

Ducts for uniform air distribution – textile diffusers

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Abstract

The paper contains basic information about the perforated ducts for uniform air distribution with constant cross section. It also describes the issues of internal pressure profiles and their impact on the uniformity of air discharge. This is closely connected with the description of the air discharge from perforation. Then it provides an overview of actions leading to ensuring a uniform distribution. Closer it engages in textile diffusers, their applications, advantages and disadvantages. It also gives some examples and innovations in their design.

Key words: *ventilation, perforated duct, textile air distribution systems*

Abstrakt

Příspěvek obsahuje základní informace o perforovaných vzduchovodech pro rovnoměrný rozvod vzduchu s konstantním průřezem. Dále popisuje problematiku průběhů vnitřních tlaků a jejich vliv na rovnoměrnost výtoku vzduchu. S tím úzce souvisí i popis výtoku vzduchu z perforace. Následně uvádí přehled opatření k zajištění rovnoměrné distribuce. Blíže se zabývá textilními vyústkami, jejich použitím, výhodami a nevýhodami. Uvádí také příklady použití a novinky v jejich konstrukci.

Klíčová slova: *větrání, perforovaný vzduchovod, textilní vyústky*

1. Introduction

An integral part of buildings is ventilation and air conditioning. A very important parameter with significant influence on the internal environment is a distribution of velocity. The biggest influence on the distribution of velocity has a method of distribution supply air.

Usually we require uniform ventilation because we have to create good conditions in whole space. To uniform ventilation is necessary to ensure uniform supply of air, uniform distribution respectively.

There are many ways of air distribution in the space. In addition to normal distribution of metal elements (for example grilles, nozzles), we can use elements from textile or foil. These, so-called textile diffuser (diffuser foil), are from the aesthetic and technological considerations often produced as ducts with constant cross section. Air is supplied from the textile diffusers due to both natural permeability and perforations or its combinations.

The discharge of the air from textile materials or foil diffusers (air distribution in space) is significantly affected by internal aerodynamics.

Although the usage of textile (foil) diffusers isn't new, this method of design isn't on the same level as the diffusers from metal.

My goal is to propose a method of design of textile (foil) diffusers with constant cross section (the most used) for a uniform air supply.

2. Basic informations

2.1. Types of duct

Basic division:

- for supply
- for exhaust

Cross section:

- circular
- square
- other (circular segment, polygon, ...)

Material:

- fixed (sheet, plastic, from brick, ...)
- flexible (foil, textile, metal foil, ...)

2.2. Discharge air from perforation

The discharge velocity of a ideal incompressible fluid (theoretical velocity) from the Bernoulli equation is:

$$v_o = \sqrt{\frac{2 \cdot \Delta p}{\rho}} \quad (1)$$

For real incompressible fluid is:

$$\dot{V} = \mu \cdot A_o \cdot v_o = \mu \cdot A_o \cdot \sqrt{\frac{2 \cdot \Delta p}{\rho}}, \quad (2)$$

where the discharge coefficient consists of a contraction and velocity coefficients:

$$\mu = \varepsilon \cdot \varphi \quad (3)$$

The contraction coefficient reflects the influence of the flow inertia. The velocity coefficient express a energy dissipation.

The values of the discharge coefficient depend on the ratio of the wall thickness and the hydraulic diameter of the hole (the hole without pipe), the shape and the dimensions of any pipe, the curvature of the wall at the hole and the curving walls of the hole and obstacle before the openings (e.g. wall adjacent to the hole).

The air in the duct can be considered as an incompressible fluid, because the influence of the pressure changes on the density is small.

In the discharge of the fluid from the duct, in which the fluid flow perpendicular to the axis of the hole, there is a flow deflection from the axis. The deflection is caused by the axial velocity of fluid in the pipe. The angle of deflection is dependent on the dynamic and static pressure in the duct and perforation geometry.

2.3. Uniform air supply

The uniform supply means that the air discharge form the diffuser is constant over the length. In order to constant discharge along the length must be constant the product of the theoretical outflow velocity, discharge coefficient and area of perforation, resp. product of the outflow velocity and perforation area.

The discharge velocity is according to the equation (1) depends on the difference of static pressures inside and outside the duct. For the uniform supply of air must be constant pressure difference by uniform spaced perforations.

But in the air duct is changing a static and dynamic pressures, because the flow rate in the duct is decreasing. This is caused by the discharge of the air duct. The Bernoulli equation (for incompressible gas):

$$p_1 + \frac{v_1^2}{2} \cdot \rho + h_1 \cdot \rho \cdot g = p_2 + \frac{v_2^2}{2} \cdot \rho + h_2 \cdot \rho \cdot g + \Delta p_z \quad (4)$$

shows that with the decrease in the dynamic pressure (flow) is increasing the static pressure. The static pressure is also reduced by the pressure losses. The non uniformity air supply is the result of these pressure changes. It is therefore not possible to ensure a uniform supply without further measure.

2.4. Pressure loss, velocity profiles

The pressure loss occurs by the air flow in the perforated duct. These losses are divided into friction and local.

The friction pressure loss is generated by the moving of neighboring layers of the air. The faster layer is hampered by the frictional force acting between the two layers. This braking is due to the air viscosity, which is the molecular mixing process to the transport of momentum across the air stream.

When the air flows in the duct, the velocity profile develops where the air velocity is zero on the wall - the wall is the largest frictional force. The shape of the velocity profile in a long straight line (developed undisturbed profile) depends on the Reynolds number. If the Reynolds number is higher, the velocity profile is near the rectangular profile.

The frictional pressure losses are expressed Darcy-Weisbach equation:

$$\Delta p_{z\lambda} = \lambda \cdot \frac{l}{D_h} \cdot \frac{v^2}{2} \cdot \rho \quad (5)$$

where λ is the coefficient of friction, which is dependent on the Reynolds number and the relative roughness of the duct. Its value is for the stable (developed) velocity profiles relatively well known and verified by the experiments. In the perforated duct is changing the velocity profiles by the discharge (the profiles are deformed), and for these cases are not the available value.

The local pressure loss is generated by the disturbance velocity profile and its return to the profile generated by the friction (by creating the profile).

The local pressure loss is expressed as:

$$\Delta p_{zm} = \zeta \cdot \frac{v^2}{2} \cdot \rho \quad (6)$$

where ζ is the coefficient of the local loss.

In the perforated duct is the local loss of branching flow in a straight line and the equalization of profiles. It is the pressure loss of a sudden extension, according to some authors. In the account also comes the loss of direction change and the change in the duct cross section.

The local loss coefficient in a straight line after the turn is difficult to determine. Only a single branching was investigated experimentally, where the loss coefficient was also contained in the loss of equalization of velocity profile. When there are more branching, the results are not. The perforated air ducts is complicated by the fact that the holes can be placed in the wall as an irregular along its length and the circumference.

In the densely perforated (breathable) air ducts are not seen each branch and the whole area look like a boundary layer suction through the wall. This means that there is a drain boundary layer (the air layer with the least momentum).

For the local pressure loss coefficient of the velocity profiles compensation (the change profiles) were derived from the momentum theorem [1]:

$$\zeta = \alpha_1 - \alpha_2 + 2 \cdot (\beta_2 - \beta_1) \quad (7)$$

where the velocity profiles are described in the Coriolis coefficient of kinetic energy and the momentum of the Boussinesq coefficient. The equation (7) applies to the duct with the constant cross section.

The determination of the pressure loss is complicated by the interaction of the local pressure loss on the friction pressure loss (influencing the velocity profiles).

The velocity profiles in the perforated duct are influenced by the geometry and shape of perforations. If the duct is uniformly perforated (breathable) around its circumference, the velocity profile is very balanced; resp. will be near the ideal rectangular profile.

If the perforations are on one side of the longitudinal duct only, there will be a decrease in velocity on the opposite side. At the end of the duct where the air flow is already low, is a reverse flow at the opposite side. The higher longitudinal velocity at the perforated wall is due to the discharge. Moreover, in the plane of perpendicular to the plane with perforation will be different velocity profile, where was axisymmetric.

2.5. The pressure profile in perforated duct

If the ideal incompressible fluid flowed in the perforated duct, the static pressure will rise to monotonous towards the end. If the real fluid flow, the static pressure is reduced of the pressure losses, see chapter 2.4. The pressure loss is depending on the velocity of the air. The pressure loss can be greater than the increase in pressure, see equation (4), (5) and (6).

The pressure profile in duct is dependent on its length - the influence of the frictional pressure losses. For the mutual comparison of the length of the duct is converted into a dimensionless length:

$$L' = \frac{L}{D} \quad (8)$$

Another important parameter is the aperture ratio:

$$\sigma = \frac{\sum A_o}{A} \quad (9)$$

Sometimes uses an effective aperture ratio, which is based on (9):

$$\sigma_{ef} = \frac{\sum \mu A_o}{A} \quad (10)$$

The parameters (8) to (10) describe the basic geometry of the duct. Beyond it is necessary to describe the distribution of perforations (uniform, nonuniform, ...).

We introduce a dimensionless static pressure for a comparison:

$$p' = \frac{p_x}{p_0} \quad (11)$$

and a dimensionless distance from the closed end of the duct:

$$x' = \frac{x}{L} \quad (12)$$

On the Fig. 1 is a pressures profiles in a several duct with a similar value of L' (the short ducts) and a uniform perforation. The static pressure in the duct increases monotonically until the end of the duct. The figure shows that the pressure difference between entering the duct and its end decreases with the decreased value of σ . This leads to an increase in the uniformity of air discharge.

Other experiments also show that in short duct (L' to about 30) can be neglected the friction pressure loss, because it is very small. In these short ducts the pressure increases monotonically. This also illustrates Fig. 2, where is also visible the effect of the duct length on the profile of the dimensionless pressures. With the increasing length of the duct will alter the

pressure – the pressure loss at the beginning of duct is higher than the pressure increase. These ducts are uniform perforated.

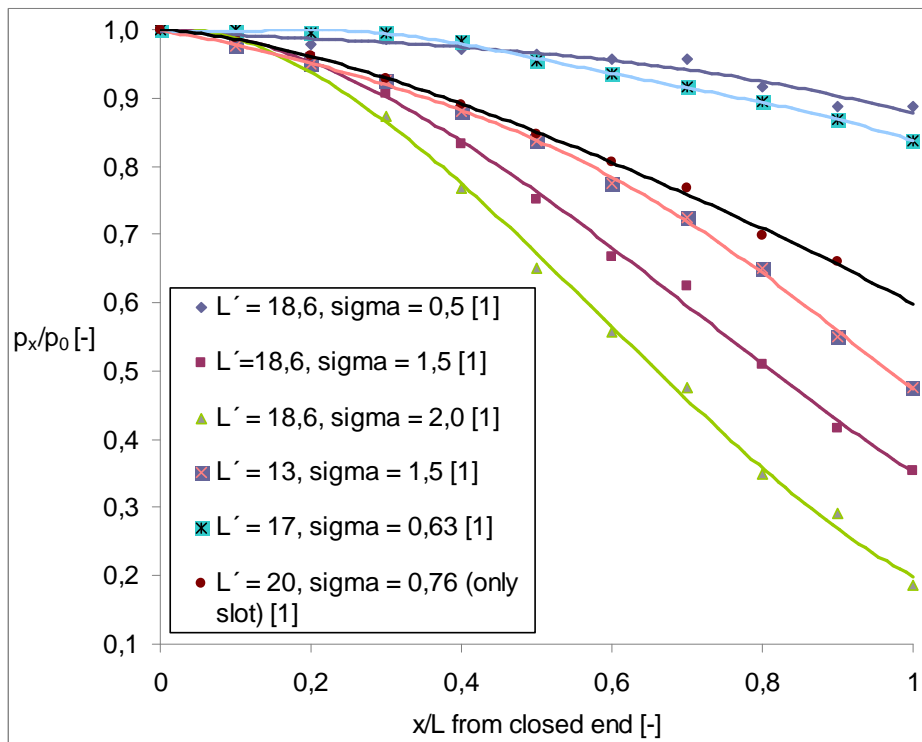


Fig. 1 The static pressure profile in a short uniform perforated duct

There is few measured values for a nonuniform perforation. The problem is also an accurate description of nonuniform perforations.

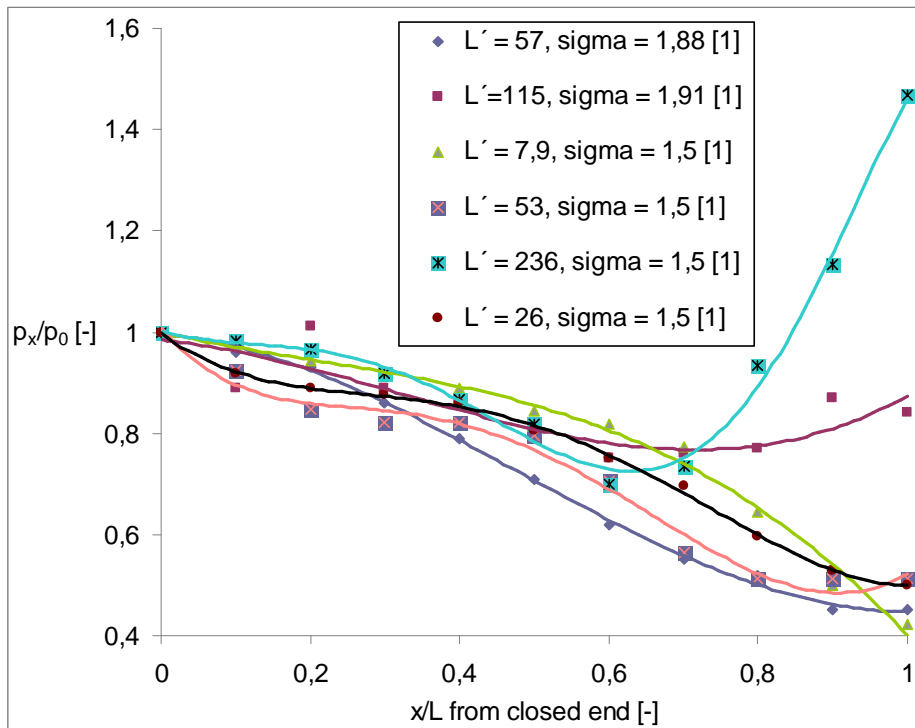


Fig. 2 The static pressure profile in a uniform perforated duct

2.6. The measures for the uniform supply

These measures are to:

- throttling of excess static pressure by the restrictions. The static pressure profile in a short smooth perforated duct with the embedded restrictions is on Fig.3. In this case there is a non uniformity but appropriate choice of the restrictions can be reduced to an acceptable levels.
- adaptation of the perforation area. In this way we can either change the aperture size or change their number. It is also possible partial covering of the holes evenly perforated duct or a combination of these options.
- increase in the pressure loss of perforation, so that the static pressure loss in the ducts is negligible over the loss of perforation. At the same uniform distribution of the holes will be the nonuniform flow at acceptable levels. See Fig. 1. for $\sigma = 0,5$ a $0,63$.
- ducts with a variable cross-section and uniform perforation, where the variable cross-section is designed so that the static pressure was constant along the diffusers.

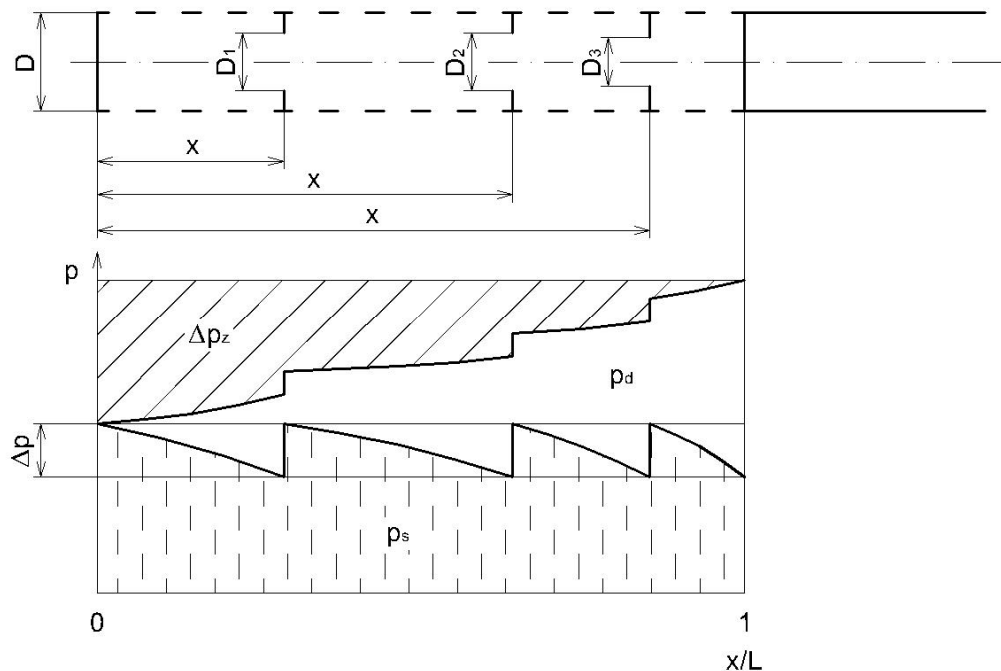


Fig. 3 The static pressure profile in a short smooth perforated duct with the embedded restrictions

3. Discharge air from the textile and foil duct

For the design of perforated air ducts is also necessary to know the discharge coefficient of a perforation or the pressure lost of a perforated material. For the perforation produced mechanically these values are known, see Idělčik [2].

For the perforating textiles and foils is applying a laser (see next section). This allows the microperforation. The size of these holes is several tenths of mm. The textile is perforated textile with a density of up to several hundred thousand holes per m^2 . So produced perforation is specific. The Fig. 4 shows the detail of the hole in textile with the thickness of 0,54 mm. It is slightly irregular, has a sharp edge and the round edge stands out above the level of the textile. The Fig. 5 shows detail of the hole in the foil with a thickness of 0,1 mm. The hole is a regular with the protruding edge and with the area affected by laser. It is assumed also a blurred edge. The rounded edges of the holes, a high ratio of a wall thickness and a diameter of the hole have a significant effect on the discharge coefficient. The hole with rounded edges

in a thick wall has a higher discharge coefficient (the lower pressure drop) than the same size hole in a thin wall with a sharp edge.

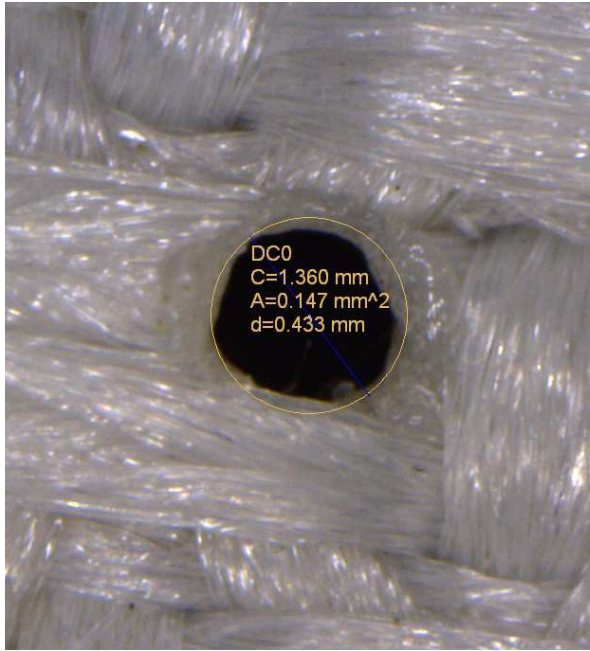


Fig. 4 The hole in the textile

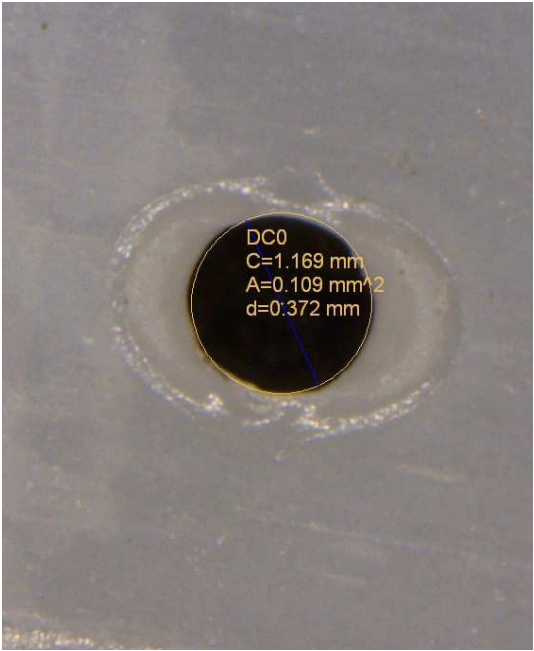


Fig. 5 The hole in the foil

The values of the discharge coefficient or the pressure lost of perforated materials do not provide by manufacturers generally. Therefore it was necessary to measure these values. For their determination it was necessary to measure the air flow flowing through the sample and the difference of static pressures before and after the sample (the pressure loss of the sample). The samples of textiles and foils were placed in the measuring adapter, see the Fig. 6. The air was fed to the measuring adapter by a fan UV-1. According to BS the removable conical restriction with an inner diameter of 15,5 mm was placed at the suction fan. The flow rate was controlled by an electronic inverter for fans.

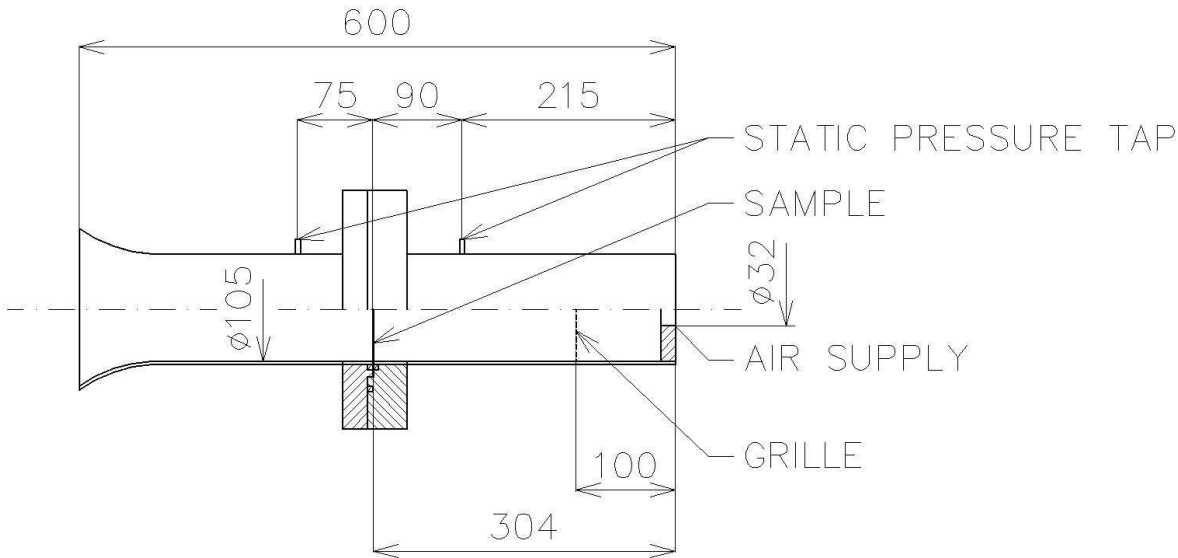


Fig. 6 The measuring adapter

The samples were from a textile NMS and films NLF with microperforation (see Fig. 4 and 5) with a density of 250 000, 150 000 and 50 000 holes/m². All these materials are a standard products of the company Příhoda s. r. o. [3]. Spacing of holes is at a density of 250 000 holes/m² 2 x 2 mm, at a density of 150 000 holes/m² 2 x 3,33 mm and at a density of 50 000 holes/m² 4 x 5,06 mm.

The Fig. 7 shows the measured results as the dependence of the local pressure loss coefficient on the Reynolds number (apply to the diameter of microperforation). This expression was chosen so that the measured values could be compared with the values from Idělčik [2], where the values are with a very similar geometry. Also, the evaluation showed that the calculation of the discharge coefficient is significantly affected by a diameter of the microperforation, which can be difficult to measure (a large number of microscopic holes). Most of the discharge coefficients are also reported for a solitary hole in the wall. The Fig. 7 shows that the local pressure loss coefficient decreases with the increasing Reynolds number and the increasing flow area of the perforation. It is seen that the local loss coefficient for textiles is slightly lower than for films. It is due to a greater curvature of the input lines and a higher ratio of the wall thickness and diameter of the hole. The correspondence between measured values and those of [2] is good at a density of 50 000 holes/m², other densities can only correspond to the order. A poor compliance at higher densities of the perforation will be caused by a slightly different geometry of perforations in [2]. The lower density of the perforation has a greater impact for the pressure loss, for example, a larger pitch holes.

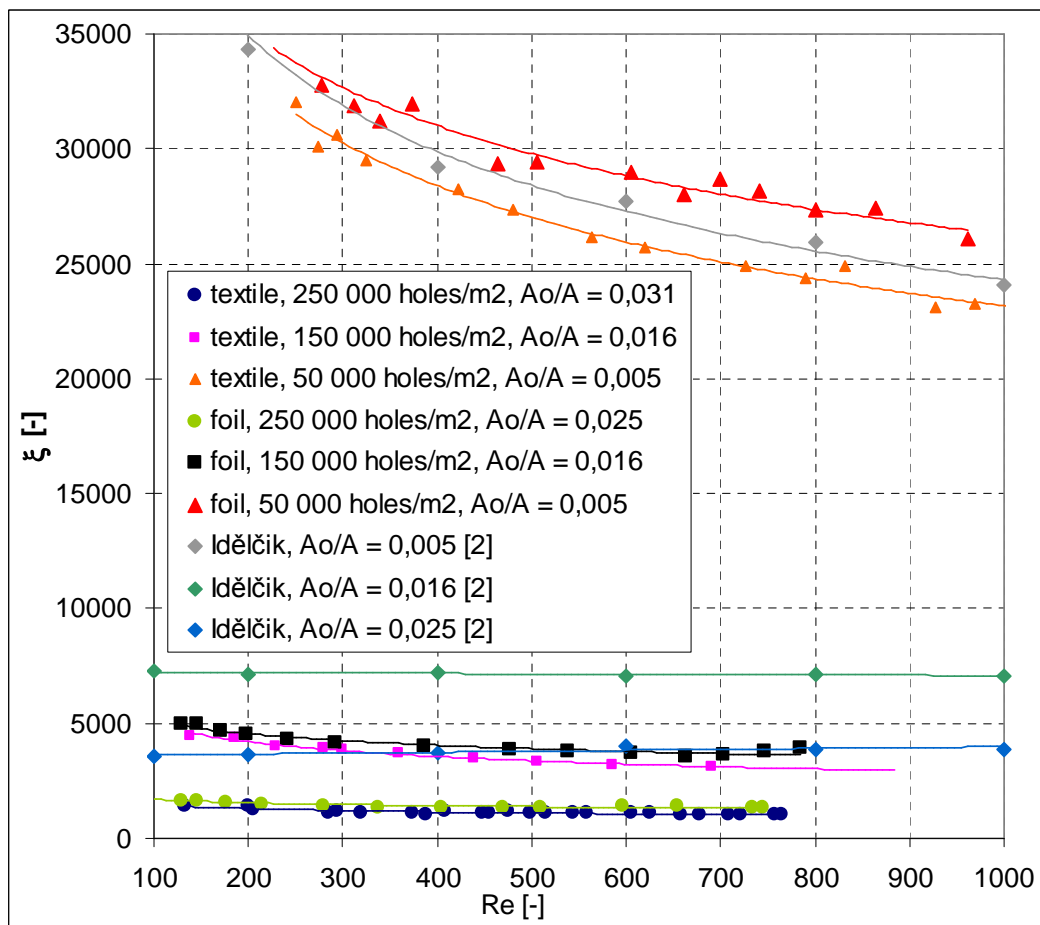


Fig. 7 The dependence of the local pressure loss coefficient on the Reynolds number

4. New trends in textile duct, advantages and disadvantages

4.1. The advantages of textile (foil) duct

- lower cost compared to fixed duct
- faster and easier installation
- large number of the design
- more environmentally friendly - less demand for transport
- easy to clean duct – laundry
- high corrosion resistance
- increased resistance to
- higher aesthetics

4.2. The disadvantages of textile (foil) ductwork

- a lower fire resistance
- the risk of static electricity
- if isn't the duct in the operation, it changes its shape (not "inflated")
- a complicated structure for non-circular shapes and for air ducts to outlet air duct, because it is formed as an internal pressure

4.3. The use of air ducts

Due to the easy cleanability, of the textile ducts are used in the food and pharmaceutical industries. Farther they are used for ventilation of humid areas, offices, shops, and in most industries. In these it uses the large variability of air ducts.

4.4. New trends in design

In the last chapter has been mentioned a new way of a perforating duct by laser. In addition to the microperforation the laser manufactures perforations in sizes up to tens of mm so. The laser allows a great variability of products and a high productivity. Another change is the use of new fabrics. These textiles of synthetic endless fibers have a higher strength and a less frayed than those previously used. It can also deliver textile with a improved fire resistance, antistatic and antibacterial. The textiles are manufactured in several colors. It is possible to use textiles in multiple colors on a one duct. On the Fig. 8 is seen a textile duct in the fan shop Slavia Praha [3].



Fig. 8 Multiple colors of textile on a one duct in the fan shop of the football club Slavia [3]

News are also on foils. Thick PE foils are usually used, sometimes are woven.

A novelty is the use of textile duct to the exhaust air. The textile must be stretched to the fixed frame, see Fig. 9 [3]. A supply duct is tensioned of the internal pressure. The same system can also be used for an air supply, if we require a square duct.



Fig. 9 The square textile duct with the fixed frame [3]

Another design innovation is a double textile duct. The second layer is used to adjust the direction of the discharge air into the space so that the air issued perpendicular to the surface throughout all the length.

5. Conclusion

The ducts from the textiles or the films are very convenient elements of ventilation systems. Their main advantage is a low cost, easy installation and high variability.

For the proper design is necessary to know the discharge coefficient or the coefficient of local pressure losses of the perforated textile. For specific samples of textiles and films was

measured the coefficient of local pressure losses, which decreases with the increasing Reynolds number and the increasing flow area of the perforation. The correspondence between measured values and values of [2] is good at the density of 50 000 holes/m², other densities can only correspond to the order. A poor compliance at higher densities of the perforation will be caused by the slightly different geometry of perforations in [2].

Beyond it is necessary to correctly determine the profile of the static pressure in the duct. The pressure losses are very important, so. For the long air ducts dominate the friction losses, which will changed the static pressure from monotonically increasing.

A future work will focus on the pressure losses in the perforated air ducts. My goal is to create the design procedure for the perforated air ducts.

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Symbols

| | | |
|------------------|--|----------------------|
| A | cross section | [m ²] |
| A _o | cross section of perforation | [m ²] |
| D | diameter | [m] |
| D _h | hydraulic diameter | [m] |
| L | duct length | [m] |
| L´ | dimensionless duct length | [m] |
| Re | Reynolds number | [-] |
| V | volumetric flow rate | [m ³ /s] |
| g | acceleration of gravity | [m/s ²] |
| h | height above the reference plane | [m] |
| l | length | [m] |
| p | pressure | [Pa] |
| p´ | dimensionless pressure | [-] |
| p _d | dynamic pressure | [Pa] |
| p _s | static pressure | [Pa] |
| p _x | static pressure in the distance x | [Pa] |
| p ₀ | static pressure at the end of the duct | [Pa] |
| v | velocity | [m/s] |
| v _o | discharge velocity | [m/s] |
| x | distance in the x-axis | [m] |
| x´ | dimensionless distance from the closed end of the duct | [-] |
| α | Coriolis coefficient | [-] |
| β | Boussinesq coefficient | [-] |
| Δp _z | pressure loss | [Pa] |
| Δp _{zm} | local pressure drop | [Pa] |
| Δp _{zλ} | fiction pressure drop | [Pa] |
| ε | contraction coefficient | [-] |
| φ | velocity coefficient | [-] |
| λ | friction coefficient | [-] |
| σ | aperture ratio | [-] |
| σ _{ef} | effective aperture ratio | [-] |
| μ | discharge coefficient | [-] |
| ρ | density | [kg/m ³] |
| ζ | coefficient of local losses | [-] |

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