that the lack of the experimental results and theoretical analyses in the available literature dealing with the problem of uniformity of flow distribution in cross-flow fans has been a sufficient reason to undertake the task of investigating this issue.

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Wpływ łopatki wewnętrznej na jednorodny rozkład prędkości w wentylatorze poprzecznym

Streszczenie

Niniejsza praca zawiera próbę uzyskania jednorodnego rozkładu prędkości w strefie wylotowej wentylatora poprzecznego za pomocą płaskiej łopatki zamontowanej obrotowo w osi wirnika. Dla różnych położeń kątowych łopatki wewnętrznej α otrzymano zróżnicowane struktury przepływu wewnątrz wentylatora oraz różne rozkłady prędkości w przekroju poprzecznym kanału wylotowego, co zaprezentowano na 10 rysunkach. Symulacje numeryczne przepływu przeprowadzono wykorzystując program Flo++ oparty na metodzie objętości skończonych.