Determination of the Local Pressure Loss Coefficient Experimentally and Using CFD Methods

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Abstract. When choosing silencers in air conditioning, it is necessary to pay attention not only to the acoustic attenuation, but also to the pressure loss of the silencer. If the pressure loss of the damper is too high, noise will occur directly in the damper. The pressure losses of the silencers are determined mainly experimentally. Based on the performed measurement, a CFD model of the selected silencer was constructed, where the influence of various parameters on the value of the pressure loss of the selected silencer was investigated.

1 Introduction

At present, great emphasis is placed on reducing the noise associated with the operation of air conditioning systems, so components are built into the piping network, whose task is to attenuate and absorb this noise. However, for the correct design of the system, it is necessary to know the pressure loss of individual components of the pipeline network. When designing a silencer in practice, the pressure drop of this component is often forgotten and only its acoustic attenuation of the sound is evaluated.

Today, an integral part of various measurements and experiments is a computational model constructed using CFD methods. The created computational model must be verified by measurement. This verified model can greatly facilitate further experiments, as it can be used to solve similar tasks.

2 Hydraulic losses

Bernoulli's equation (1) is extended by a member in the flow of a real fluid, characterized as the energy needed to overcome the hydraulic resistances. Overcoming these resistances converts mechanical energy into heat, which manifests itself as energy loss.

$$h.g + p/\rho + v^2/2 + e_z = \text{const} \qquad [\text{J.kg}^{-1}] \qquad (1)$$

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Hydraulic resistances are caused both by the friction of the fluid against the pipe walls (friction losses), as well as by a change in geometry or a change in the flow direction (local losses). Hydraulic losses are expressed as a multiple of the kinetic energy per unit mass of the fluid (2).

$$e_z = p_z/\rho = \xi.(v^{-2}/2) \qquad [\mathrm{J.kg^{-1}}] \tag{2}$$

Assuming that each hydraulic resistance manifests itself independently of the effect of the other resistances. The total pressure loss is thus given by the sum of the individual losses [1].

2.1 Friction pressure losses

The pressure losses by friction in the pipe can be calculated using Darcy Waisbach's equation (3).

$$e_{z,t} = \Lambda.(l/d).(v^2/2) \qquad [\mathrm{J.kg^{-1}}] \tag{3}$$

To express the pressure drop, we can write this equation in the form (4).

$$p_{z,t} = \Lambda.(l/d).(v^2/2).\ \rho \qquad [\mathrm{Pa}] \tag{4}$$

The coefficient of friction Λ is generally given by a function (5). It includes the properties of the transported medium as well as the properties of the pipeline.

$$\Lambda = f\,(v,\nu,d,l,k) \tag{5}$$

With sufficiently long pipes, the length of the pipe does not affect this factor, due to the linear dependence. For different pipe sizes as well as for different speeds, the functional dependence of the coefficient of friction is expressed by means of the Reynolds number, and the ratio between roughness and diameter (6) [2].

$$\Lambda = f\,(Re,k/d) \tag{6}$$

2.1.1 Pipe wall roughness

In general, roughness is determined by the height of the protrusions of surface irregularities. It is called k. We know several types of pipe roughness. Absolute roughness is the height of the surface roughness protrusion. However, it is not possible to use this value well for the calculation, as the height of the individual protrusions is not the same. The mean roughness is determined as the mean value of the height of the protrusions on the surface. It was introduced as a value for calculations. Relative roughness is determined as the ratio between the mean roughness value and the pipe diameter. This value better captures the effect of roughness on the coefficient of friction than the mean value of roughness alone [3].

2.1.2 Coefficient of friction for round pipes

Initially, the coefficient of friction was considered constant. However, it has gradually been shown to be dependent on the value of the mean flow velocity. Its value is mainly influenced by the type of flow and the size of the Reynolds number. Since there is no universal formula for calculating this coefficient, it is necessary to know the value of *Re*. For the calculation in the area of laminar flow, the relation was derived from the Hagen-Poiseuille law. This formula (7) is valid for *Re* in the range 0 to 2300.

$$\Lambda = 64/Re \tag{7}$$

In 1911, based on the then known experiments, Blasius proposed a relation (8) to calculate the coefficient of friction in a smooth pipe.

$$\Lambda = 0.3164/Re^{0,25} \tag{8}$$

Using this equation, it is possible to express well the value of the coefficient of friction in the range Re = 4.103 to 105. Later, other empirical relationships were proposed, which are intended for a wider range than Blasius equation (7). The most universal of these equations is the relationship derived by A.D. Altšula (9) valid for Re in the range 2,5,103 to 1012 [2].

$$(1/\sqrt{\Lambda}) = 1.82.\log (Re/100) + 2 \tag{9}$$

2.2 Local pressure losses

The cause of these losses is local current disruption. With such a disturbance, the flow velocity profile is deformed. As a result of such a disturbance, the current tends to break away from the wall, so that vortex regions are formed. The individual vortices are then carried by the current in the direction of flow, gradually disintegrating into smaller ones until they completely dissolve. Their kinetic energy changes to heat during decay.
The pressure drop is determined according to Bord's relationship of local losses (10). However, the calculation of local pressure losses using this formula very often differs from the actual values found experimentally. This calculation method is derived from the difference in speed before and after the element that causes the local pressure loss.

$$p_z = (\rho/2).(v_1 - v_2)^2 \qquad [\mathrm{Pa}] \tag{10}$$

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The most reliable method of determining the local pressure losses of system components is based on determining the local pressure loss coefficient ξ.

The factor ξ always refers to the flow velocity, which is given by the cross-sectional area of the pipe. Assuming that the pressure drop does not change, it is possible to convert this coefficient to another pipe cross-section. The given conversion is based on the relation (11):

$$\xi_1.(v_1/2)^2.\rho = \xi_2.(v_2/2)^2.\rho \tag{11}$$

The local resistance coefficient usually also includes the pressure loss by friction or the loss of dynamic pressure. When determining the coefficient of local pressure loss, the element is usually inserted into the pipeline, so the pressure loss is also included in the coefficient ξ by balancing the velocity profile. Elements arranged in series with a known local pressure drop coefficient interact with each other. It follows that the resulting value of the pressure loss will not be equal to the simple sum of the pressure losses of these inserted resistors [4].

2.2.1 Coefficient of local pressure losses

The value of the local pressure loss factor is determined from (12) :

$$p_{z,m}=\xi.(v^2/2).\rho \tag{12}$$

Where ξ is the local loss factor. The value of this factor depends on the geometry of the local resistance and on the fluid flow rate. Its determination is experimental and is valid only under the same conditions under which it was determined or in physically similar cases [5].

3 Design of a modeled silencer

A silencer is designed to calculate the pressure drop. The outer shell of the silencer is a square pipe made of galvanized sheet metal terminated with flanges.
The frame of the silencer insert is made of galvanized sheet metal. The inserted absorbent filling is made of non-flammable, sound-insulating material, covered on both sides with a laminated, hygienically harmless fabric. The inserted mineral wool is hygienically harmless, rot-resistant and moisture-repellent. With the designed length of the damper, the insulation is stabilized by reinforcement. The curtains are attached to the pipe jacket with rivets.

3.1 Construction and dimensions

The silencer will consist of six curtains mounted in a square pipe. The dimensions of the pipe are shown in the figure (Figure 1). The unfilled cross-section of the damper will consist of seven gaps between the individual slides. The spacing between the individual flanges will be 66 mm in length, while the spacing between the outer walls of the pipe and the flaps will be 33 mm.

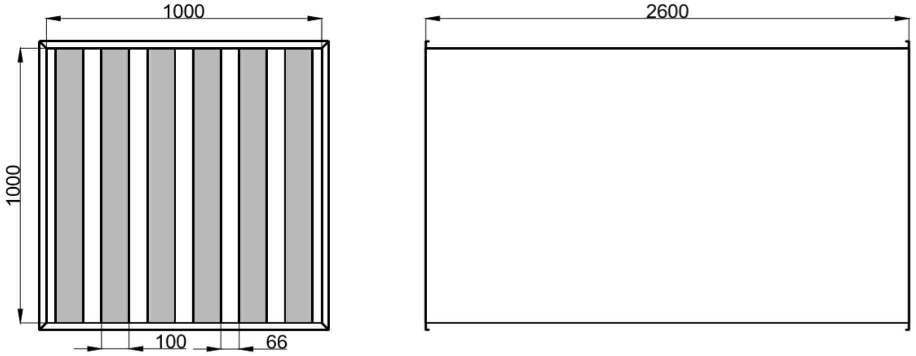

Fig. 1. Cross section of a modeled silencer.

Each of the fitted links will be attached to the pipe with rivets. The dimensions of the slide are shown in the figure (Figure 2). In our case, there will be six damping curtains in the damper.

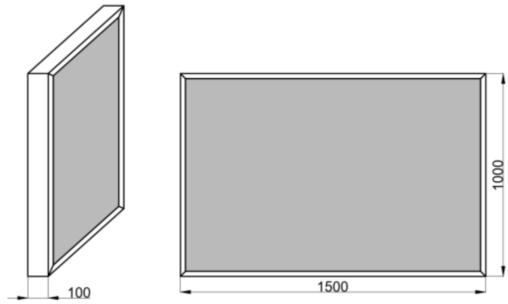

Fig. 2. Obstacle inserted in the muffler.

The air supply to the system will be ensured by means of a ducted axial fan, which will be connected to a duct measuring 500 x 500 mm. The length of the connecting pipe in this case will be 1500 mm. The silencer itself is mounted in a pipe with dimensions of 1000 x 1000 mm, which is connected to the supply pipe by means of a symmetrical transition for square pipes with an angle of 45°. Pipe with the same dimensions will continue behind the fitted scenes to stabilize the flow. The whole constructed assembly is shown in the picture (Figure 3).

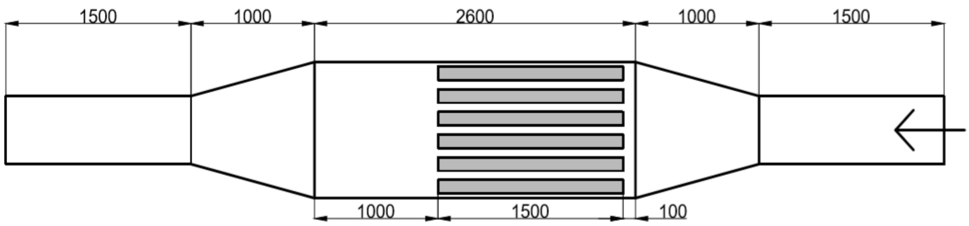

Fig. 3. Longitudinal section with modeled silencer.

4 Experimental determination of the pressure drop of a modeled silencer

The performed experiment was designed on the basis of the standard STN EN ISO 7235. To determine the coefficient of local pressure loss, it is necessary to perform at least five different measurements at different volume flows.

The test set-up and the device for measuring the mean value of the static pressure on both sides of the test object and its entire pressure drop must be as shown in the figure (Figure 4). The line pressure must be measured with a calibrated manometer.

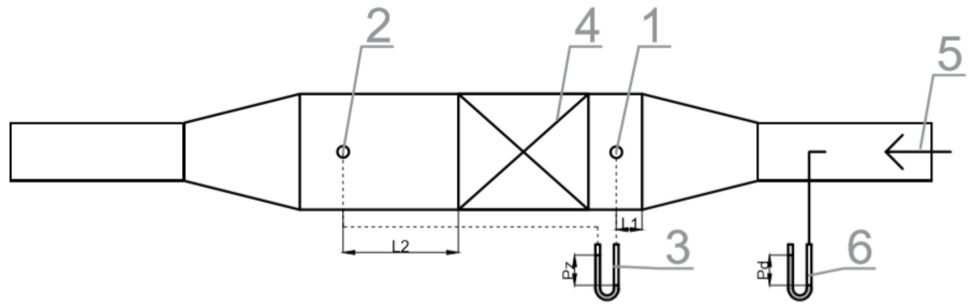

Fig. 4. Scheme of pressure loss measurement according to STN EN ISO 7235 1-measurement of static pressure against flow in front of the tested object, 2-measurement of static pressure downstream of the tested object, 3-manometer, 4-link damper, 5-direction of flow, 6-flow measurement.

4.1 Measurement of a model silencer

The measurement was performed on a real silencer, constructed as shown in Chapter 3 in Figure 3. The experiment consisted of measuring pressure drop, temperature, and flow rate.

The flow rate was also measured using a Wilson grid with an Airflow PTSXR-K pressure transducer, to increase the accuracy of the measurement.

The individual measuring devices were connected as shown in the diagram in Figure 4.

The air supply to the measured damper is ensured by means of an axial duct fan with a maximum air flow of 9000 $m^3.h^{-1}$. The fan volume flow was regulated by means of a frequency converter. The fan was connected to a pipe measuring 500 x 500 mm. The measured silencer itself is mounted in a pipe with dimensions of 1000 x 1000 mm, which is connected to the supply pipe via a pipe passage. The Wilson located at the end of the assembly is mounted in a pipe measuring 500 x 500.

4.2 Measurement procedure

Individual measurements were performed for different volume flow values. The flow control was performed using a frequency converter.
The measurement of the pressure difference was performed according to Figure 4 in points 1 and 2.

The resulting velocity was determined as the arithmetic mean of the measurement on the Wilson grid and the average value measured using the ALMEMO velocity probe. The measured and averaged speed values refer to the cross-section of the pipe with dimensions of 500 x 500 mm.

From the measured velocity values, the volume flow through the pipe was subsequently determined using equation (13).

$$Q = S.v.\rho \tag{13}$$

The value of the local pressure loss coefficient ξ, is calculated according to equation (12) given in Chapter 2.2.1. Since the silencer itself is located in a pipe with dimensions of 1000 x 1000 mm, to determine the coefficient of local pressure loss ξ for the silencer, we had to convert the measured speed to the value in the given cross section. This conversion was performed using the continuity equation $S1.v1 = S2.v2$.

The resulting value of the factor ξ, as well as the flow velocity in the wider part of the piping assembly is given in the table Table 1.

Table 1. The resulting value of the factor ξ.

Fan frequency [Hz]	v_1 [m.s^{-1}]	v_2 [m.s^{-1}]	ξ
20	4.40	1.10	6.2
22	4.85	1.21	5.8
24	5.30	1.33	6.2
26	5.74	1.44	7.2
28	6.16	1.54	8.9
30	6.64	1.66	8.9
32	7.08	1.77	8.9
34	7.44	1.86	8.9
36	7.99	2.00	6.9
38	8.40	2.10	6.9
40	8.82	2.21	7.5
Arithmetic mean			7.48

4.3 CFD model

Based on the actually constructed silencer (Figure 5), a CFD model was constructed using Ansys Fluent software. The purpose of this model was to calculate the pressure drop and at the same time to find out which calculation model is most suitable for the given application.

Fig. 5. Silencer on which the measurement was made.

To use numerical methods to calculate the pressure drop, it was necessary to construct a three-dimensional model of a real silencer, on which the measurement was performed (Figure 6). The geometry was made using Ansys Design Modeler software.

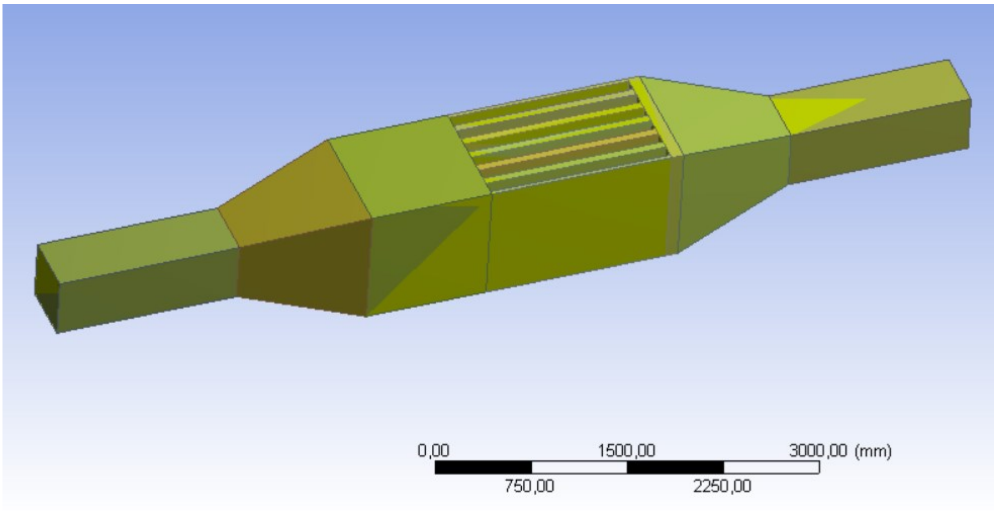

Fig. 6. Geometry of the modeled silencer.

From the turbulence models offered by Fluent, we chose four models. Each of these turbulence models is based on the Reynolds time averaging principle. These are the k-ε RNG, k-ε Realizable, k-ω Standard and k-ω SST models.

Eleven calculations were performed for each of the selected turbulence models, and an arithmetic mean for the local pressure drop coefficient was generated using CFD (Figure 7).

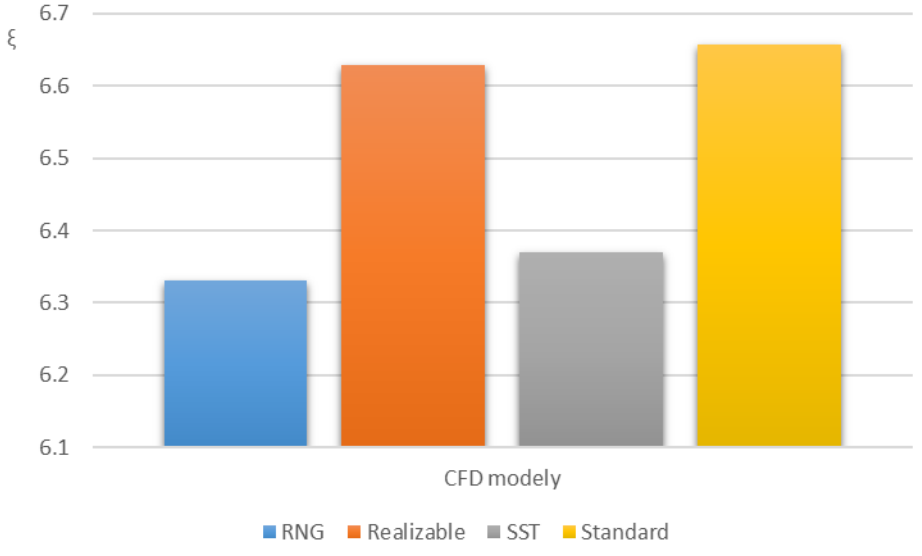

Fig. 7. Graph of the average value of the coefficient ξ.

5 Conclusion

At present, great emphasis is placed on the pressure losses of air-conditioning components. The work addresses the issue of determining the pressure loss of link silencers in determining the coefficient of local pressure loss.

Part of the work is devoted to the description of hydraulic losses in flow. These losses are caused either by the friction of the fluid against the walls of the pipe or by local resistances, which are caused either by bypassing the obstacle or by changing the direction of flow.

The practical part consists in constructing a polynomial of a function for determining the coefficient of local pressure losses. The creation of this equation consisted of determining the coefficients ξ, using a computational model constructed using Ansys Fluent software. The inspection of the constructed CFD model was performed by measuring the pressure drop on the model case of the silencer.

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