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DEVELOPMENT OF NEW TYPE VENTILATION DUCTS SYSTEM

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Abstract: *The paper presents a way of basic parameters measurement – local losses coefficient ζ and line resistance coefficient λ – which determining pressure loses in ducts of ventilation systems. There was taken into consideration wide scope of cross-sectional areas from A = 0.051 m^2 to A = 2.323 m^2. All measurements were provided for constant Reynolds number Re = 100000.*

Keywords: Ventilation, Rounded rectangular cross-sectional area, Minor (local) losses coefficient, Line resistance coefficient.

1. Introduction

Air flow in circular and rectangular ducts is commonly encountered in ventilation and air-conditioning systems. Both of them have their advantages and disadvantages. Circular systems have better flow and strength properties but they are characterized by worse use of space. The air in a typical ventilation system passes through various fittings, bends, elbows, inlets, exits, enlargements, and contractions in addition to the ducts. Flow through fittings is very complex, and a theoretical analysis is generally not plausible. Therefore, local losses are usually experimentally determined by the manufacturers of the components. The Polish manufacturer, "Nucair Technologies Sp. z o.o." develops new ventilation system based on rounded rectangular cross-sectional area. Examination of the system air-flow properties was commissioned to Mechatronics and Working Machines Group of FME, UTP University of Technology and Life Sciences in Bydgoszcz, Poland.

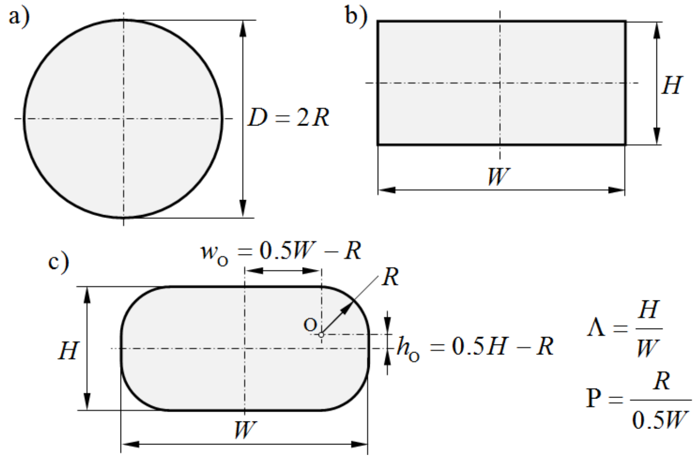

Fig. 1: Characteristic parameters of ducts: a) circular; b) rectangular; c) rounded rectangular.

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Cross-sectional area is characterized by three parameters: width W, height H, and fillet radius R (Fig. 1). These parameters, during the analysis, are used in two non-dimensional forms: flatness of rectangle $\Lambda = H/W$ and relative rounding $\mathrm{P} = R/0.5W$, where width W is the basic parameter.

Fillet radius R is substantial. Therefore, the knowledge of rectangular cross-section cannot be directly used. The new type of ducts mixes various properties of ducts with circular cross-section (best theoretically recognised) and rectangular cross-section (most used).

From the dimensional point of view, the system consists of 50 recommended, 20 permissible, and 7 not recommended cross-sections (Fig. 2), where white cells are recommended, 5 % of grey cells are permissible, 25 % of grey cells are not recommended, and 35 % of grey cells are impossible.

Cross-sectional area A [m^2]

A		H [mm] 200	250	300	400	500	600	800	1000	1200
R [mm]	W [mm]									
100	300	0.051	0.066	0.081	0.111	0.141	0.171	0.231	0.291	0.351
100	400	0.071	0.091	0.111	0.151	0.191	0.231	0.311	0.391	0.471
100	500	0.091	0.116	0.141	0.191	0.241	0.291	0.391	0.491	0.591
100	600	0.111	0.141	0.171	0.231	0.291	0.351	0.471	0.591	0.711
100	800	0.151	0.191	0.231	0.311	0.391	0.471	0.631	0.791	0.951
200	1000				0.366	0.466	0.566	0.766	0.966	1.166
200	1200				0.446	0.566	0.686	0.926	1.166	1.406
200	1400				0.526	0.666	0.806	1.086	1.366	1.646
200	1600				0.606	0.766	0.926	1.246	1.566	1.886
300	1800						1.003	1.363	1.723	2.083
300	2000						1.123	1.523	1.923	2.323

recommended | permissible | not recommended | impossible

Fig. 2: Dimensions of new system.

The cross-sectional area A varies from $A_{min} = 0.051\ m^2$ to $A_{max} = 2.423\ m^2$. This wide scope of areas imposes high demands relating to the measurement stand.

2. Measurements

The study of new components flow properties consists of determination of two basic parameters: (a) line resistance coefficient λ and (b) local losses coefficient ζ, both are dimensionless. These parameters are used to calculate the pressure loss in ventilation system composed of serial connected i straight ducts and j components (e.g. elbows, fittings) (Orzechowski et al., 1997)

$$P_{\mathrm{los}} = \frac{\rho V_{\mathrm{avg}}^2}{2}\left(\sum_i \lambda_i \frac{l_i}{D_{\mathrm{h},i}} + \sum_j \zeta_j\right) \quad (\mathrm{Pa}) \tag{1}$$

where ρ is the air density(kg/m^3), V_{avg} is the air average velocity(m/s), l_i is the length of straight ducts (m), $D_{\mathrm{h},i}$ is hydraulic diameter of straight ducts (m), λ_i and ζ_i as mentioned above.

Hydraulic diameter was calculated from the formula

$$D_{\mathrm{h}} = \frac{4A}{p} = \frac{2\left(\Lambda - (4-\pi)\mathrm{P}^2\right)}{1 + \Lambda - (4-\pi)\mathrm{P}} W \tag{2}$$

where A is a cross-sectional area of duct (m^2), p is its perimeter (m), other nomenclature discussed above.

Number of components must be reduced to $i = 2$ and $j = 1$ for measurements of properties λ and ζ. As a result, we obtain system presented in Fig. 3. In this figure $Q_{\mathrm{in}} = Q_{\mathrm{out}}$ means air flow rate (m^3/s) through examined duct. After reduction and rearranging equation (1), we obtain formula to determine local losses coefficient ζ

$$\zeta = \frac{2P_{\text{los}}(l)}{\rho v_{\text{avg}}^2} - \lambda \frac{l_{\text{in}}}{D_{\text{h}}} - \lambda \frac{l_{\text{out}}}{D_{\text{h}}} \tag{3}$$

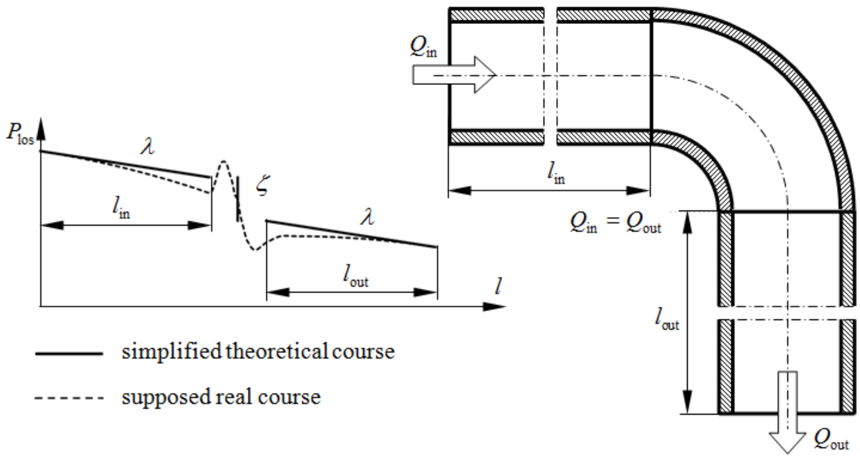

Fig. 3: The idea of experimental minor (local) losses determination.

The actual image of the laboratory stand is presented in Fig. 3. Part a) shows duct with *W = 0.6 m*, *H = 0.2 m* and *R = 0.1 m*. Part b) shows supply system, which consists of fan controlled by power inverter and flow straightener (cuboid in the foreground) located in the background in the left side of part a). Part c) shows measurement point, which consists of Prandtl probe with digital pneumo-electric transducer and it is connected to a computer located in the main part of Fig.4a). Part d) of Fig. 4 shows main part of flow straightener in a honeycomb shape with length 0.5 m. Dimensions of flow straightener are 0.18 m x 0.12 m. Hexagon side is 35 mm.

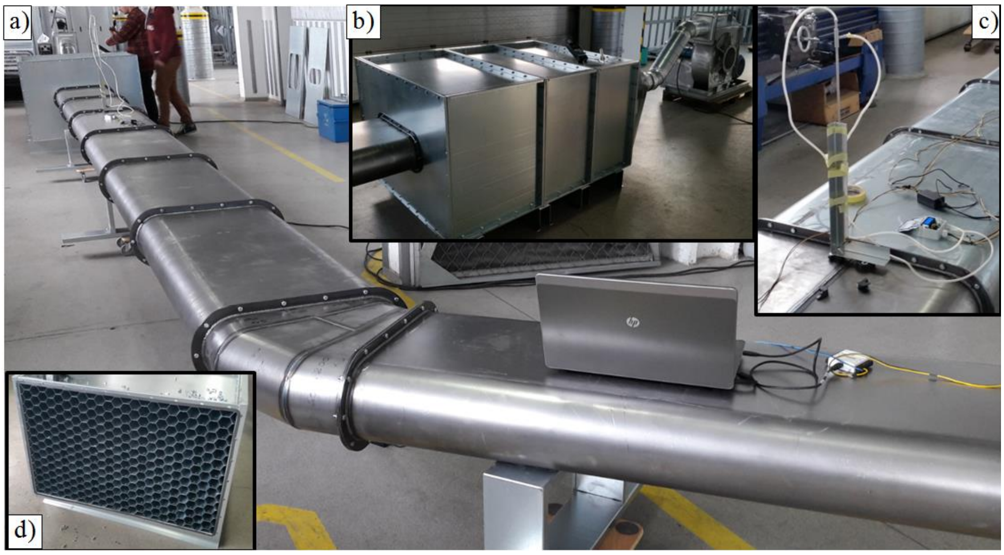

Fig. 4: Laboratory stand a) duct with supply system, b) view of supply system, c) measurement point, d) flow straightener.

It is necessary to determine λ for calculations ζ, as we can see in the formula (3). Line resistance coefficient λ can be determined after substitution of $\zeta = 0$ into the equation (3), and after rearranging we obtain

$$\lambda = \frac{2P_{\text{los}}}{\rho V_{\text{avg}}^2} \cdot \frac{D_{\text{h}}}{l_{\text{in}} + l_{\text{out}}} \tag{4}$$

A new configuration of laboratory stand is a result of substitution $\zeta = 0$ and it is presented in Fig. 5.

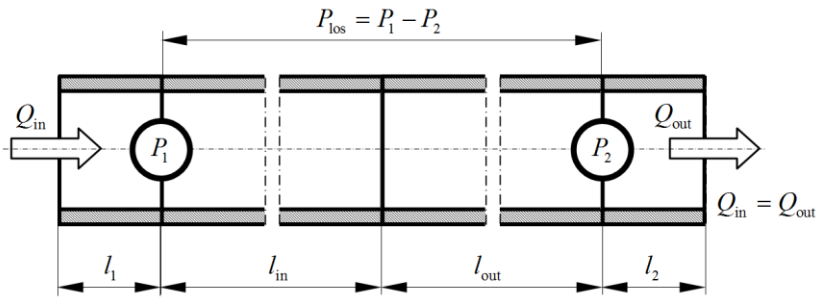

Fig. 5: Idea of laboratory stand for determination of line resistance coefficient λ .

In Fig. 5, l_1 and l_2 are inlet and outlet parts of the duct and they are necessary for smoothing the flow, both about $3D_h$. l_{in} and l_{out} are bigger than $10D_h$.

All tests are performed for $Re = 100000$. This number results from analysis V_{avg}

$$Re = \frac{V_{avg} D_h}{\nu} \quad \rightarrow V_{avg} = \frac{Re \cdot \nu}{D_h} \tag{5}$$

For standard $\nu = 1.5 \cdot 10^{-5}\,\mathrm{m^2/s}$ for air, we obtain very simple formula $V_{avg} = 1.5/D_h$. For $D_h \in \langle 0.248; 1.579 \rangle (\mathrm{m})$, we obtain scope of average velocity $V_{avg} \in \langle 6.041; 0.926 \rangle (\mathrm{m/s})$. The maximum permissible average velocity in ventilation ducts is $V_{avg} = 10\,\mathrm{m/s}$. Maximum of average velocity is limited by noise produced by ventilation system. The next step is to calculate average velocity at a maximum velocity V_C in the center of the duct (Peszyński et al., 2016)

$$V_C = V_{avg} \frac{\Lambda - (4-\pi)\mathrm{P}^2}{\Lambda \frac{n}{n+1}\left(\frac{n}{n+1}\left(1-\left(\frac{4\mathrm{P}^2}{\Lambda}\right)^{\frac{n+1}{n}}\right)+\pi 4^{\frac{1}{n}}\left(\frac{\mathrm{P}^2}{\Lambda}\right)^{\frac{n+1}{n}}\right)} \tag{6}$$

where $1/n$ is exponent Prandtl power-law velocity profile. Velocity at the central point of cross-sectional area is measured by Prandtl probe and tuned to correct value using power inverter.

3. Conclusions

Presented studies show that smaller maximum velocities $(V_{C,} < 2.0\,\mathrm{m/s})$ for bigger ducts sizes, where Reynolds number $Re = 100\,000$, cause measurement problems of low pressures $(P_{C,\,dyn} < 3.0\,\mathrm{Pa})$. Instead of Prandtl probe, the thermo-anemometer is used for these cross-sectional areas to measure maximum velocity. The quality of individual connections of duct segments has significant effect on line resistance coefficient λ

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