LINEAR PRESSURE LOSSES COEFFICIENTS IN A NEW VENTILATION SYSTEM

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Abstract: *This paper presents the results of research on linear losses in a new ventilation system based on channels with a rounded rectangle cross-section. The friction coefficients of linear pressure losses referred to the unit of the straight length of the duct section $\zeta_l \left[\mathrm{m}^{-1} \right]$ as well as generalized dimensionless friction coefficient of linear pressure losses $\lambda \left[- \right]$ are presented. The main achievement of the paper is the statement that the lambda coefficient λ can replace the coefficients ζ_1 for all 79 examined duct cross-sections.*

1. Introduction

For three years, Nucair Technologies Sp. z o.o., Solec Kujawski (Poland), the manufacturer of ventilation systems and the Faculty of Mechanical Engineering of UTP conducts research on a new ventilation system based on rounded rectangular cross-section area ducts (Peszyński et al.2 2017). In the initial phase of the research, a comparative analysis of the properties of new and old ducts was made (Peszyński et al. 2016). The main problem during this research was to find an analytical model of the air velocity distribution in the new type of ducts (Peszyński et al.3 2017). This model was necessary to determine the average air velocity in the duct, which is the basis for determining the pressure losses in the system components. Due to the wide range of tests (in total 79 cross-sections), different models had to be developed. Particular problems were caused by highly flattened cross-sections. For this type of cross-section, models based on the virtual division of the cross-section into a square and a slot have been developed (Peszyński et al.1 2017). In total, four models of velocity distribution were developed, and their comparison shows the last cycle paper (Peszyński, 2018). The developed models were verified experimentally. Numerical simulations using the ANSYS-FLUENT software have been also widely used, in particular where experimental tests are very difficult, e.g. pressure and velocity distribution in fittings of the system (Smyk et al.1 2017) or as an element supporting the design of the test stand (Smyk et al.2 2017).

Although the theory of air flow is reasonably well understood, theoretical solutions are obtained only for a few simple cases such as fully developed laminar flow in a circular pipe. Therefore, we must rely on experimental results and empirical relations for most air flow problems rather than closed-form analytical solutions. Noting that the experimental results are obtained under carefully controlled laboratory conditions and that no two systems are exactly alike, we must not be so naive as to view the results obtained as "exact."

The basic task of the conducted research was to determine the local losses ζ of the ventilation system elements. However, to experimentally determine the local losses coefficient, it is necessary to know the coefficient of linear losses (Darcy–Weisbach friction factor) λ or ζ_l of straight sections of ventilation ducts.

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2. Linear losses

There are different theoretical ways to determine this coefficient λ, the most popular is the phenomenological Colebrook–White equation, obviously used for turbulent flow in smooth and rough pipes

$$\frac{1}{\sqrt{\lambda}} = -2\log\left(\frac{2.51}{\mathrm{Re}\sqrt{\lambda}} + \frac{k}{3.7 D_{\mathrm{H}}}\right) \qquad (1)$$

where: k is roughness of duct, D_{H} – hydraulic diameter, Re – Reynolds number.

Equation (1) has an implicit nature, the result can be obtained only by iterative methods, which in the current state of computational technology do not cause any problems. However, when calculating using this formula, it seems that it applies to hydraulically smooth channels only. This, however, cannot be said about the ducts of the system under investigation. These ducts consist of segments of length $l = 1.5\,\mathrm{m}$ or $l = 1\,\mathrm{m}$. There is a seal between the segments, which, according to observations resulting from the conducted tests, has a much greater influence on the linear losses coefficient λ than that occurring in (1), the surface roughness k of the plates from which the ducts were made. In addition, the sealing effect is stochastic. Therefore, during the tests, λ was determined experimentally. The idea of laboratory stand for determination of coefficient of linear losses λ was presented in (Peszyński et al.2 2017). This coefficient was determined by the formula

$$\lambda = \frac{2 P_{\mathrm{los}} D_{\mathrm{H}}}{\rho v_{\mathrm{avg}}^2 (l_{\mathrm{in}} + l_{\mathrm{out}})} \qquad (2)$$

where: $l_{\mathrm{in}} + l_{\mathrm{out}}$ is the length of the straight duct, P_{los} – pressure drop along the length of the duct, D_{H} – hydraulic diameter, ρ – air density, v_{avg} – air average velocity in duct.

The equation (2) illustrates the importance of determining the average flow velocity in the ventilation system duct, therefore the determination of this value in previous publications was devoted to particular attention.
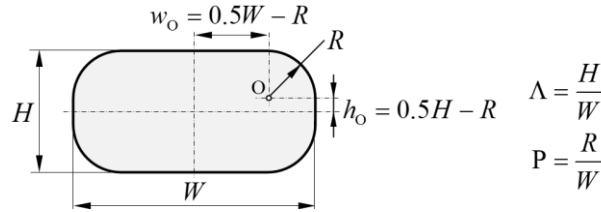

Fig. 1: Basic parameters of rounded rectangle duct cross-section area.

Hydraulic diameter D_{H} of rounded rectangular (Fig. 1) was determined from equation:

$$D_{\mathrm{H}} = \frac{4 A_{\mathrm{rr}}}{U_{\mathrm{rr}}} = \frac{4\left(H \cdot W - 4\left(1 - \frac{\pi}{4}\right)R^2\right)}{2\left(W + H - (4 - \pi)R\right)} = \frac{2\left(\Lambda - (4 - \pi)\mathrm{P}^2\right)}{1 + \Lambda - (4 - \pi)\mathrm{P}} W \qquad (3)$$

where: A_{rr} is area of rounded rectangular, U_{rr} – perimeter of rounded rectangular, Λ – dimensionless height, P – dimensionless radius, W, H, R – geometrical parameters of the rounded rectangle

Fig. 2 shows linear losses marked with the symbol ζ_l, for all 79 experimental cross-sections tested, given by the formula

$$\zeta_l = \frac{\lambda}{D_{\mathrm{h}}} = \frac{2 P_{\mathrm{los}}}{\rho v_{\mathrm{avg}}^2 (l_{\mathrm{in}} + l_{\mathrm{out}})} \quad \left[\mathrm{m}^{-1}\right] \qquad (4)$$

This form of linear losses coefficient presentation is very popular in the catalogs of ventilation system published by manufacturers. Graphic form of $\zeta_l(w)_{h=const}$ for selected h is presented also in Fig 4 – dashed lines. Losses in the channel are determined by multiplying the value ζ_l by the length of the duct. Each duct

cross-section area has a different linear loss value ζ_l. These are the direct results of the experimental studies described above.

ζ_l $[\mathrm{m}^{-1}]$		W [m]										
		0.3	0.4	0.5	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
H [m]	0.20	0.099	0.085	0.077	0.072	0.068						
	0.25	0.092	0.078	0.070	0.063	0.056	0.052					
	0.30	0.084	0.073	0.066	0.060	0.052	0.048	0.045				
	0.40	0.073	0.064	0.058	0.053	0.046	0.041	0.038	0.036			
	0.50	0.062	0.056	0.050	0.046	0.040	0.035	0.032	0.030	0.029		
	0.60	0.054	0.050	0.045	0.041	0.036	0.031	0.028	0.026	0.024	0.023	0.022
	0.80	0.049	0.045	0.041	0.037	0.031	0.026	0.023	0.021	0.020	0.019	0.018
	1.00	0.045	0.042	0.038	0.034	0.028	0.023	0.020	0.018	0.017	0.016	0.016
	1.20	0.042	0.039	0.036	0.032	0.026	0.022	0.019	0.017	0.016	0.015	0.015

Fig. 2: Values of measured linear loss coefficients ζ_l for 79 cross-section area.

Dimensionless linear loss coefficients λ – equation (2) – has a lot more general meaning. In order to obtain a dimensionless pressure loss coefficient λ based on the data presented in Fig. 2, it is necessary to multiply this data by the appropriate hydraulic diameter D_H determined by equation (3). Values of W and H were taken based on the coordinates of the table in Fig. 2, the parameter $R = 0.1\,\mathrm{m}$ was constant for all cross-sections. The result of this multiplication is shown in Fig. 3 in the form of a graph.
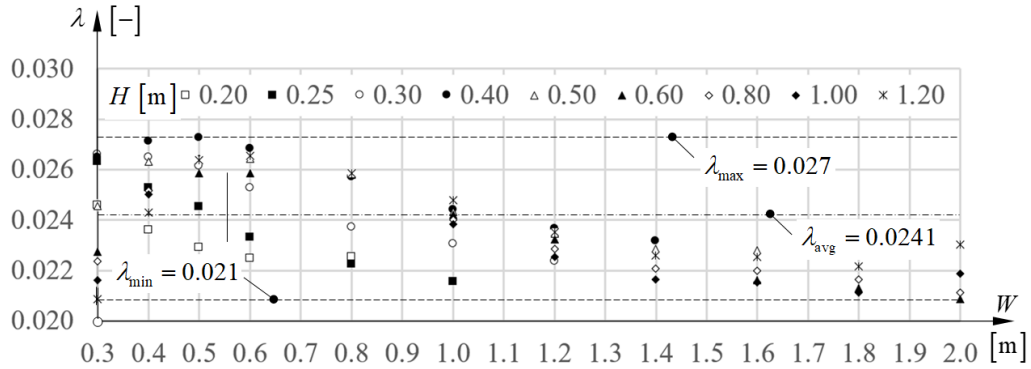

Fig. 3: Dimensionless pressure loss coefficient λ.

The values shown in Fig. 3 are within a narrow range of values $\lambda \in (0.020;\, 0.027)$. If we accept as true the sentence included in one of the fundamental textbook on fluid mechanics (Cengel et all, 2006), chap. 8, p. 322 – *An error of 10 percent (or more) in friction factors calculated using the relations in this chapter is the "norm" rather than the "exception."* – it is reasonable to calculate the average value for all 79 duct shapes. Therefore

$$\lambda_{\mathrm{avg}} = \frac{1}{79}\sum_{i=1}^{79}\lambda_i = 0,024 \tag{5}$$

The value of dimensionless linear loss coefficient $\lambda = \lambda_{\mathrm{avg}}$ determined in the above manner was then used for any comparative analysis of ventilation ducts, first of all for determining local losses coefficient ζ of system fittings.

Fig. 4 presents a comparison of ζ_l coefficients measured directly during tests with $\zeta_l\!\left(\lambda_{\mathrm{avg}}, D_H\right)$ coefficients calculated on the basis of average λ_{avg} lambda coefficient and hydraulic diameter D_H. For clarity of the image, only 4 sets of results from the available 9 are shown. The calculated coefficients are marked with a solid line and black markers, while the values measured ones with a dashed line and with corresponding white markers. The curves presented in this figure confirm the thesis that all 79 ζ_l coefficients can be replaced by one λ coefficient.
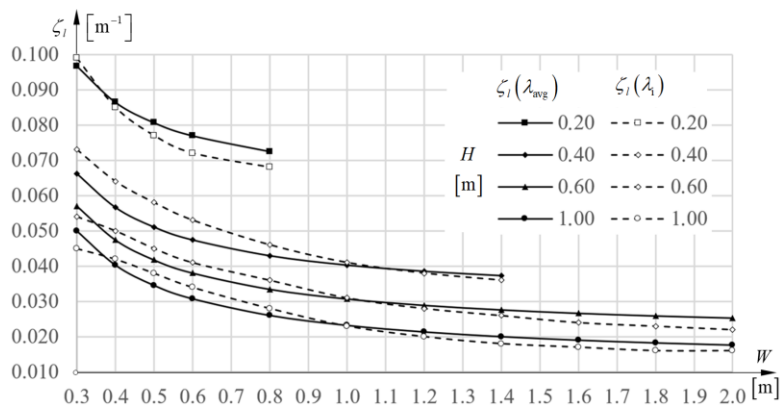
Fig. 4: Comparison of linear loss coefficients ζ_l measured directly and determined on the basis of averaged dimensionless coefficient λ.

The reader based on Fig. 2 and $\lambda = 0.024$ can at any time make the missing 5 sets of curves using the left side of the equation (4). This conclusion was very useful during later experimental testing of local pressure losses.

3. Conclusions

The dimensionless linear loss coefficient $\lambda[-]$ can replace all dimensional loss coefficients $\zeta_l\left[\mathrm{m}^{-1}\right]$ for 79 examined rounded rectangle duct cross-sections.

The advantage of the above procedure is assimilation experimentally obtained dimensionless linear loss coefficient λ to the coefficient determined from the Colebrook White formula (1). In this equation, only the Reynolds number Re, the roughness of the plate k and the hydraulic diameter D_{H} of the cross-section are present, but there is no cross-sectional shape.

The Colebrook–White equation can be applied to a duct with a different cross-section than circular, one should remember about the influence of seals between the duct segments. This goal can be achieved by the correction of the roughness coefficient k.

Acknowledgement

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