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ACOUSTICAL PARAMETERS OF THE DIFFERENT FIXING OF BLADE VENTILATION DAMPER INTO THE DUCT

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ABSTRACT

Maintaining air quality is essential to the functions of our everyday. HVAC systems used in industrial and residential spaces and composed of ducts, dampers, silencers and others elements are necessary to keep high-quality and clean air indoor spaces. In this work, we studied the acoustic parameters of the blade's damper, which are an integral element of VAV and CAV systems in ventilation. The dampers under study varied fixing systems into duct. The two common fixes of blade damper - circular and square rods and three, non-disturb flow, specially constructed fixes for blade dampers were tested. The finite element method for simulations of the flow and acoustic parameters of the study objects was used. The simulation results were compared for blade's damper with different fixing into the duct.

Keywords: *HVAC, noise, blade's damper, fixing type*

1. INTRODUCTION

With the new climate problems, also the building sector demands comfort and energy efficiency [1]. But, the design of heating, ventilation and air conditioning (HVAC) systems has a significant impact on indoor air quality. A key decision in HVAC design is selecting an adequate air-handling configuration: constant air volume (CAV) or variable air volume (VAV). Each option has advantages and disadvantages, and using the right configuration enhances the comfort of users and the efficiency of systems. VAV is used where the conditioning space (office, residential rooms) load varies, CAV is used where constant airflow is required. In some research project VAV unit were evaluated to identify major factors connected with airflow measurement in these objects [2, 3]. There are also very general guidelines for the acoustics such systems [4].

In VAV and CAV systems, the manually adjustable or automated grid or damper is used as the regulation element. Dampers in CAV or VAV units together with ducts and fittings are part of the ventilation system involved in the distribution of air but also cause the formation of the noise. In Polish regulation, the need to install dampers is specified in the regulation on the technical conditions of the building [5]. Additionally, Polish Standard PN-B-02151-2 [6] defines requirements on permissible sound level in rooms designated for people stay and meant for different purposes. Standard focus on noise, which can be created by different technical devices and utilities inside of the building like example the HVAC systems. For single or multi-family rooms, the permissible model sustainable sound level A is 25 dB. In school classrooms, lecture rooms and teachers rooms, the permissible model sustainable sound level A, should not exceed 35 dB. The sound power of the damper depends on the speed of airflow and the pressure drop which is connected to the degree of throttling of the damper. The value of the sound power level, during the operation such device is variable, but in extreme cases, it can reach about 70-80 dB(A). However, noise can be reduced by: insulating the outer casing of the damper, using additional silencers or changes in the construction of the damper. In summary, this is very important that the construction of ventilation system should provide the low level of noise.

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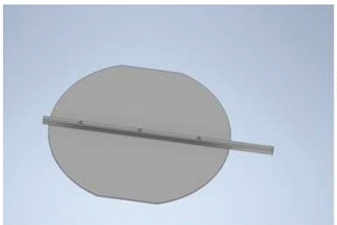
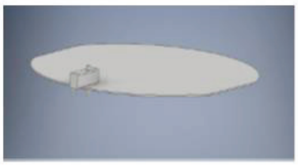
In this work, the aeroacoustics parameters of different fixing of blades in damper used in the duct of HVAC systems were studied. The three types of fixing were studied (Fig. 1):

a) fixing by a semi-circular rod (radius 8mm) along the damper blade;
b) fixing by a short square rod (8mm×8mm) with rivets or with a screw on the two sides of the damper blade;
c) fixing by a short trapeze handles on the two sides of the damper blade, differing in the angles between longer base and the side of the trapeze (angle 25°, 35° and 45°). The height of trapeze handles was 9mm because into that the rod was mounted maintaining the blade damper in duct. This solution for these fixings is reserved construction.



type a)



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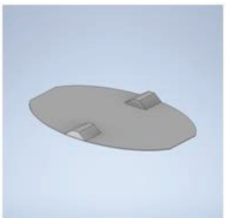

type c)
c1-25 angle
c2-35 angle
c3-45 angle

Figure 1. Scheme of types of fixing with studied blade damper.

In this work, the damper blade attachment system in the circular duct was considered in relation to the damper blade "without attachment" - treated as a base by simulation in the Comsol programme [7].

2. CFD AND ACOUSTIC SIMULATION AND RESULTS

For CFD simulation 3D solid models of the damper's plate with fixing were created by the Inventor program. After drawing simplified geometry, extraction of fluid volume was needed to perform CFD analysis in Comsol [9], so the inverted models were created in Inventor. The analyzed damper had a 246 mm outer diameter. The plate of the damper had a thickness of 1 mm. The diameter of the housing was 250 mm and it was the fluid domain. In reality, the whole length of the units was 1000 mm. This length is divided as inlet - 200mm from the axis of the damper; outlet - 800mm from the axis of the damper. One position of damper - angle 0° (100% opened) was studied because the influence of fixing was important not the position of damper blade in these cases.

The mesh was composed of tetrahedral elements. In Comsol programme mesh elements were physic-controlled with size fine. In order to reduce computational times, investigations were made in half of the damper system and a symmetric plane boundary condition is used. Three-dimensional calculations were made as a stationary analysis. The standard SST model is selected for the turbulence evaluation with an intensity of 5%, solution condition tolerance of 0.001, and solves GMRES 50 iteration. The material was the air with a constant temperature, density 1.2 kg/m³ and a viscosity of 18.053e-6 Pas. Three inlet velocities = 2 m/s; 4 m/s and 8 m/s were simulated. The velocity vector at the ventilation duct inlet has the same value throughout the entire duct area was established. On the outlet, the pressure condition was used (p static = 0 Pa). The automatic wall treatment (no slip walls condition) was chosen.

The pressure distribution behind the variants of fixing is presented in Fig.2. For types b) and c) fixing the pressure is equalized in the central part of the duct. Only at the point of attachment, a lower pressure zone is observed. This is independent of the airflow velocity. It can be seen, that there are zones of overpressure and under pressure, above and below the damper, at the point of attachment. However, it is characteristic that these zones do not extend along the entire damper, but occur along a small length of the damper. For types b) and c), there is also a faster equalization of pressure behind the fixing. It is therefore reasonable to use the attachment at the edges of the damper than along the entire diameter of the damper.

Fig.2 and 3 illustrate the effect of the mountings in each variant on the velocity distribution inside the channel behind the fixing of the blade damper at 2m/s and 8m/s. The semi-circular rod and square rod with screw or rivet

due to their shape are the disturbing flow elements, so the strong decrease of velocity behind these elements can be observed. Additionally, for variant a) - semi-circular rod the strong vortex zone formation is seen along the diameter of the damper blade which could suggest that higher outlet noise at the end of the duct. The vortex formation for variant b) is also observed, but only near the wall of the duct, where there is the fixing. But behind this type of fixing (type b) in the higher inflow air velocity, the stronger vortex effect is observed (weaker and stronger blue zone behind the square rod) - Fig. 4. Due to the position of this fixing (near the wall of the duct), this effect might not matter for acoustic parameters at the end of the duct.
In the case of trapezoidal fixings (type c with different trapezoidal inclination arrangements), a drop in velocity is observed behind the fixings right at the channel wall - Fig. 5. The decrease of the flow velocity is lower and more smoother when the angle of inclination of the trapezoid is smaller. On the other hand, if we increase the angle of inclination of the trapezoidal walls, the velocity field changes behind the fixing and a vortex are seen (fixing type c3).

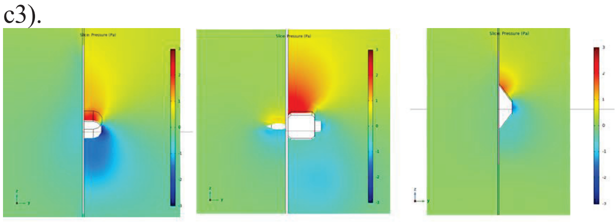

Figure 2. The pressure distribution in the fixing place (distance 95 mm from the central axis of the model) for the studied variants of fixing at flow velocity 2m/s.

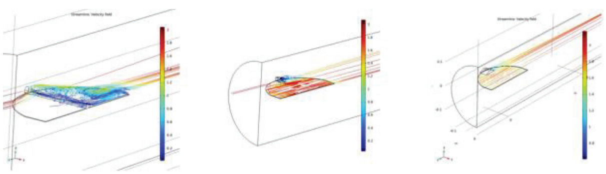

Figure 3. The flow velocity (streamline) behind the fixing place for the studied variants of fixing at flow velocity 2m/s.

To simulate the acoustic parameters for the studied types of damper blade fixing CFD solution results were taken into account, next the linearized Navier–Stokes equations in the frequency domain were applied. Background acoustic field, whose parameters were obtained from the flow part of the simulation was selected as a noise generator. The flow fields of pressure, velocity, density, temperature, and turbulent viscosity were mapped onto the acoustic mesh. The generated mesh was designed taking into consideration that results were to be obtained for 1/3 octave bands and the highest frequency tested was equal to 2500 Hz (due to hardware limitations in this case).

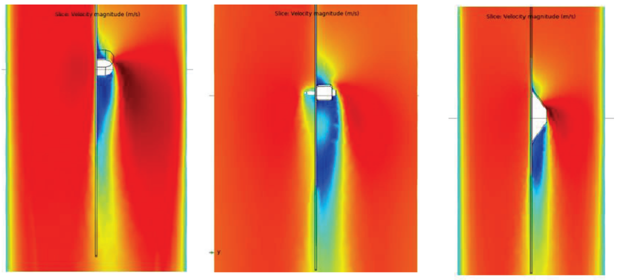

Figure 4. The field of flow velocity behind the fixing place for the studied variants of fixing at flow velocity 8m/s.

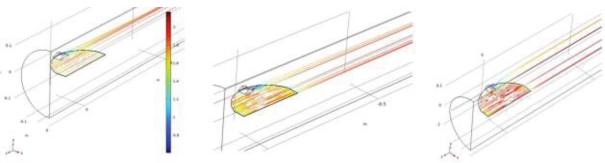

Figure 5. The flow velocity (streamline) behind the fixing place for the studied variants of c) fixing at flow velocity 2m/s.

The sound pressure distribution in the model domain for studied variants of blade damper fixing is presented in Fig 6, 7 and 8. The colour changes from red through yellow to blue illustrates the variation in sound pressure levels (SPL), where the red field illustrates higher levels and the blue fields illustrate a decrease in SPL values in the imaged area. The waviness of the SPL is apparent at some analysed frequencies.
Significant differences in the distribution of sound pressure level for type a) of blade damper fixing compared to the damper without any attachment - "base" were observed. These differences were observed regardless of the modelled speed. The waviness of the SPL value for 800 Hz for type a) blade damper fixing may influence on acoustics signals along the 1m length of the duct or longer when the blade damper is fixed by the semi-circular rod (type a). This could mean that the commonly used selection of the length of the duct section in ventilation systems to equalize the flow rate

that depends on the number of duct diameters may not work well in acoustic issues. In these cases, the lengthening of straight duct sections can be of significant importance for noise reduction at the duct outlet.

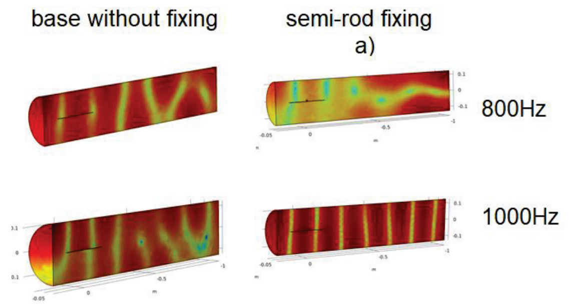

Figure 6. The distribution of sound pressure level in modelled domain (plane Z-Y) for damper blade without the fixing (on the left) and type a) blade damper fixing (on the right) at 800Hz and 100Hz at 2m/s.

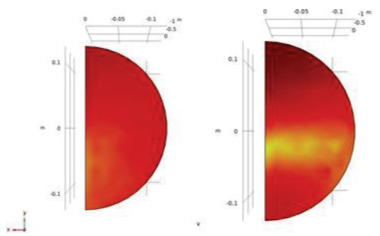

Figure 7. The distribution of sound pressure level at the end of the duct (plane X-Y) in modelled domain for damper blade without the fixing (on the left) and type a) blade damper fixing (on the right) at 800Hz at 2m/s.

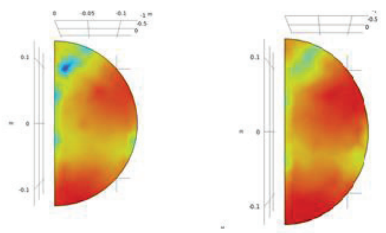

Figure 8. The distribution of sound pressure level at the end of the duct (plane X-Y) in modelled domain for damper blade type b) fixing (on the left) and type c3) blade damper fixing (on the right) at 1250Hz at 8m/s.

The phenomenon of "waviness" at 800 Hz is not observed for type b) and c) blade damper fixing. On the other hand, slightly different distributions of the SPL at the end of the duct for frequencies of 1000 Hz and 1250 Hz are observed than for the blade damper without fixing ("base") and with type a) fixing. The use of side attachment of the blade damper in the form of a trapezoidal bracket with a variable angle of the trapezoidal base also affects the distribution of TSPL at the duct outlet for frequencies of 1250 Hz (Fig. 8) and may stand out this frequency in the acoustic spectrum.

The average values of sound pressure level were collected at the outlet of the model domain for the "base" object and the objects with different types of fixing. The differences between the 1/3-octave level of acoustic pressure of the “base” blade’s dampers without the fixing 7 and the studied variant of fixing were used to present the results of noise reduction (ΔL_w), using the equation (1):

$$\Delta L_p = L_{p"type"} - L_{p"base"} \tag{1}$$

where $L_{p"base"}$ - is the level of the acoustic pressure in the frequency band considered for the "base" blade’ damper without fixing; $L_{p"type"}$ - is the level of the acoustic pressure in the frequency band considered for the studied variant of blade’s damper fixing.

The graphs for the studied type of fixing are presented in Fig. 10. The positive values of the 1/3-octave differential spectrum tell about the noise production at these frequencies by the studied blade’s dampers type of fixing. The highest differences between the spectrum for the base object blade's damper without fixing and the studied types of fixing can be seen in the differential acoustic spectrum for the semi-circular rod. For this acoustic spectrum, two peaks are observed - one strong at 1kHz and the second at 2kHz. The acoustic signals in the simulation domain at 1kHz were also observed. So, the semi-circular rod as a type of fixing in ventilation systems may not be a good idea, taking into account the acoustic parameters of such systems.

Table 1 takes away the values of the total A-weighted acoustic pressur level (L_{pA}) for the tested types of blade damper fixing. As can be observed for the blade's damper in the fully open position, the differences in acoustic pressure levels are small between the types b) and c) of fixing. It can be assumed that in this position the effect of these mountings on L_{pA} is insignificant. However, higher values of acoustic pressure levels are observed for fixing in the form of semi-circular rod at each modelled velocity.

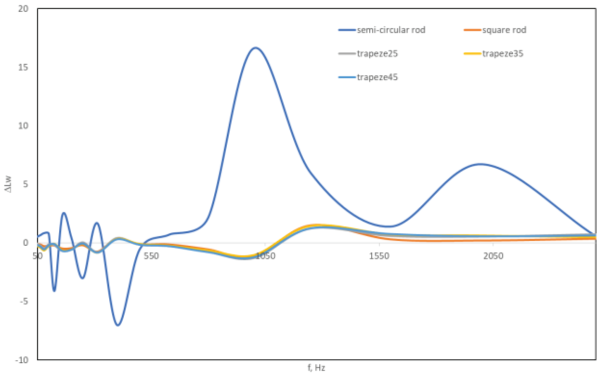

Figure 9. The flow velocity (streamline) behind the fixing place for the studied variants of c) fixing at flow velocity 2m/s.

Table 1. The calculated A-acoustic pressure level L_{pA} for the studied type of blade's damper type of fixing in different flow velocity.

	v, m/s		
	2	4	8
	L_{pA}, dB		
type a)	56.9	57.6	57.7
type b)	51.6	52.0	52.2
type c1)	51.9	52.3	52.5
type c2)	51.9	52.2	52.4
type c3)	51.9	52.3	52.5

3. CONCLUSION

Type a) fixing the blade's damper is the least favourable in terms of flow equalization and unification of the fluid flow in the entire duct area. This fixing causes intense turbulence of the air behind the damper and affects the sound field at the end of the ventilation duct even at a distance of 1m behind the damper axis;
Type b) fixing the blade's damper causes intense turbulence behind the fixing in the wall area and the formation of vortices that destabilize the flow. This type of fixing affects the acoustics of the ventilation system in the area of higher frequencies.
Type c) fixing the blade's damper (trapezoidal) changes the velocity distribution near the duct walls, but the fluid flow is more uniform than in types a) and b). The trapezoidal fixing of the blade's damper is the most acoustically favourable mounting. In the simulation of acoustics, changes were observed only at 1250 Hz. The single-number acoustic sound pressure level is lower for types b) and c) blade damper fixing, so these types of fixing should be preferred in ventilation systems.

4. REFERENCES

[1] U.S. Department of Energy. Annual energy outlook. Energy Information Administration; 2013. http://www.eia.gov/forecasts/aeo/.

[2] R. Liu, J. Wen, X. Zhou, C. Klaassen, Stability and accuracy of VAV box control at low flows, part 1 Controller test, system test, and field test. *HVAC&R Research*, 20, 3-18, 2014.

[3] R. Liu, J. Wen, X. Zhou, C. Klaassen, A. Regnier, Stability and accuracy of VAV box control at low flows, part 2 laboratory test setup and VAV sensor test. *HVAC&R Research*, 20, 19-35, 2014.

[4] ASHRAE, ASHRAE Handbook, American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), ASHRAE Inc.,Atlanta, 2015.

[5] Regulation of the Minister of Infrastructure about the technical conditions in buildings and their location (Dz.U. 2022 poz. 1225 from 9th June 2022)

[6] PN-B-02151-2, Polish Standard, Building Acoustics. Protection form noise in building. Part 2: requirements on permissible sound level in room, 2018.

[7] Comsol - Software for Multiphysics Simulation