Stanisław FORTUNA[*], Tomasz SIWEK[*], Piotr FIGIEL[*]

VISUALIZATION OF AN OUTFLOW IN THE RADIAL BLADE PASSAGE ON THE BASIS OF THERMOANEMOMETRIC MEASUREMENTS

SUMMARY

In this paper results of measurements of velocity distribution in the blade passage of radial rotor are presented. Construction of professional test rig with covered rotor passage and thermoanemometr usage made possible fluid flow visualization and detailed analysis of flow direction. Carried out tests showed high speed in negative pressure region. This means contrast to recently known theory about positive pressure regions. Correctness of measurements and results has been confirmed by smoke visualization and examples of computational simulations.

Keywords: *blade passage, rotor, flow visualization, thermoanemometric measurements, velocity distribution*

OBRAZOWANIE WYPŁYWU Z KANAŁU MIĘDZYŁOPATKOWEGO NA PODSTAWIE BADAŃ TERMOANEMOMETRYCZNYCH

Artykuł prezentuje rezultaty badań rozkładu prędkości w kanale międzyłopatkowym wirnika promieniowego. Skonstruowanie specjalnego stanowiska badawczego z zaklejonym kanałem wirnika i wykorzystanie termoanemometru umożliwiło wykonanie wizualizacji przepływu czynnika wraz z dokładną analizą kierunku jego przepływu. Przeprowadzone doświadczenia wykazały występowanie wysokiej prędkości promieniowej po stronie podciśnieniowej łopatki, a nie jak dotąd sądzono po stronie nadciśnieniowej. Poprawność badań została potwierdzona na podstawie wizualizacji dymowej oraz literaturowych symulacji komputerowych.

Słowa kluczowe: *kanał międzyłopatkowy, wirnik, obrazowanie przepływu, pomiary termoanemometrem, rozkład prędkości*

1. INTRODUCTION

One of the most discussed topic in the modern world of politics, media and science is production of clean energy and its efficiency. The newly created standards form more and more stringent restriction for efficiency of conversion electrical energy to useful forms i.e. mechanical energy. The level of losses in rotor machines during processing of energy supplied to the shaft and transformed into pressure depends on geometry of rotor and its volute. This geometry has final influence in flow forming. Improper flow can cause many additional losses e.g. rapid changes of flow directions, moving streamlines from rotor walls, acceleration and deceleration of the flow, fluid mixing, frictions etc.

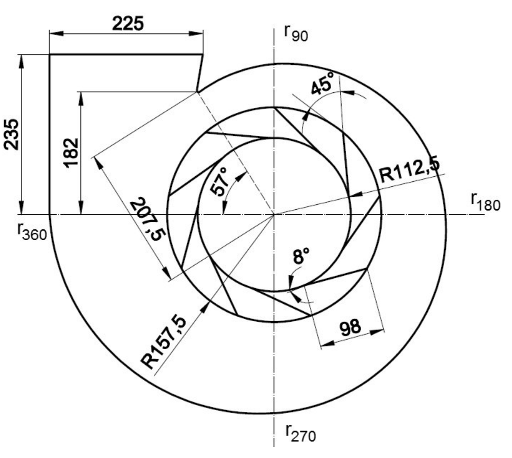


Fig. 1. Geometry of tested fan

Analysis of flow kinematics and its references to the geometry can be useful in designing more efficient and environment friendly units with reducing usage costs. The main aim of this article is an investigation of flow losses to find better solutions in fan designing and producing. The measurments was conducted on the model of the fan shown in Figure 1.

2. MEASURMENT METHODS

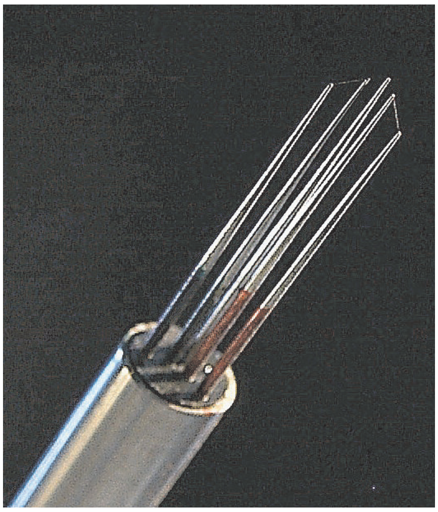
In this article visualization of an outflow was obtained on the basis of three-fiber thermoanemometric measurements. The device enables measurement of: turbulences, absolute velocity of airflow and value of its components in the Cartesian coordinate system. Additionally taken calculation of the method error shows a difference ca. 1–2%.

Measurement set (presented in Fig. 3) contains:

- three-channel thermoanemometric sensor TURBULENCE METER type ATM with three fibers perpendicular to each other,
- computer card A/C PC LabCard PLC814,
- Personal Computer with professional measurement software “Application for calculation of velocity components and frequency analysis” prepared by Flow Metrology Department of Institute of Orogene Mechanics of Polish Academy of Science in Cracow.

The sensor is mounted on positioning unit with two screws. The first one (green screw on Fig. 3) moves sensor parallel to the suction pipe, the second one (blue screw on Fig. 2) provides needed height coordinate for sensor.

[*] Faculty of Mechanical Engineering and Robotics, AGH University of Science and Technology, Krakow, Poland



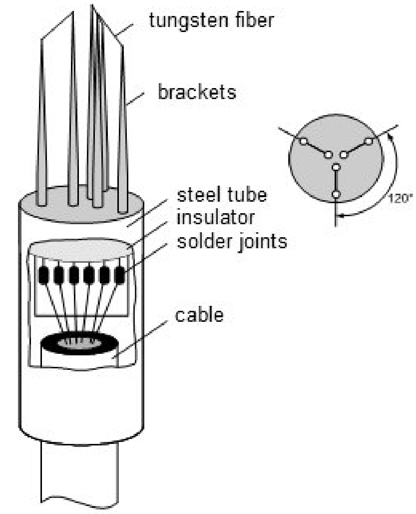


Fig. 2. A three-fiber sensor – close-up and scheme (Gawor *et al.* 1994)

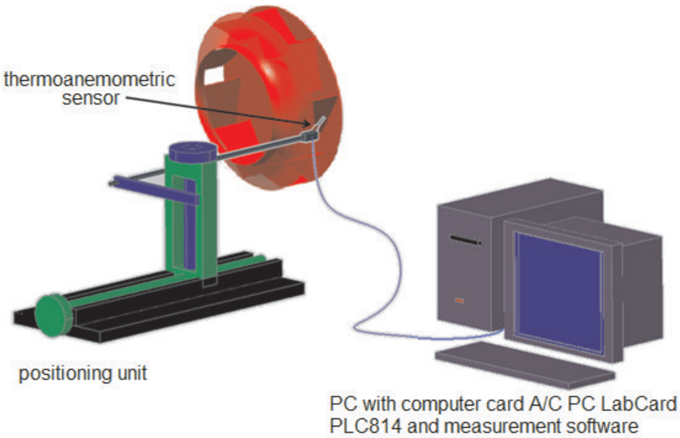
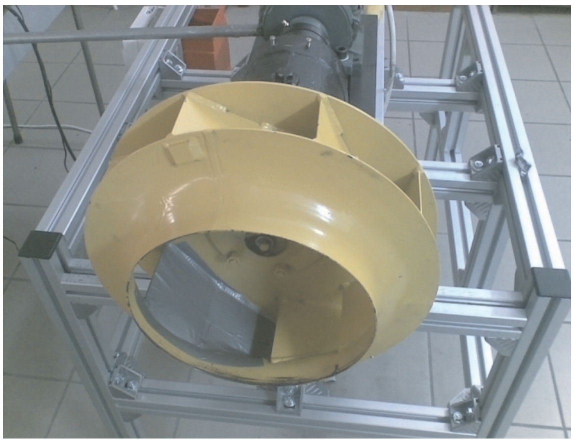


Fig. 3. Schematic diagram of the test stand

Visualization of flow through the blade passage by using three-channel thermoanemometr is a very laborious and tough task. The key point is to create procedure which enables localization of test points relative to rotating blades of rotor during representative parts of time.

The first step is to prepare proper model and gain information about position of passages and rotor blades. For this purpose one of passages was completely covered as it is presented in Figure 4. It blocked flow through passage and identified position of rotor according to the velocity



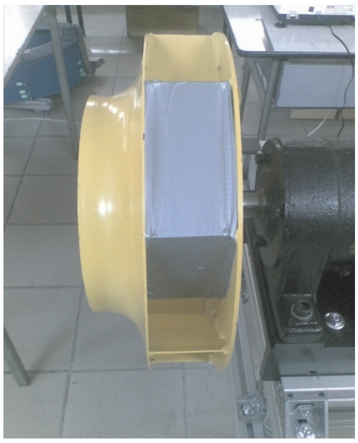


Fig. 4. Tested rotor with covered passage

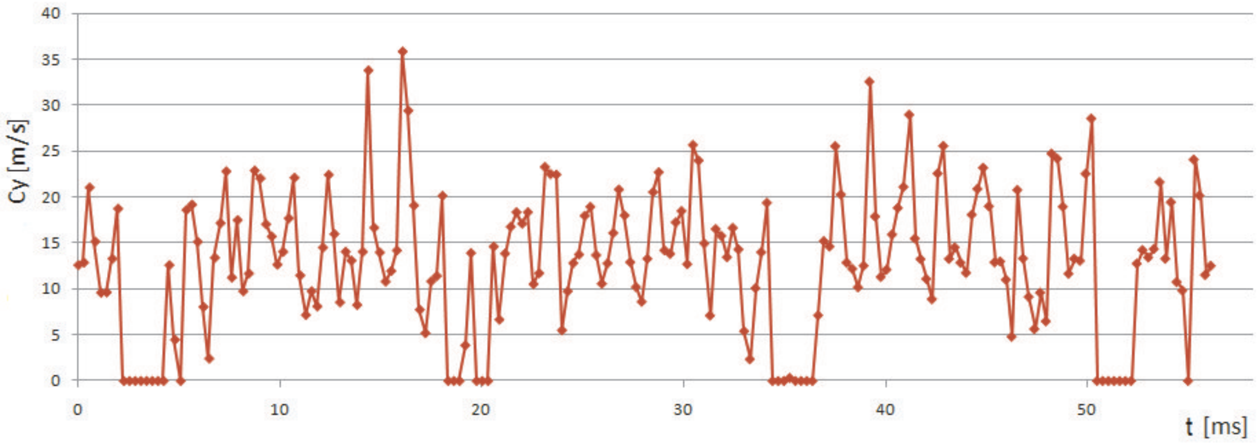


Fig. 5. An example of time characteristic of radial velocity behind the rotor with covered blade passage ($c_r = f(t)$ 5 mm from the rear surface)

distribution in function of time. The sensor registered no radial velocity in the area of covered passage (Fig. 5). Number of test points for one rotation is known so it means that 7.5 samples are assigned to one passage. Rotational speed is measured for correlation between position of rotor and thermoanemometric data and equals 2860 rpm. Dimension t_2 equals 110 mm. It leads to conclusion that samples are spaced in every 14.6 mm what comes from simple calculation:

$$\Delta t_2 = \frac{110}{7.5} = 14.6 \text{ mm.}$$

The velocity distribution was determined for surface π_4 bordered by edges of two nearby blades and front and rear corpus surfaces as this is presented in Figure 6. During experiment time characteristics have been recorded 18 times (e.g. Fig. 5) with the step of 3 mm moving from front

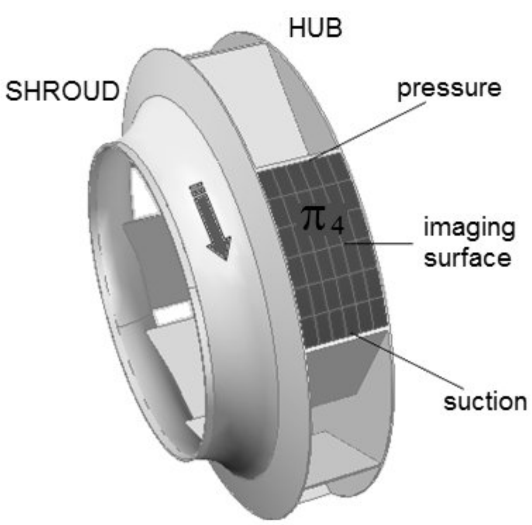


Fig. 6. The visualization surface of the velocity distribution in the blade passage

(in direction of shroud) to rear surface (in direction of hub). The sensor was at distance of 5 mm from rotating blades. After separation of test points and localization of coordinates interpolation of 2D velocity distribution was obtained by using 'cubic' methods which gave full 3D visualization of radial velocity distribution in the blade passage of rotating fan. A gird of test points used in flow visualization through the blade passage is shown in Figure 7.

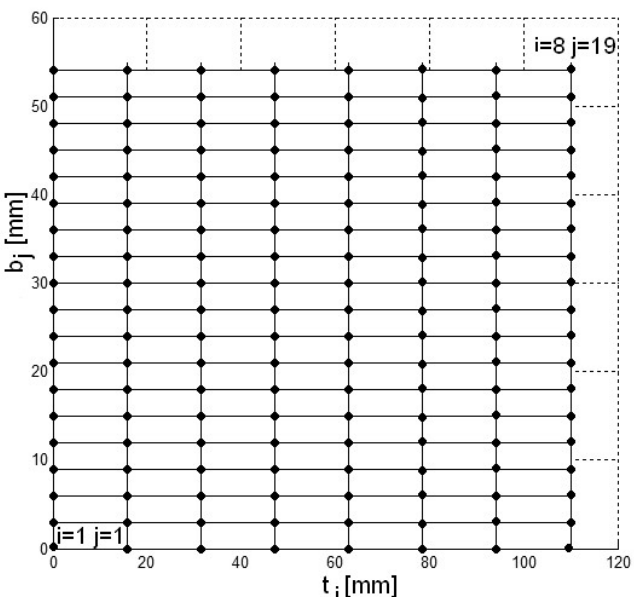


Fig. 7. A grid of test points used in flow visualization through the blade passage

3. RESULTS AND CONCLUSION

Figures 8, 9 and 10 present image of radial velocity distribution generated by Matlab after initialization of m-file. Final results are shown in 3 ways: 3D chart, plot of velocity in outlet from passage between blades and velocity map (pattern) built from lines of constant velocity.

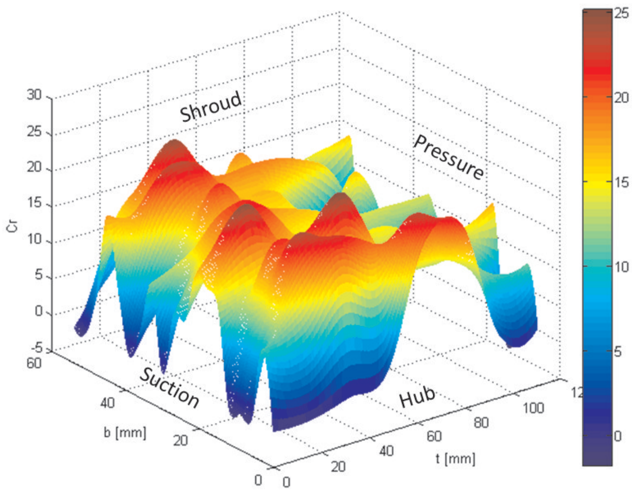


Fig. 8. The radial velocity cr distribution in an outlet from the blade passage of a rotor (r/r_2 = 1.032 – 3D chart)

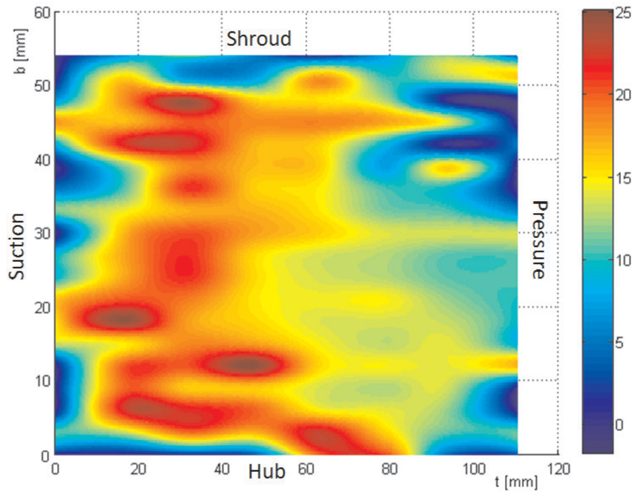


Fig. 9. The radial velocity cr distribution in an outlet from the blade passage of a rotor (r/r_2 = 1.032 – velocity field)

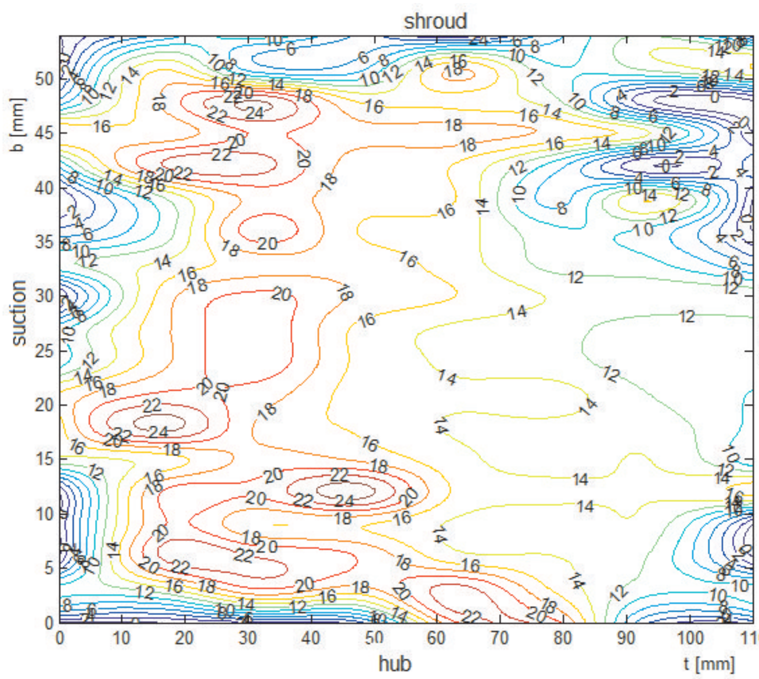


Fig. 10. A The radial velocity c_r distribution in an outlet from the blade passage of a rotor (r/r_2 = 1.032 – constant velocity lines)

Flow is not uniform in whole blade passage cross-section. Airflow from the rotor concentrates in a part close to rear surface of rotor. Observed bigger flow rate on the side behind the blade is the conclusion from charts. It means that rotating blade sucks air under it and generates flow through rotor. Presented chart is popular presentation of velocity distribution in the outlet from the blade passage made by Eckardt (Fig. 11).

The Eckardt's fan was constructed as an axis-radial fan. The outlet part of fan was radial so exactly the same as in the tested fan. Main difference between results of thermo-anemometric measurements and widely known Eckardt's chart comes from concentration place of flow. In Figure 11 high radial velocities exist in a region near the positive pressure part of blade.

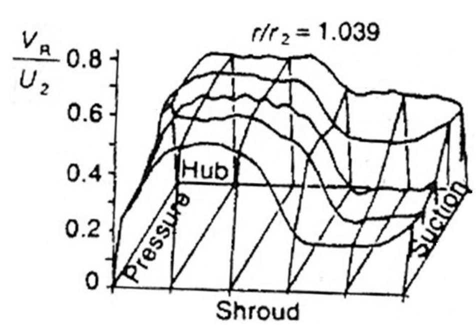


Fig. 11. The Eckardt's distribution of radial velocity c_r in an outlet from the blade passage of rotor (Grudziński *et al*. 2003, Eckardt 1979)

Fig. 12. The smoke visualization of velocity

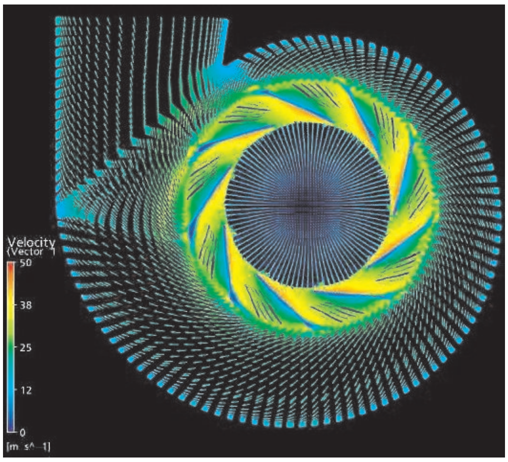


Fig. 13. The CFD simulation of an example rotor F2+ob (ANSYS) (Fortuna and Sobczak 2008)

According to experiment (Fig. 8) high values are on the opposite negative pressure side and low on the positive pressure side. There is no divergence in the distribution of velocity along width *b*, it is the same in both analysis and shows higher flow in part close to the rear surface. Correctness of hypothesis has been examined and confirmed by additional smoke visualization test (Fig.12) and computational simulation (Fig. 13 and 14). The special rotor used in the smoke visualization had the similar construction as the tested rotor, (F2) but the shroud was removed. Mixture of smoke and air was used only for better visual indication of the flow. The unsteady simulations of the air flow through the radial fan were conducted by means of ANSYS CFX code.

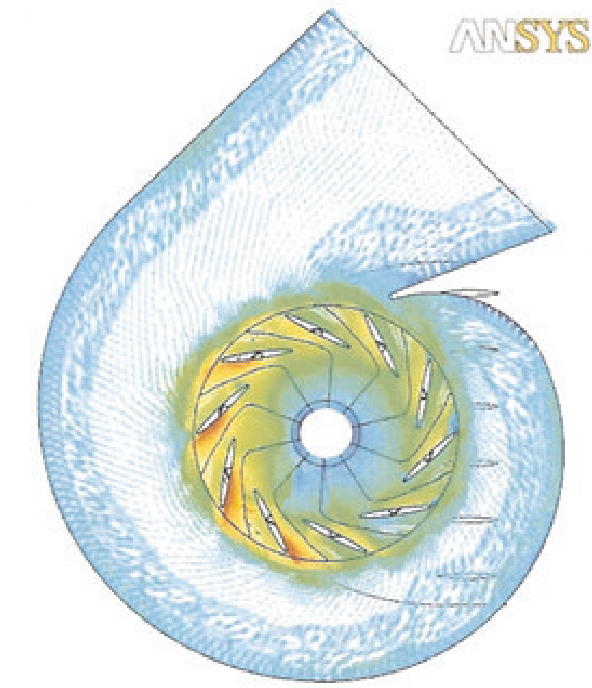


Fig. 14. The CFD simulation of an example rotor (ANSYS) (Beczkowski *et al*. 2007)

The applied hexahedral mesh was composed of ~2 367 000 nodes. The mass flow rate and temperature at the inlet of the fan as well as a static pressure at the outlet were imposed. All fan impellers was rotating 2880 rpm. Gained figures and results precisely showed that high velocities dominate in the part of the blade passage close to the underpressurized region.

References

Beczkowski J., Sobczak K., Borzęcki T., Jóźwik K. 2007, *Modelowane badania eksperymentalne i numeryczne promieniowego wentylatora energetycznego*. VII Międzynarodowa Konferencja „Wentylatory i pompy przemysłowe”, z. 18, Gliwice (in Polish).

Eckardt D. 1979, *Analysis of the unsteady Jet-Wake flow at centrifugal compressor discharge*. Cieplne Maszyny Przepływowe, z. 86, Łódź.

Fortuna S., Sobczak K. 2008, *Numerical and experimental investigations at the flow in the radial fan*. Mechanics, vol. 27, No. 4 (in Polish).

Gawor M., Ligęza P., Rachalski A. 1994, *Termoanemometryczne systemy wyznaczania wektora przepływu prędkości gazu*. III Konferencja Naukowa „Czujniki optoelektroniczne i elektroniczne” COE ’94 (in Polish).

Grudziński M., Grzelczak M., Walczak J. 2003, *Analiza struktury przepływu na wlocie i w gardzieli dyfuzora łopatkowego*. VI Konferencja Naukowa „Wentylatory przemysłowe”, z. 13, Gliwice (in Polish).

Ligęza P. 2001, *Układy termoanemometryczne – struktura, modelowanie, przyrządy i systemy pomiarowe*. Wydawnictwo AGH, Kraków (in Polish).