Fan duct noise elimination by the use of helicoidal resonators

Wojciech ŁAPKA[1]

[1] Poznan University of Technology, Institute of Applied Mechanics, Poland

ABSTRACT

This work focuses on describing the fan duct noise elimination by the use of helicoidal resonators. It is the newly patented passive acoustic filter in duct - especially cylindrical. The narrowband noise attenuation could be obtained by properly designed helicoidal shape inside cylindrical duct. The helicoidal resonator gives the possibility to reduce the discrete tonal sounds in different ways, a single or multiple application. The possible band filtering could be used to attenuate discrete noise generated in the range of rotational speeds of fan. Also, this work consists the theoretical considerations supported by practical examples of reduction of fan duct noise by the use of helicoidal resonators.

Keywords: fan duct noise, helicoidal resonator, noise reduction
I-INCE Classification of Subjects Number(s): 37.2, 37.4, 37.6.

1. INTRODUCTION

New technologies in fan duct noise elimination are very much needed to improve the World through the noise control. Almost in every building or unit the fans are installed, which may emit very annoying tonal noise. In industrial cases the fans are required to meet the different needs for the implementation of technological processes. And because of the continuous development of civilization those needs are still increasing. Hence, more and more is also the noise. Additionally important is the issue of energy consumption. Therefore, research into new technologies in fan duct noise reduction are still very important.

One of the new technology,, which meets those needs, is the newly patented solution helicoidal resonator (3), as presented in Figure 1.

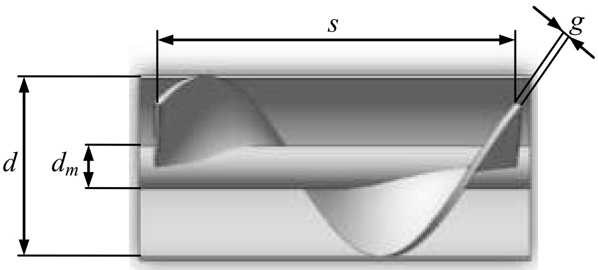


Figure 1 – Helicoidal resonator: *s* - helicoidal pitch, *d* - internal diameter of duct, d_m - mandrel diameter, *g* - thickness of helicoidal profile, *n* - number of helicoidal turns.

It is a new kind of acoustic filter in the domain of passive silencers (1,2). Due to its narrowband sound attenuation properties it can be used for tonal fan duct noise elimination.

The first predicted acoustic parameter of helicoidal resonators like twisted helicoidal screws with different pitches and turns inside 1m long cylindrical duct was a Noise Reduction (NR) in reference (4). This parameter showed the sound pressure level difference between inlet and outlet of duct with screws and the conclusions underlined that the increase of the number of helicoidal turns results in bigger NR in the low- and mid-frequencies. But there were no any informations about band-stop

[1] wojciech.lapka@put.poznan.pl

filtering of noise by the helicoid inside duct. Thus, the Transmission Loss (TL) parameter was firstly used for analysis of acoustic attenuation performance of a round silencer with the helicoidal resonator at the inlet in reference (5). The increase of TL for the range of helicoid pitch *s* to cylindrical duct diameter *d*, ratio *s/d*, from 0.4 to 8.0 were presented. Also the specific sound pressure levels (SPL) distribution inside the silencing system with selected helicoidal resonator for the highest value of the TL increase was showed. The fully compatible comparison of numerical and experimental SPL distributions for the same type and dimensions of helicoidal resonator was presented in (6). Already well known Band Stop Filter (BSF) is the Helmholtz Resonator (1,2), and it can be substituted by the Helicoidal Resonator, as it was presented in (7). There was introduced, that for some cases the helicoidal resonator can be much more efficient solution, when considering the sound attenuation inside duct, than the Helmholtz resonator - especially in large diameter cylindrical ducts. The next important step on the recognition of helicoidal resonators properties was the comparison of numerical and experimental acoustic attenuation performances. The simple experimental set-up was prepared to measure Insertion Loss (IL) parameter in (8). Another time almost full compliance was observed, "almost" due to not so strong resonances in reality in comparison to ideally reflective surfaces in numerical analysis. But the range of frequencies of attenuated sounds and so important resonance frequencies were fully matched. The lack of mathematical descriptions of helicoidal resonators acoustical properties was partially filled by the presented in (9) its substitutional transmittance function. But it is correct for Band Stop Filters with symmetric distribution of attenuation in the frequency domain, also for selected types of helicoidal resonators.The second importand parameter of helicoidal resonators - pressure drop - was raised in the paper (10), about comparison of this parameter obtained in aeroacoustical module and turbulent flow in computational fluid dynamics (CFD) module in the same numerical environment. It showed that the difference between aeroacoustics and CFD turbulent flow is bigger when the mean air volume velocity grew up. The reason is the weak formulation of flow equations for aeroacoustics in numerical environment. But the other way, the numerical aeroacoustic analysis was used to make some researches on the influence of the air volume velocity on the acoustic attenuation performance of selected helicoidal resonators presented in (11). The results showed that the greater air volume velocity the lower resonance frequencies of the helicoidal resonators. But, to make the exact conclusions in this field, the experimental researches should be undertaken. The multi-resonant helicoidal resonators as a passive noise control device in ducted systems was presented in (12). Conducted research presented helicoidal resonators with different ratio *s/d* in relation to the existence of a multi resonances. The real industrial application of a large multi-resonant helicoidal resonator was presented in reference (13). The other side of scientific considerations under helicoidal resonators was presented in reference (14), when studying the acoustic-structure interaction of selected helicoidal resonator with flexible helicoidal profile. There were considered properties of metals and non-metals, especially rubber. Final conclusion: applying the elastic material on the helicoidal profile could decrease the acoustic resonance - in the worst case amplify the sound. The experimental study of pressure drop depending on the air flow rate in duct of selected helicoidal resonators with constant ratio *s/d*=1,976 was presented in (15). The experimental set-up for testing silencers was used to measure pressure drop of three helicoidal resonators with numbers of turns *n* that equaled 0.671, 0.695 and 1.0. Also three total pressure drop coefficients ζ were determined for each resonators, that equal 4.3, 4.4 and 4.9, respectively. Thus, the consequent conclusion that the more helicoidal turns the more pressure drop is induced. A numerical analysis of transmission loss characteristics and pressure drop for a range of helicoidal resonators with constant *s/d* ratio that equals 1,976, but for different numbers of helicoidal turns *n* was presented in (16). As the acoustic attenuation properties are the most important part of helicoidal resonators considerations, the pressure drop is the consequence and it must be taken into account during the functional analysis of ducted system. The range of helicoidal turns *n* from 0 to 2.0 was investigated for acoustic modelling. The specific band attenuation of sounds of helicoidal resonators with ratio *s/d*=1,976 exist almost for all investigated cases. But the most interesting part of *TL*s starts from about *n*=0.4 and ends for about *n*=1.0.On the basis of most interesting values of acoustic attenuation performance parameter *TL*, the range of helicoidal turns *n* from 0 to 1.0 was investigated for computational fluid dynamics with turbulent flow. The pressure drop increases when the mean air volume velocity grows up for all investigated cases. Although the biggest and nearly linear increase of pressure drop takes place for the numbers of helicoidal turns *n* from about 0.1 to about 0.6. From 0.6 to 1.0 the pressure drop increases nonlinearly. Natural next step is the normalization of parameters as in undertaken research work (17), where the transmission loss characteristics of helicoidal resonators were integrated and normalized to the highest value to obtain one global parameter of acoustical attenuation performance (Ratio from 0 to 1.0). A numerical map of normalized transmission losses TL_{norm} was obtained, as presented in Figure 2.

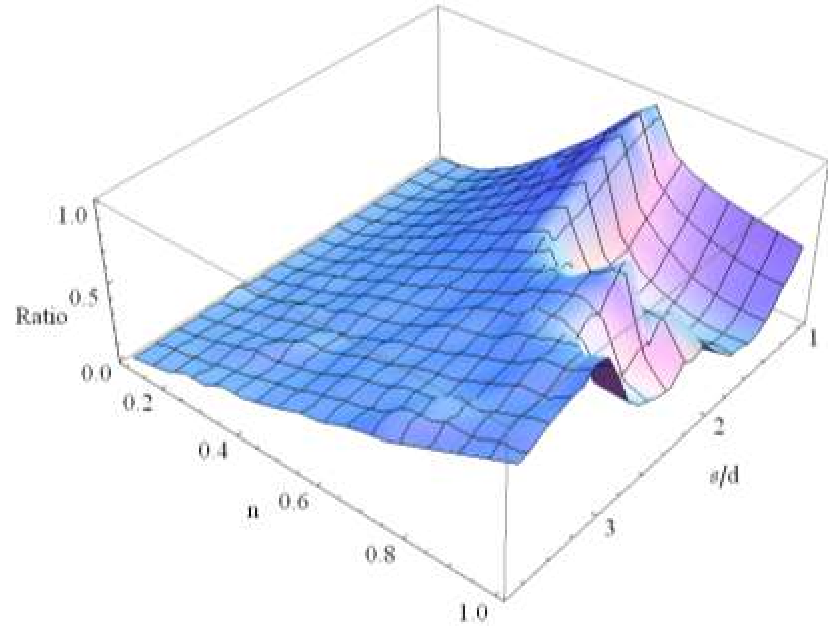


Figure 2 - Normalized transmission losses TL_{norm} for helicoidal resonators in straight cylindrical ducts in the range of ratio *s/d* from 1.0 to 4.0 and numbers of helicoidal turns *n* from 0.1 to 1.0, as presented in (17).

There were obtained TL_{norm} contours of the same values from 0.2 to 0.8. And for the same range of parameters of helicoidal resonators the total pressure drop coefficients ζ were calculated. The TL_{norm} contours of the same values from 0.2 to 0.8 and total pressure drop coefficients ζ of the same values from 1 to 8 were superimposed, as presented in Figure 3.

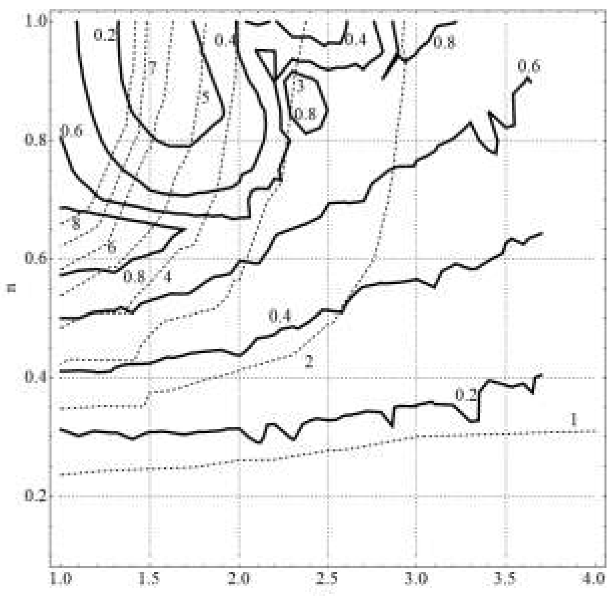


Figure 3 - Superimposed contours of TL_{norm} with contours of the same values from 0.2 to 0.8 (solid) and total pressure drop coefficients ζ of the same values from 1 to 8 (dotted) (17).

On this broad base of scientific research work under helicoidal resonators, it is possible to present in this paper the example ways of eliminating tonal fan duct noise by use of this solution.

2. POSSIBLE NOISE REDUCTION EFFECTS

2.1 Reduction of fan duct noise in environment

Most fans generate pure tones that corresponds to the blade-passing frequency (BPF) and its harmonics (18), which could be the most annoying noise eg. for workers or nearby residents. In some cases (eg. centrifugal fans) the peak at the BPF appears as dominating (it generates the greatest acoustical energy), and the first and other harmonics are very low and they are often practically masked by the broadband noise (19), as presented in Figure 3.

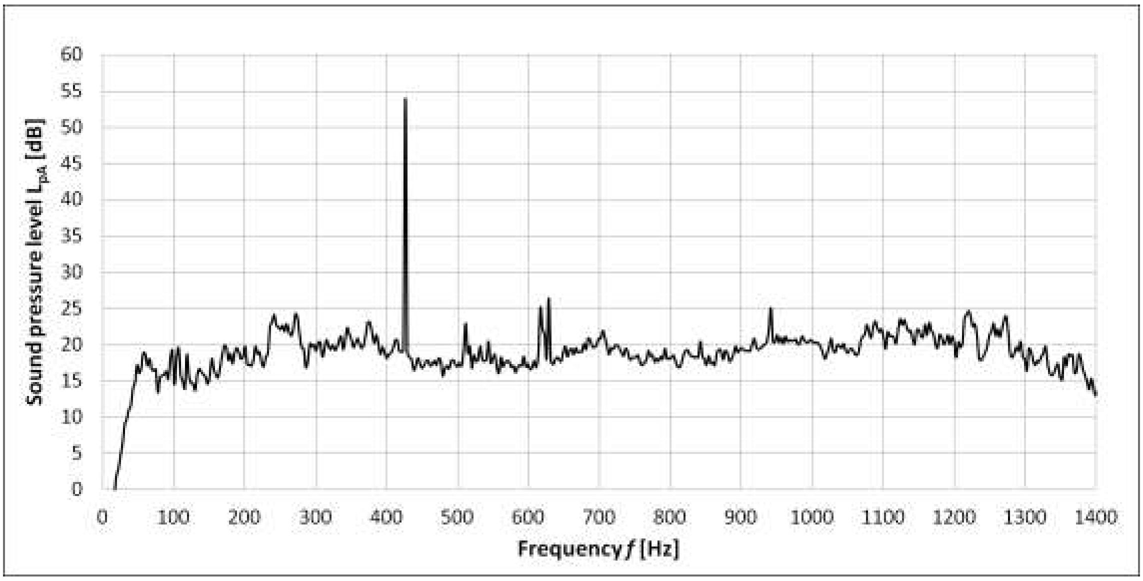


Figure 3 - Example spectrum of sound pressure levels in environment close to industrial plant with working centrifugal fan with BPF near 425Hz.

By eliminating the pure tone from example spectrum in Figure 3, it is possible to reduce the total sound pressure level (SPL) in measurement point placed on the border of industrial plant area from existing 55dBA to about 46dBA. Also the attractive total reduction of about 9dB can be obtained by the use of helicoidal resonator that strongly attenuates the sounds in the range of frequencies from about 400Hz to 460Hz including sound attenuation at BPF=425Hz of about 50dB, as presented in Figure 4. Thus, some changes in rotational speed of fan are taken into account.

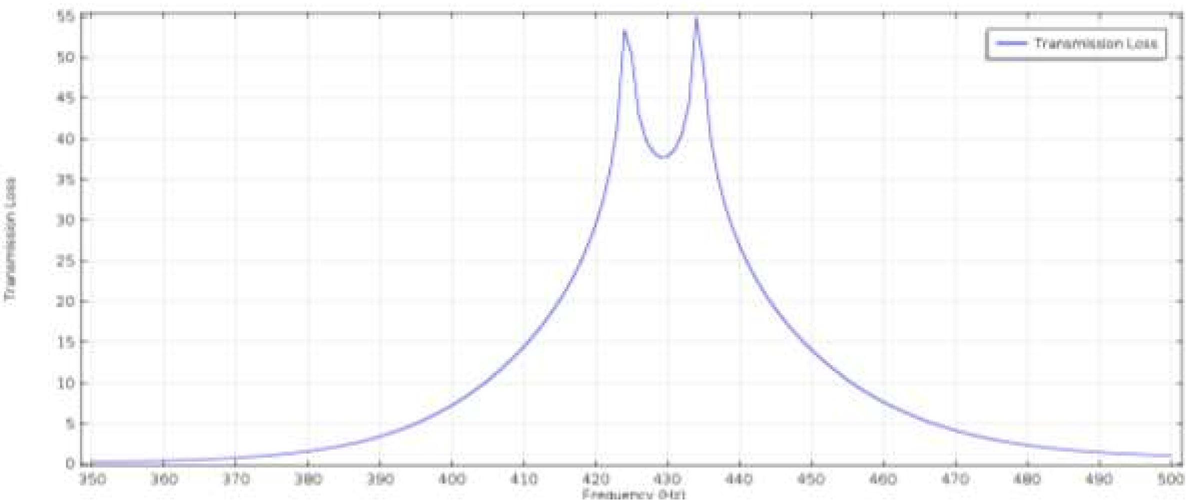
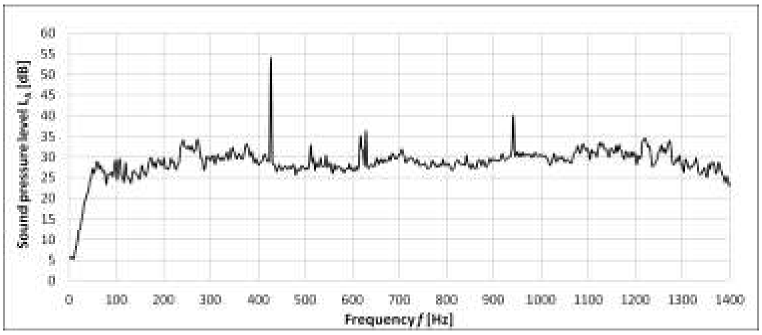
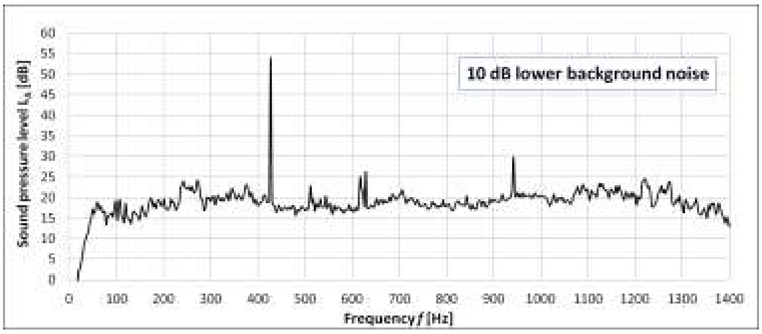
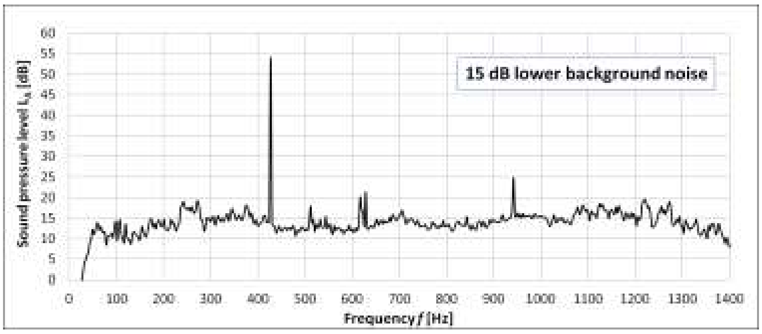


Figure 4 - Transmission Loss characteristic of helicoidal resonator for attenuating sounds around frequency 425Hz.

The tonal noise is most annoying at night when the background noise is very low. Also at this time the total SPL is determined by the highest discrete value of a noise spectrum. The reduction of total SPL will be then the highest, when eliminating the tonal maximum sound level. In Table 1 are presented the values of total SPL before and after elimination of the discrete value of sound at BPF= 425Hz in the function of different levels of background noise.

Table 1. Values of total SPL before and after elimination of the discrete value of sound at BPF= 425Hz in the function of different levels of background noise.

No.	Noise spectrum before elimination the discrete value of BPF=425Hz of the SPL=54dBA	Total SPL **before** elimination of BPF value, $L_{pA,1}$ [dB]	Total SPL **after** elimination of BPF value, $L_{pA,2}$ [dB]
1		**58**	**56**
2		**55**	**46**
3.		**54**	**41**

The reduction of total SPL is small when the background noise is at the level of about 30dBA, and it equals only 2dB (example 1 in Table 1). When the background noise is 10dB lower (about 20dBA) the reduction of total SPL equals 9dB (example 2 in Table 1). The greatest reduction of noise is achieved with the background noise that equals about 15dBA, and it is 13dBA, when eliminating the discrete value of sound at BPF=425Hz (example 3 in Table 1). Also it is possible to reduce the total SPL from unacceptable level to acceptable level, when considering the environmental noise.

2.2 Single helicoidal resonator in ducted suction system

The single helicoidal resonator can be used when the chimney or ducted system satisfies the requirements of length and diameter of duct to obtain the acoustical resonance. The cylindrical duct system should include as long duct section with the helicoidal resonator in the middle as possible. Also, the best result of noise reduction can be obtained by comparing the helicoidal resonators strong resonance with absorptive materials properties.

The example duct system with good conditions to reduce the fan duct noise is presented in Figure 5.

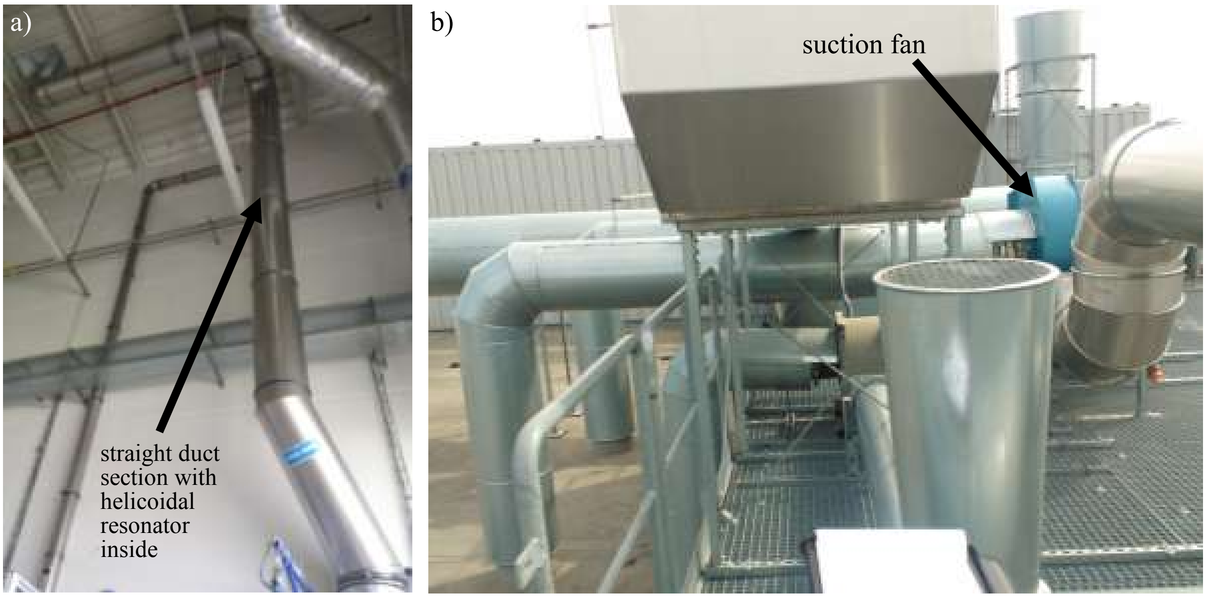


Figure 5 - Example ducted ventilating installation at working environment with good conditions to use helicoidal resonator to reduce the fan duct noise: a) interior part, b) exterior part with suction fan.

In Figure 6 are presented the sound pressure level (SPL) characteristics before and after noise reduction of ventilating installation at working place inside production room.

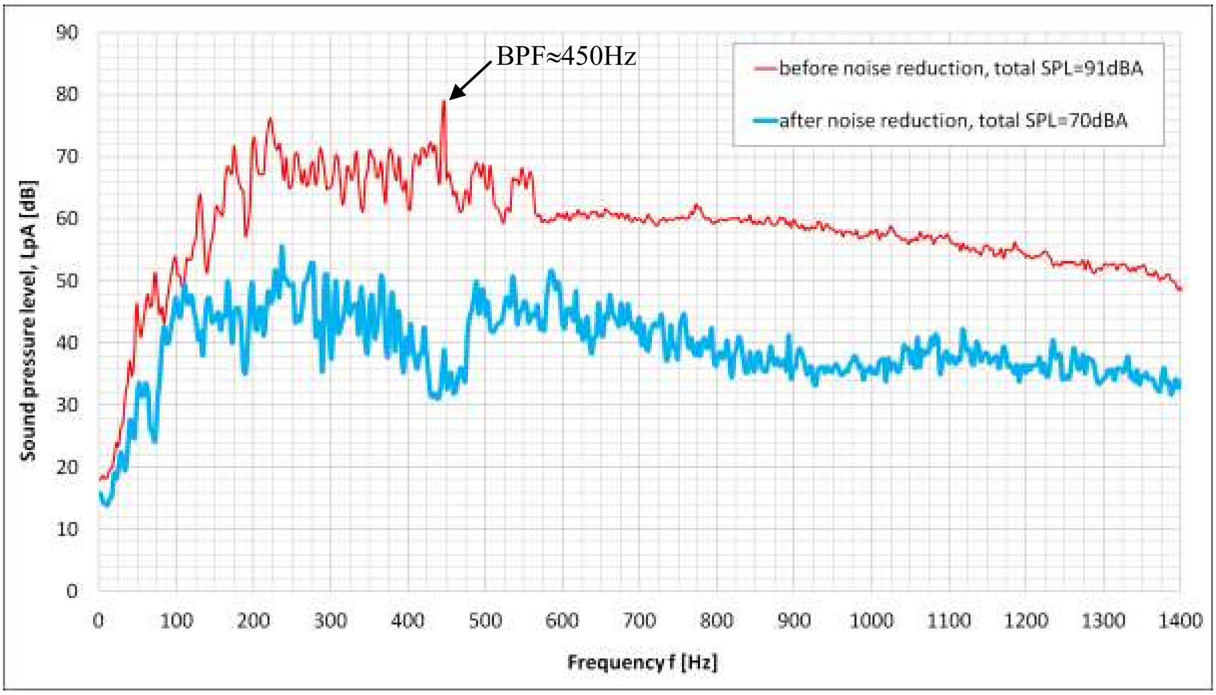


Figure 6 - Sound pressure levels at working place inside production room before and after noise reduction of ventilating installation by the use of single helicoidal resonator.

Here, the single helicoidal resonator could be tuned for the annoying BPF of about 450Hz of suction fan and placed in the straight duct section inside production room. At the interior inlet of suction system were installed absorptive layers, which worked similarly to absorptive silencers. As it is visible in Figure 6 the SPL near BPF were strongly reduced, and the acoustical attenuation performance of helicoidal resonator is about 40dB. Also the total SPLs are much different, and the total reduction is 21dB.

2.3 Multiple helicoidal resonators

Muliple helicoidal resonators can be used in different ways and configurations to achieve the expected acoustical attenuation performance. It is possible to place two or more helicoidal resonators inside cylindrical duct of the same diameter, but it should be reasonably long duct. However, it is possible to replace the section of cylindrical duct of a large diameter and insert a few ducts with tuned for the same BPF helicoidal resonators, as it is presented in Figure 7.

a) b)

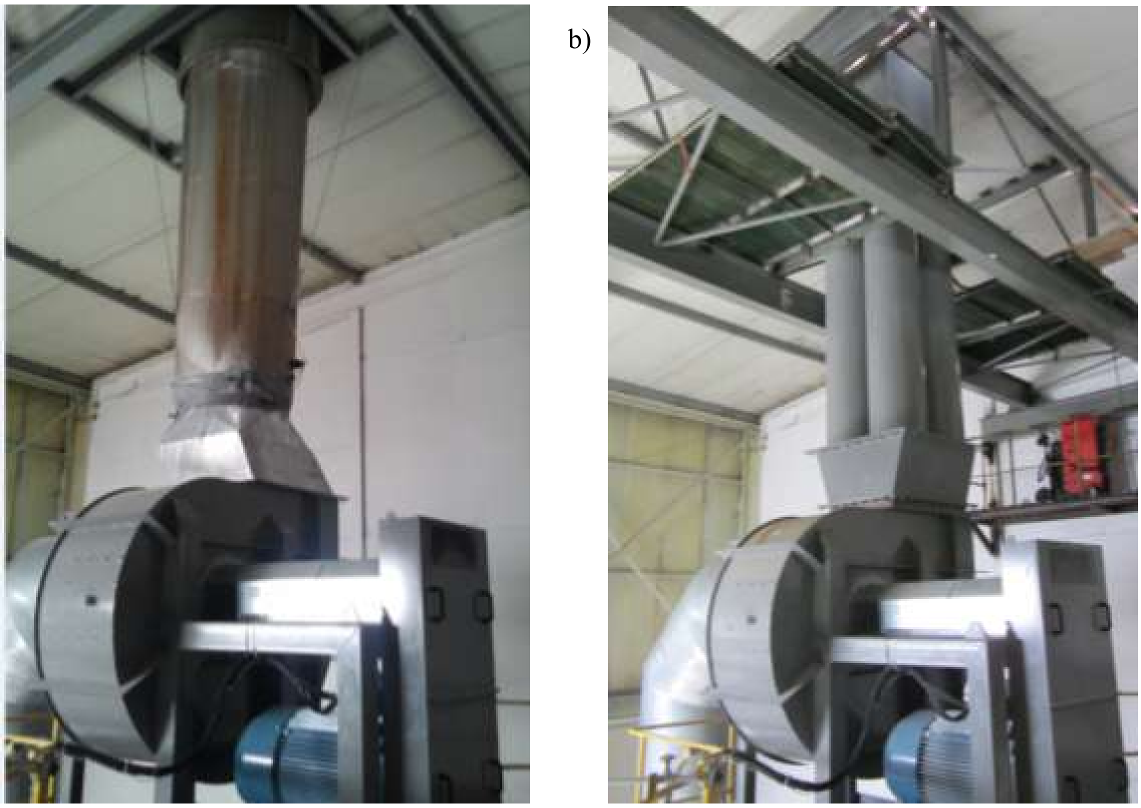


Figure 7 - Industrial fan with large outlet diameter of about 1000mm before (a) and after applying multiple helicoidal resonators (b).

Also, the need of replacing large diameter duct depends on the possibility of obtaining acoustical resonance for BPF inside duct. As presented in Figure 7, to obtain the acoustical resonance it was necessary to divide the outlet duct into four smaller ducts.

3. CONCLUSIONS

This paper recognized the capabilities of fan duct noise elimination by the use of helicoidal resonators. Hence, the new technology in fan duct noise elimination was presented, which may help to improve the World through Noise Control.

Presented examples showed that the elimination of one discrete tone from a noise spectrum can radically reduce the total sound pressure levels. However, the environmental noise analysis should include a background noise, which has a strong influence on the final effect - total sound pressure level.

Also, the blade pass frequency of different kind of fans can be reduced by the newly patented helicoidal resonator in different ways and ducted systems with good applicability conditions. Because of mass fans applications it is possible to reduce noise at working environment, environmental noise from industrial plants, fan noise at home installations, etc. by the use of helicoidal resonators.

ACKNOWLEDGEMENTS

Author acknowledge the partial financial support in the year 2014 by the research project 02/21/DSPB/3454.

REFERENCES

1. Munjal ML. Acoustics of Ducts and Mufflers with Application to Exhaust and Ventilation System Design. Inc. Calgary, Canada, John Wiley & Sons. 1987.
2. Munjal ML. Galaitsis AG. Ver IL. Passive silencers. In: Beranek LL, Ver IL, editors. Noise and Vibration Control Engineering - Principles and Applications. 2nd ed. New York, USA: Wiley; 2006. p. 887-909.
3. Łapka W. Cempel C. Acoustic filter for sound attenuation in ducted systems. Polish Patent Office. PAT.216176. Date of grant 25.07.2013.
4. Łapka W. Cempel C. Noise reduction of spiral ducts. International Journal of Occupational Safety and Ergonomics (JOSE). Vol. 13 (4); 2007. pp. 419-426.
5. Łapka W. Acoustic attenuation performance of a round silencer with the spiral duct at the inlet. Archives of Acoustics. Vol. 32 (4) (Supplement). pp. 247-252. 2007.
6. Łapka W. Cempel C. Computational and experimental investigations of a sound pressure level distribution at the outlet of the spiral duct. Archives of Acoustics. Vol. 33 (4) (Supplement). 2008. pp. 65-70.
7. Łapka W. Cempel C. Acoustic attenuation performance of Helmholtz resonator and spiral duct. Vibrations in Physical Systems. Vol. 23. 2008. pp. 247-252.
8. Łapka W. Insertion loss of spiral ducts - measurements and computations. Archives of Acoustics. Vol. 34 (4). 2009. pp. 407-415.
9. Łapka W. Substitutional transmittance function of helicoidal resonator. Vibrations in Physical Systems. Vol. 24. 2010. pp. 265-270.
10. Łapka W. Comparison of numerically calculated pressure drop for selected helicoidal resonators. Polish Acoustical Society-Poznan Division. 59th Open Seminar on Acoustics joint with Workshop on Strategic Management of Noise including Aircraft Noise. 2012. pp. 145-148.
11. Łapka W. Numerical Aeroacoustic Research of Transmission Loss Characteristics Change of Selected Helicoidal Resonators due to Different Air Flow Velocities. Vibrations in Physical Systems. Vol. 25. 2012. pp. 267-272.
12. Łapka W..Multi resonant helicoidal resonator for passive noise control in ducted systems. Experimental Mechanics-New Trends and Perspectives. J.F.S. Gomes. M.A.P. Vaz. Proc. of ICEM15. Porto. Portugal. 2012. pp. 995-996.
13. Łapka W. Helicoidal resonators for passive noise control in ducted systems with practical application. Proc. of Internoise 2012. New York. USA. 2012.
14. Łapka W. Numerical study of acoustic-structure interaction of selected helicoidal resonator with flexible helicoidal profile. Postępy Akustyki (Advances in Acoustics). Polish Acoustical Society-Rzeszow Division. 2013. pp. 194-205.
15. Łapka W. Szymański M. Górzeński R.. The study of pressure drop depending on the air flow rate in duct of selected helicoidal resonators. Postępy Akustyki (Advances in Acoustics). Polish Acoustical Society-Rzeszow Division. 2013. pp. 168-180.
16. Łapka W.. Transmission loss and pressure drop of selected range of helicoidal resonators. Vibrations in Physical Systems. Vol. 26. 2014. pp. 121-128.
17. Łapka W. Kędzia P., Numerical analysis of transmission loss and pressure drop of helicoidal resonators in straight cylindrical ducts. Proceedings of Forum Acusticum 2014. Kraków, Poland. 2014.
18. Bolleter U. Chanaud RC. Propagation of fan noise in cylindrical ducts. The Journal of the Acoustical Society of America. Vol. 49. No. 3 (Part 1). 1971. pp. 627-638.
19. Veldare-Suarez S. et al, Experimental determination of the tonal noise sources in a centrifugal fan, Journal of Sound and Vibration. Vol. 295. 2006. pp. 781-796.