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PETAL-SHAPED SILENCERS USAGE FOR NOISE REDUCTION IN CYLINDRICAL CHANNELS

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***Abstract**: The article presents data on the results of petal-shaped silencer mathematical modeling. Dissipative silencers of complex shapes are the most promising technology. This design allows for achieving the required noise reduction. At the same time, geometric shape optimization allows reducing the aerodynamic drag to the smallest values. The article compares the variants of the silencer with the rotation angles of the plates 45 and 70 degrees. In this case, the sound waves necessarily fall on the surface of the plates of the silencer. In the article, there are the results of noise calculation from a dry cooling tower. The use of a petal-shaped silencer will significantly increase acoustic efficiency. The extra aerodynamic drag will be minimal. For comparison presented the results of modeling a cylindrical silencer. The cylindrical silencer has an equal through-section and long. Justified the approach to choosing the most preferred option. The initial velocity field of the gas or air flow in the channel determines the choice of silencer design.*

***Keywords:** Petal-shaped silencer, cylindrical silencer, aerodynamic drag, mathematical modeling, dry cooling tower*

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1. INTRODUCTION

Increased industrial noise exposes most of the population of large cities. Often residential buildings are near industrial enterprises. This is a result of urbanization. Modern plants are safe for the surrounding population by exposure to chemical factors. There are various technologies that allow you to achieve low emission values. In cases where emissions are significant, they use special installations to capture pollutants. Industry gives less importance to factors of acoustic impact. While studies show [1-4] that most of the population of large cities lives in conditions of acoustic discomfort.
Dissipative silencers that used to reduce noise propagating in the gas and air paths of fans are well studied [5-10]. Dissipative silencers come in various shapes. It depends on the type of channel filling with sound-absorbing material. They use a plate, tubular, cellular, link and cylindrical silencers [11-14]. Also found the use of silencers for special shapes. More often than others industry uses plate dissipative noise silencers.

Recently, more and more attention paid not only to the acoustic efficiency of silencers. Their impact on the operation of related equipment is also very important. For example, any extra silencer installed in the gas or air duct is an extra drag. Energy efficiency requirements push for the development of dissipative silencers of complex shapes. Such silencers have high acoustic efficiency. But at the same time reduced their aerodynamic resistance. This is due to their special shape. Engineers develop modern dissipative silencers of a new generation taking into account two things. They are acoustic efficiency and energy efficiency indicators.

Below are the results of modeling the petal silencer developed by the authors.

2. PETAL-SHAPED SILENCER

The authors developed a new design of the silencer. This silencer for open cylindrical channels. There is a patent for the proposed design [15]. The petal-shaped silencer reduces noise in the industry: power, metallurgy, chemical, and others. Noise sources can be, for example, fans of dry cooling towers, fans, ventilation systems. Common feature is the presence of open cylindrical channels.

The radiation effect is the main problem of open channels with a silencer installed inside. In this case, the sound-absorbing material absorbs only the part of the sound energy. The rest part passes through and radiates from the cutoff. This effect leads to a decrease in the acoustic efficiency of the silencer.

Cylindrical noise silencer was a prototype of the petal-shaped silencer [16]. It consists of straight cylinders, inside of which there is sound-absorbing material. Fiberglass and a perforated sheet protect this material from blowing. At the ends of the plates, there are fairings to reduce the aerodynamic drag. A larger number of cylinders allows increasing the acoustic efficiency of the prototype. This solution leads to a decrease in the flow section of the channel. As a result of what increases its aerodynamic drag. The aerodynamic drag of the silencer may limit the main technical characteristics of the equipment. For example, limiting the performance of fans and reducing the cooling capacity of the cooling tower. This leads to an overspend of electricity for their own needs and fuel.

Installing petal-shaped plates in a cylindrical channel leads to intensive noise reduction. The sound waves necessarily fall on the surface of the plates of the silencer. Also, because of the direct contact of the flow with the surfaces of the plates, the sound energy reflects back into the channel. The radiation effect will absent when $\vartheta \geq \vartheta_{min}$ the rotation angle of the plates is min. This angle depends on the number of petal-shaped plates and calculates:

$$\vartheta_{min} = 360/n \quad (4)$$

where

$n \geq 4$ is the number of plates installed in the channel. The recommended number of plates is from 4 to 8.

Petal-shaped plates allow to rotate outgoing (incoming) flow in the direction of fan blades rotation. The silencer should install directly behind or in front of the fan. The rotation of the flow reduces the aerodynamic drag introduced by the silencer. This reduces the aerodynamic drag of the silenced section and increases the acoustic efficiency. The special profile of the petal-shaped plates leads to the effect. Plates of the silencer provide the channel overlap and prevent the direct propagation of noise.

Installation of a petal-shaped silencer allows reducing the aerodynamic drag by 18-50%. Increase the acoustic efficiency of the silencer is 5-10 dB. The changes compared with a cylindrical silencer.

The general view of the lobe silencer in the cylindrical channel is in Fig. 1. The silencer consists of plates 1 inside which there is a sound-absorbing material 2. Fiberglass 3 and a perforated sheet 4 protect the material from blowing. The fairings 5 at the ends of the plates reduce aerodynamic drag. The plates are in the cylindrical channel 6 and held on shaft 7.

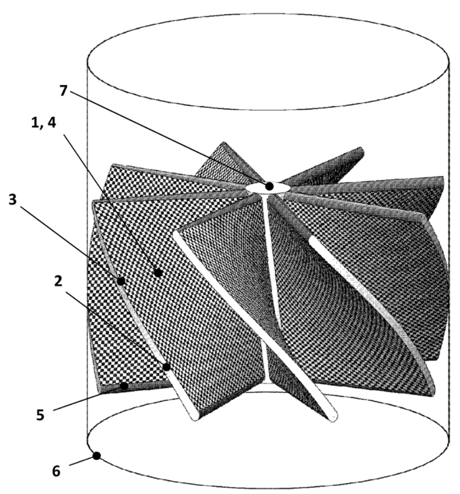

Fig. 1: Petal-shaped silencer in a cylindrical channel

3. NOISE PROPAGATION FROM FANS OF DRY COOLING TOWER

Dry cooling towers are a promising technology. Systems of reverse cooling of combined-cycle gas units use such cooling towers. Combined-cycle gas technologies (CCGT) help to modernize and increase the capacity of existing thermal power plants. In particular, in large cities. The use of CCGT reduces the emissions of pollutants. The main equipment of the CCGT has noise silencers and thus does not cause exceeding permissible sound levels. But, the fans of cooling towers are the powerful noise source. Below is an example of noise propagation from a dry fan cooling tower of one of the Moscow thermal power plants. The noise sources of the cooling tower are axial fans with the vertical exhaust. There are a total of 45 fans on the cooling tower at a height of 30 m.

The 3D calculation scheme and the results of the acoustic calculation are in Fig. 2. It is clear that the cooling tower is a source of excess for the adjacent residential development. At a full load of the fan cooling tower in the nearest points of residential development, the excess is 13,8 dBA. At the calculated points at a height of 1.5 m, the sound levels are 4.1 dBA lower than at the height of the last floor. This is due to the screening effect of buildings in the path of sound propagation. Also, the lower noise levels due to the fact that the cooling tower fans are at a height of 30 m.

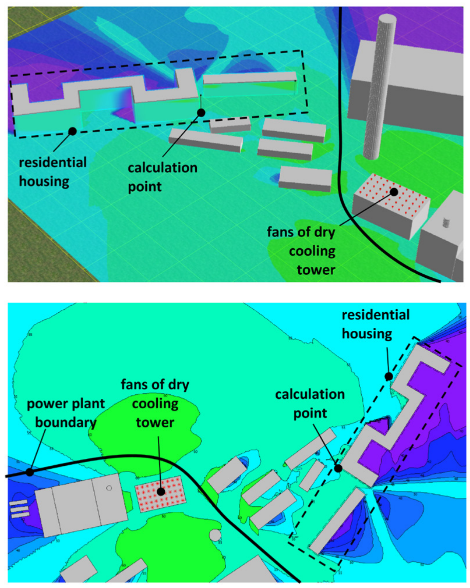

Fig. 2: Calculation scheme and the results of the acoustic calculation

A comparison of the calculated data and results of noise measurements from the fan cooling tower is in Fig. 3. The calculation takes into account the partial load of the cooling tower during full-scale measurements. In total, there were 33 fans in operation. The comparison shows a good convergence of the calculated and measured data for octave bands from 63 to 4000 Hz. The difference at 8000 Hz caused by the high values of the attenuation of noise in the air at high frequencies. When measuring at octave band of 8000 Hz, recorded the values of background noise.

Analysis of the measurement and calculation data shows that the fans of dry cooling towers are the sources of significant excess noise. This is especially important for the upper floors. In this case, there is a radiation effect. The use of petal-shaped silencer allows to exclude the radiation effect and to increase the acoustic efficiency.

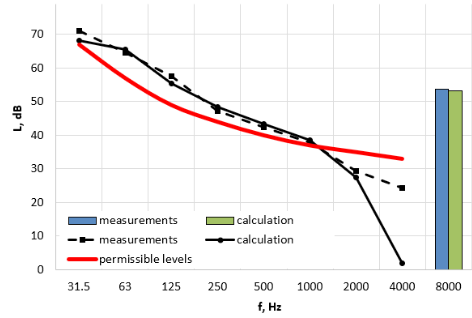

Fig. 3: Comparison of calculated data and measurement results

4. MODELING OF A PETAL-SHAPED SILENCER

We modeled a cylindrical channel behind the fan of a dry fan cooling tower. The air comes out from the fan vertically upwards. Cooling tower fans are high-altitude noise sources. The noise from the fans in question radiates freely through the channel. Then it reaches the upper floors of the adjacent residential development. The diameter of the channel behind the fan is 5.5 m. The air consumption of 277 m^3/s.

Modeling of a petal silencer is necessary to establish the cases in which its use is most appropriate and justified. Below are mathematical modeling results of petal-shaped silencers with a rotation angle of the plates 45 and 70 degrees. They compared with same results for a cylindrical silencer. Sketches of calculation models are in Fig. 4. In three cases, with the same height of the silencer, the lengths of the channels between the plates through which the air passes will differ. This will result in different sound energy absorption in the channels. To allow comparison of the three variants, the models in all three cases have an equal channel length. It remains constant and equal to 3.65 m. Behind the axial fans, when there are no straightening blades, the swirling flow continues to move through the channel. For the analysis, we have selected different angular velocities ω of the input flow. They vary from -20 to +15 rad/s. Negative values correspond to cases when the flow twists in the direction of the twist of the petal-shaped plates. Positive values correspond to cases when the flow twists in the opposite direction relative to the twist of the silencer plates. In the simulation, all variants have the same cross-sectional area to allow comparison of the results.

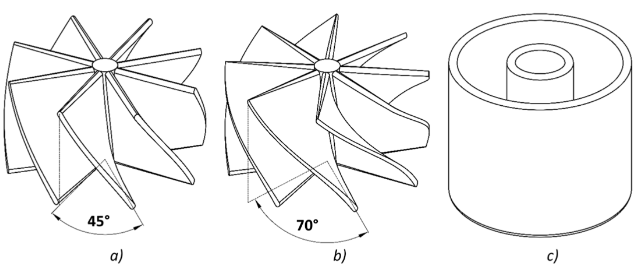

Fig. 4: Sketches of calculation models – a), b) petal-shaped silencers, c) cylindrical silencer

The simulation results are in Fig. 5 and in Tab. 1. The sign of the angular velocity shows the direction of rotation of the flow. Analysis of the results shows that the most used and most obvious design option (cylindrical silencer) is not always optimal. A cylindrical silencer is acceptable in cases where a straight or slightly twisted flow is moving in the channel. But when the angular velocity of the flow increases from 0 to -10 rad/s, the cylindrical silencer loses its advantage. Even at -10 rad/s, the resistance of a cylindrical silencer is twice as high as that of a petal-shaped silencer with a 45° plate angle. With a further increase in the angular velocity, the difference in resistance decreases. But even at -20 rad/s, the resistance of the cylindrical silencer remains the greatest. Thus, to reduce noise in cylindrical channels petal-shaped silencers are the most suitable. Such silencers allow to achieve higher noise reduction with less aerodynamic drag. For angular velocities greater than 0 silencer's plates have an opposite direction of the twist than the flow. In this case, the aerodynamic drag of the petal-shaped silencers is more than the cylindrical silencer.

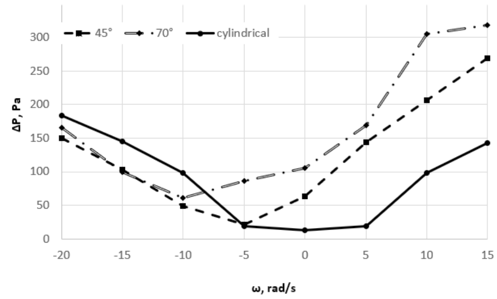

Fig. 5: The dependence of the silencer resistance on the angular velocity of the input flow

ω, rad/s	-20	-15	-10	-5	0	5	10	15
45°	150	104	49	22	63	144	206	269
70°	166	100	61	86	106	170	305	318
cylindrical	183	145	98	19	13	19	99	143

Tab. 1: Aerodynamic drags, Pa

Aerodynamic characteristics of the twisting flow explain the presented results. There are eddies in the channel in a twisting flow. Eddies lead to an increase in aerodynamic drag. The installation of a petal-shaped silencer allows softly straighten the flow passing through it. That reduces the unevenness of the flow behind the silencer. A cylindrical silencer, contrary, worsens the aerodynamic parameters. In the channels between the cylinders, there is an uneven cross-section. Due to the action of centrifugal forces, the flow accumulates at the outer wall of the channel. In this area, there is a zone of increased pressure. At the inner wall, in opposition, there is a zone of low pressure. The cylindrical silencer by its presence creates an additional artificial unevenness in the flow.

5. CONCLUSION

The results of the research allow us to perform the following conclusions:

1. There are specific sources, that radiate the noise from the fans through the outlet of vertical cylindrical channels. In such cases, measures on the ground level to reduce noise have no effect. The noise reaches the upper floors of residential buildings without hindrance.

2. In the example, the change in noise levels over the height of the building reaches 4.1 dBA. This illustrates the need to develop measures to reduce noise, taking into account the height of buildings in the residential area.
3. The use of classic cylindrical silencers in the fan channels is not an optimal solution for two reasons. First, the acoustic efficiency of the cylindrical silencer is low. Secondly, the twisting flow stratifies in the cylindrical silencer and leads to an increase in aerodynamic drag.
4. The use of petal-shaped silencers is a promising technology. Such silencers have a greater acoustic efficiency of 5-10 dB, in comparison with cylindrical silencers. With the correct choice of the angle of the petal-shaped plates, they have less aerodynamic resistance (up to 50%) in comparison with cylindrical silencers.

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