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DESIGN OF SUCTION PIPE FOR A WIND-TUNNEL

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1. INTRODUCTION

An open circuit wind-tunnel for flow measurements was designed in 2009. The size of the test section is 500x500x800 mm [1, 2]. The prismatic bodies placed in the test section of the wind-tunnel and the flow around the prismatic bodies is investigated by LDA (Laser Doppler Anemometry), PIV (Particle Image Velocimetry), CTA (Constant Temperature Anemometry) [3-5]. The temperature field is determined by special probe of CTA system, Z-type Schlieren system and BOS (Background Oriented Schlieren) system [6]. The properties of the wind-tunnel: blow-down wind-tunnel, with the test section placed near the end of the wind tunnel. Environment air is blown into the wind-tunnel by axial fan. Oil fog is required for PIV and LDA measurements and a suction pipe is needed for the disposal of the oil fog from the test area. The first objective of this work is to design the optimal suction pipe for the wind-tunnel system. The range of suction speed: \( c = 0.3-5 \, \text{m/s} \). The suction pipe has two functions; in the first case oil fog is sucked by the suction pipe. In the second case low speed \( (c= 0.3-1 \, \text{m/s}) \) is created by only the suction pipe. Uniform velocity distribution is required in the second case; it is the main goal of this work. Vanes are placed into the suction pipe bend. The lengths and positions of the vanes are determined by set goal. Numerical simulation is made by Ansys-FLUENT software. Velocity distribution in the suction pipe is controlled by 3D numerical simulations.

2. WIND-TUNNEL

The wind-tunnel is shown in Figure 1. The suction pipe is designed for this wind-tunnel (to remove the oil fog).
3. DESIGN OF SUCTION PIPE

The following design goals are determined: the range of velocity \( c = 0.3 - 5 \text{ m/s} \), the uniform velocity distribution and disposal of oil fog. The suction pipe consists of two converging pipe sections, right angle bends (cross section: 500x500 mm) and a straight pipe (cross section 450x450 mm). The suction pipe is placed into the laboratory wall and the straight part of the suction pipe contains a roof fan (at the end of the straight pipe). The goals of numerical analysis are (a) to check if the velocity distribution is uniform (especially at low speed) and (b) to determine the hydraulic loss of the suction pipe. A suitable roof fan is selected by the curve of hydraulic loss. The adjustment and size of the suction pipe is shown in Figure 2.

![Figure 2. Complete system setup and drawing of the Suction Pipe](image)

The first goal is achieved (uniform velocity distribution) by three vanes in the bend of the suction pipe. The size of vanes \( r_1, r_2 \) and \( r_3 \) and the bend of the suction pipe are shown in Figure 3.

![Figure 3. Geometry of the bend](image)

The velocity distribution is uniform in the four part-channels (the spacing between the vanes \( i = 1-4 \)) of the bend, if the hydraulic loss

\[
e_i' [J/kg] = \lambda_i \cdot \frac{L_i}{d_{hi}} \cdot \frac{c^2}{2},
\]

all the four parts of the bend is similar. Here \( c \) is the average velocity in the pipe. In equation (1) \( \lambda_i \) is the friction factor of the pipe, \( L_i \) is the length of the centerline of the given part of the bend:

\[
L_i = \frac{(r_i + r_{i-1}) \pi}{4},
\]

and the hydraulic diameter of the four parts of the bend:

\[
d_{hi} = 4 \frac{A_i}{K_i} = \frac{4(r_i + r_{i-1})B}{2[(r_i - r_{i-1}) + B]},
\]

In equation (3) \( A_i \) is the cross-sectional area of the given part of the bend:

\[
A_i = (r_i - r_{i-1}) \cdot B,
\]

\( K_i \) is the perimeter of the given part of the bend:

\[
K_i = 2 [(r_i - r_{i-1}) + B]
\]

In this case the suction pipe is made from aluminium sheet (hydraulic smooth pipe model is applied). Therefore the friction factor of the pipe depends only on the Reynolds number, \( Re_i = (d_{hi} \cdot c)/\nu \), where \( \nu \) is the kinematic viscosity of air. For the approximation of friction factor the Blasius formula is used (velocity range: 0.3-5 m/s):

\[
\lambda_i(Re_i) = 0.3164 \cdot (Re_i)^{-0.25}
\]

The validity of the formula is \( 2320 \leq Re \leq 10^5 \). The hydraulic loss is determined from expression (1) together with Eqs. (2), (3) and (6):

\[
e_i' = 0.3164 \cdot \frac{(2(r_i + r_{i-1})B)}{(r_i - r_{i-1}) + B} \cdot \frac{(r_i + r_{i-1})\pi}{4} \cdot \frac{c^2}{2} \cdot (Re_i)^{-0.25}.
\]

The main condition: the hydraulic losses of the four parts of the bend should be equal:

\[
e_1' = e_2' = e_3' = e_4'
\]

The radii of the three vanes are calculated from expression (8). This system of equations consists of three independent equations with three variables \( r_1, r_2 \) and \( r_3 \). The solution of the system of equations (8) is independent from the flow velocity \( c \), and kinematic viscosity \( \nu \) (see the last two members of equation (7) are the same in the system of equations (8)). The results obtained: \( r_1 = 218 \text{ mm}, r_2 = 313 \text{ mm}, r_3 = 449 \text{ mm} \) (Results and scale model are shown in Figure 3). Results were checked by Ansys-FLUENT numerical simulation software.
4. NUMERICAL SIMULATION AND RESULTS

Velocity distribution and hydraulic loss are calculated by numerical simulations. The model of the simulation consists of 379168 hexahedral cells (without vanes) and 942286 tetrahedral cells (with three vanes). The quality of mesh is controlled; the quality of the worst element is 0.57233 (without vanes) and 0.795306 (with three vanes). Steady flow and k-ε turbulent models are used in the numerical simulation. The following boundary conditions were used: pressure inlet (inlet), massflow inlet (outlet) and hydraulic smooth pipe. Velocity distribution is controlled in four points of the velocity range. The influence of vanes is shown in the following figures. Pathlines are shown in Figure 4 in both cases (without vanes and with three vanes).

![Figure 4. Streamlines in the suction pipe (without vanes and with three vanes)](image)

The influence of vanes is well shown in Figure 4. Vanes have the required effect; because the streamlines in the suction pipe are arranged. Velocity distribution in cross-section (1) (the position of the cross-section can be seen in Figure 4) is shown in Figure 5.

![Figure 5. Velocity distribution in cross-section (1), without vanes (left) and with three vanes (right), [m/s]](image)

The standard deviation shows how spread out a distribution is:

\[
\sigma = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (c_i - \bar{c})^2},
\]

where \( \{c_1, c_2, ..., c_n\} \) are the velocity values of the sample items, \( \bar{c} \) is the mean velocity and \( n \) is the number of items. The standard deviation is calculated in cross-section (1) (see in Figure 6). The standard deviation of velocity in case of without vanes is 1.43 times bigger than other case (with three vanes).

![Figure 6. Standard deviation of velocity](image)

Hydraulic loss is calculated from the volumetric flow rate and the pressure difference of the suction pipe. Pressure drop is calculated from the inlet and outlet average pressure values. The calculated data are shown in Figure 7.

![Figure 7. Suction pipe pressure drop vs. volume flow rate](image)
The influence of friction can be seen in Figure 7. The hydraulic loss of the suction pipe with three vanes increases because of the extra frictional surfaces (three vanes). The change of hydraulic loss is compensated by the uniform velocity distribution (see Figure 6). The selection of the roof fan and frequency changer is assisted by the findings shown in Figure 7.

5. CONCLUSIONS

The results presented in this work confirm that the suction pipe is suitable for creating uniform velocity distribution in the whole velocity range. The influence of vanes is presented in this work. The required parameters of the roof fan and frequency changer are selected from the hydraulic loss diagram. The suction pipe is suitable for setting the suction volume flow rate (to remove of the oil fog).

6. ACKNOWLEDGEMENTS

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REFERENCES