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CALCULATION OF FLOW PATTERN WITH $\Psi - \Omega$ METHOD IN AN AXIAL FLOW FAN (PERIPHERALLY ARRANGED CAVITIES AT DIFFERENT GAP)

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Abstract

We were dealing with the calculation of the flow pattern in an axial flow fan. A 2D mathematical model, $\Psi - \Omega$ method, was used. The blade passage and the tip clearance secondary flow were calculated. The effect on the secondary flow was investigated by the clearance dimension between the running blade and the standing casing. The effect of the viscosity was also examined.

Keywords: CFD, numerical simulation, axial fan, vortex transport equation.

1. Introduction

An apparatus has been built at the Department of Fluid Flow, Budapest University of Technology and Economics, that is applicable to measurement of the flow characteristics of axial flow fans. The measurement completed on the apparatus was reported in a few papers BENCZE – FÜREDI –SZLIVKA [1, 2, 3]. Model fan characteristic graphs were measured through several years. The results were published in articles BENCZE – KESZTHELYI – FÜREDI – SZLIVKA [4] and [5]. In order to improve the power and efficiency of the fans the investigation of flow microstructure has also arisen as a new direction of the development. The measurement of the velocity field in the neighbourhood of the blade wheel is made by laser Doppler-anemometer. The research so far targeted at the fine structure of the flow velocity pattern next to the blade wheel. A data acquisition system was developed which could map the velocity field in front of and behind the selected blade wheel. The velocity map was successfully produced in the highest efficiency point in other working points. VAD [6] reported his results in his Ph.D. thesis. The further direction of the research is the computer model of flow phenomena partly or entirely in the blade wheel. The results achieved so far are shown in this paper.

2. Model Formulation

The first version model of the axial fan is a two dimensional one. The flow in the fan was only computed in a plane, which is perpendicular to its axis accounting, first of all, for the secondary flows. The blades were considered straight. This way the computation domain shape was significantly simplified. The domain of numerical computation (see *Fig. 1*) was produced in polar system of coordinates. It can be assumed that the flow pattern is the same and approximately steady.

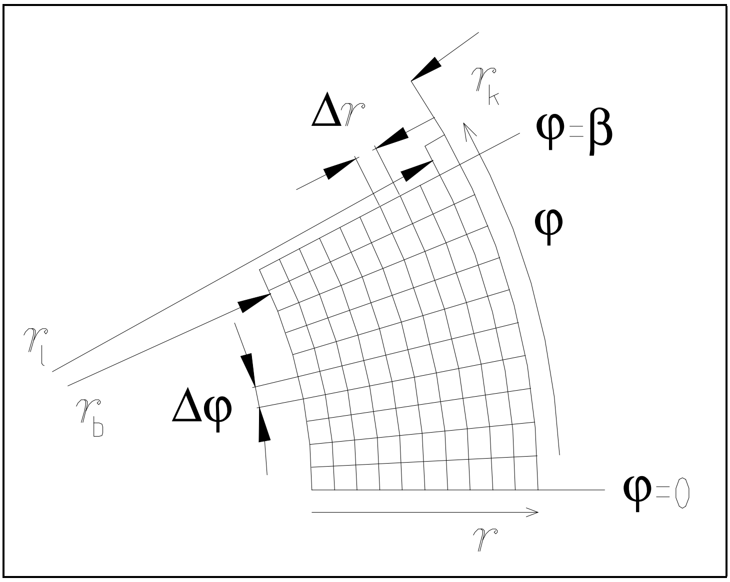

Fig. 1. Region of calculation

The equations that should be solved are the Navier-Stokes and the continuity ones (2D, constant density, rotation-free). The unknowns are the velocity components and the pressure values.

In the case of 2D flow computation it is favourable to consider the velocities as the rotation of a vector field, i.e. they are determined from vector potential as the continuity equation with the substitution of vector potential becomes an identity if the vectorpotential has the required continuity (Young's rule). The velocities are expressed with the Stokes' Ψ stream function as follows

$$v_r = \frac{1}{r} \cdot \frac{\partial \psi}{\partial \varphi}, \quad v_\varphi = -\frac{\partial \psi}{\partial r}.$$

After writing it in the N-S equation system, after simplification, a partial differential equation system of two parts is obtained:

$$\Omega = -\frac{\partial^2 \psi}{\partial r^2} - \frac{1}{r} \cdot \frac{\partial \psi}{\partial r} - \frac{1}{r^2} \cdot \frac{\partial^2 \psi}{\partial \varphi^2}$$

(vortex definition equation),

$$\frac{1}{r} \cdot \left[\frac{\partial \psi}{\partial \varphi} \cdot \frac{\partial \Omega}{\partial r} - \frac{\partial \psi}{\partial r} \cdot \frac{\partial \Omega}{\partial \varphi} \right] = \nu \cdot \left[\frac{\partial^2 \Omega}{\partial r^2} + \frac{1}{r} \cdot \frac{\partial \Omega}{\partial r} + \frac{1}{r^2} \cdot \frac{\partial^2 \Omega}{\partial \varphi^2} \right]$$

(vortex transport equation).

The boundary conditions are easily defined for velocities (e.g. adhesion condition) in the model where the hub and the blades are standing and the wall of the tube is rotating.

On the blades and on the hub (these are standing in the model) the velocity components are everywhere zero, so the derivatives of ψ are zero. On the wall of the tube (which is rotating in the model with ω angular velocity) $v_\varphi = r_k \cdot \omega$ where r_k is the radius of the tube. In the gap the boundary conditions are periodical.

3. Numerical Solution and Results

The equation system was solved by numerical method of finite differences for the geometry outlined at the model formulation. The main steps are as follows:

1. Ψ adjusting the boundary conditions (one time task only as they are constant during the computation).
2. Ψ preliminary iteration, which is a stream function computed by the Laplace's equation ($\Delta\Psi = 0$). This speeds up the computation as good approximate starting values are supplied for the iteration procedure.
3. Alternate solution of Ψ and Ω equations. Iteration of $\Psi\Omega$ previous value is taken as the inhomogeneous part of the equation and then the adjustment of boundary values of Ω from the last values of Ψ. Then the vortex transport equation is iterated taken Ψ as known from the previous computation.

The calculations used a geometry, which corresponds to the axial fan measuring apparatus at the Department of Fluid Flow, Budapest University of Technology and Economics. (Only the blade thickness was higher for more computation points could be placed between the blade and tube wall.) The figures are as follows:

hub radius $r_b = 0.213$ m, tube radius $r_k = 0.315$ m, number of blades $N = 12$. The angular velocity was chosen as $\omega = 110\,\frac{1}{\mathrm{s}}$, and computed in counter-clockwise rotating system relative to the blades. In the computation the effect of blade length and the viscosity were examined in the range $0.309\ \mathrm{m} \leq r_1 \leq 0.314\ \mathrm{m}$; $10^{-5}\frac{\mathrm{m}^2}{\mathrm{s}} \leq \nu \leq 10^{-2}\frac{\mathrm{m}^2}{\mathrm{s}}$.

4. The Effect of Blade Length and the Gap Width

In the case of a large gap (shorter blade) vortex is formed between the two blades. While the gap is reduced, the vorticity tapers away to the hub and its size decreases.

Further reduction of the gap causes the appearance of another vortex and the other vortex is pushed to the compression side end of the blade (see *Fig.2*).

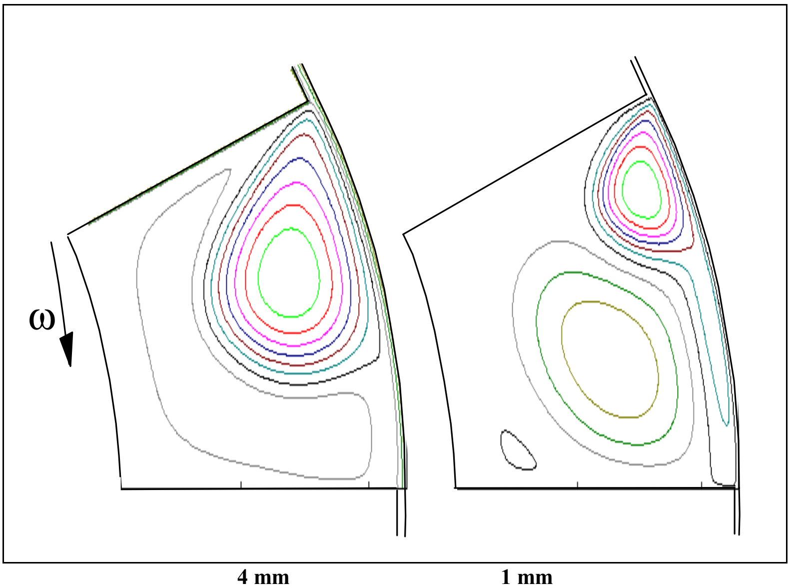

Fig. 2. Effect of the tip clearance dimension on the flow pattern

When the **effect of the viscosity** is examined similar significant results are obtained. For a high viscosity value $\nu = 10^{-2}\,\frac{\mathrm{m}^2}{\mathrm{s}}$ a high intensity vortex is formed in the blade channel. As the viscosity value is reduced $\nu = 10^{-3}\,\frac{\mathrm{m}^2}{\mathrm{s}}$ one large and several small vortexes are formed (see *Fig.3*). In the range of the laminar viscosity one relatively low intensity is formed in the blade channel.

As the viscosity increases the material velocity between the blades increases and the material flow quantity is also influenced by its viscosity.

5. Development Options

A measuring device (LDA) has been made at Department of Fluid Flow; Budapest University of Technology and Economics that is applicable to determine the velocity fields between the blades. The current computation can be compared to this measurement. In the improvement of the computation method the 2 dimensional

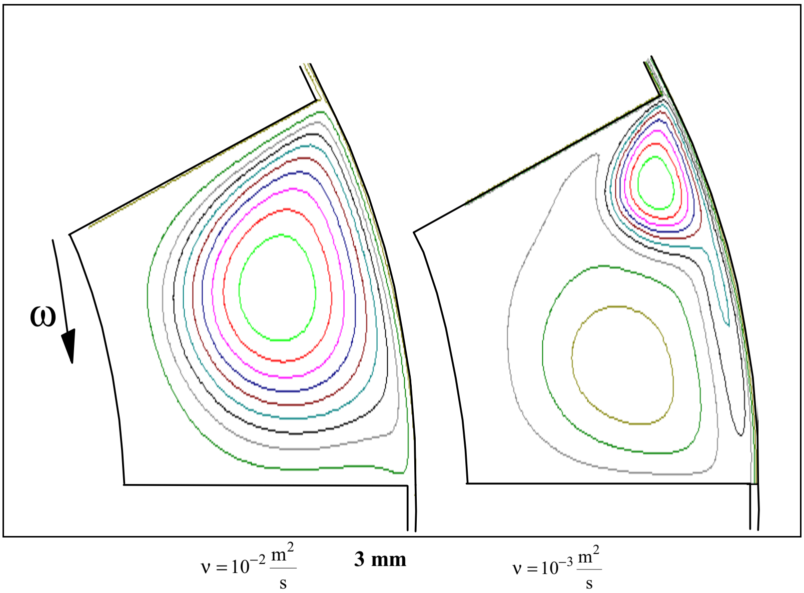

Fig. 3. Effect of viscosity on the flow pattern

model will be replaced by a three dimensional one which makes the blade geometry more accurate.

Acknowledgement

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