Vibrations in Physical Systems Vol.26 (2014)

Transmission Loss and Pressure Drop of Selected Range of Helicoidal Resonators

Wojciech ŁAPKA
Poznan University of Technology, Institute of Applied Mechanics
Jan Paweł II 24 Street, 61-139 Poznań, POLAND
wojciech.lapka@put.poznan.pl

Abstract

The paper presents the numerical analysis of transmission loss and pressure drop of acoustic helicoidal resonators with constant pitch to cylindrical duct diameter ratio and different number of helicoidal turns n. The ducted system consists of a straight cylindrical duct of constant diameter d=0.125m. The ratio of helicoidal pitch s to cylindrical duct diameter d equals s/d=1,976. Other geometrical relationships of helicoidal resonator, as a mandrel diameter d_m to duct diameter ratio d_m/d=0.024 and thickness g of helicoidal profile g/d=0.0024, were constant as well. The investigated range of numbers of helicoidal turns n was analyzed in the range from 0 to 2.0 for transmission loss parameter and from 0 to 1.0 for pressure drop. The values of normal inflow velocity v [m/s] equals 1, 5, 10, 15 and 20.

Keywords: helicoidal resonator, transmission loss, pressure drop, numerical analysis

1. Introduction

Helicoidal resonator is the newly patented invention [1] in the domain of passive silencers. It is an acoustic filter that attenuates sounds inside cylindrical duct due to its resonant properties. The sound attenuation is realized by the acoustic resonance inside helicoidal profile. The geometrical relationships between helicoidal profile, mandrel and duct diameter determine the acoustic properties of helicoidal resonators. Also its main property is the sound attenuation, and the next are flow properties, as the usually most important pressure drop.

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 [2]. 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 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 [3]. 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 [4].

Already well known Band Stop Filter (BSF) is the Helmholtz Resonator, and it can be substituted by the Helicoidal Resonator, as it was presented in [5]. 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 [6]. Another time almost full compliance was observed, "almost" due to not so strong resonances in reality. But the range of frequencies of attenuated sounds and so important resonance frequencies were matched. The lack of mathematical descriptions of helicoidal resonators acoustical properties was partially filled by the presented in [7] 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 [8], 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. But the other way, the aeroacoustic module 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 [9]. 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 [10]. 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 [11].

The other side of scientific considerations under helicoidal resonators was presented in [12], 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 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 [13]. 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.

This work presents the 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. 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. Firstly are characterized acoustical and CFD models, and then are presented the results of *TL* [dB] for the range of *n* from 0 to 2.0 and pressure drop Δp [Pa] for the range of *n* from 0 to 1.0. The main objective of this paper is to show the proper way of selection of acoustical and flow properties of helicoidal resonators with ratio s/d=1,976, as a continuation of previous research work [4-9, 12, 13].

2. Description of investigated models

In this chapter are characterized investigated acoustic (2.1) and turbulent flow (2.2) models of helicoidal resonators inside a cylindrical duct. In both cases were analyzed three dimensional (3D) models of cylindrical duct with helicoidal resonator in the middle, as presented in Figure 1.

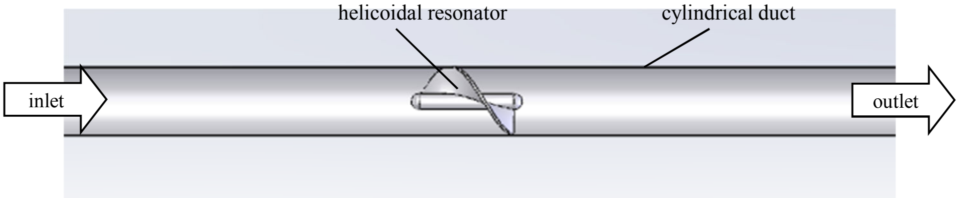

Figure 1. Investigated cylindrical duct with helicoidal resonator

The ducted system consists of a straight cylindrical duct of constant diameter d=0.125m. The ratio of helicoidal pitch *s* to cylindrical duct diameter *d* equals s/d=1,976. Other geometrical relationships of helicoidal resonator, as a mandrel diameter d_m to duct diameter ratio d_m/d=0.024 and thickness *g* of helicoidal profile g/d=0.0024, were constant as well. The length of the cylindrical duct at the inlet and outlet sides of helicoidal resonators equaled 1m.

2.1. Acoustical model

The investigated acoustical model has the same parameters as in previous, well described studies under helicoidal resonators [2-7]. It was used the finite element method in Comsol Multiphysics-Acoustic Module numerical environment [14]. The investigated range of numbers of helicoidal turns *n* was analyzed in the range from 0 to 2.0. The transmission loss (*TL*) [15] was computed as the acoustic attenuation performance parameter and the sound propagation in air of temperature 20ºC without flow was considered. The following boundary conditions were established:

- hard walls of all elements of helicoidal resonators (perfect reflection) and cylindrical duct,
- plane waves radiation - inlet (incident pressure p=1Pa) and outlet surfaces of the cylindrical duct - that satisfies the anechoic terminations to calculate *TL*.

The free tetrahedral mesh [14] was created automatically with satisfying the rule of minimum 5 finite elements per sound wave length [16] for maximum frequency- here it is f_{max}=2000Hz at 20 Celsius degrees. Also the speed of sound in air c_s=343m/s. Maximum finite element size equals $h_e=0{,}2(c_s/f_{max})$. Example mesh is presented in Figure 2.

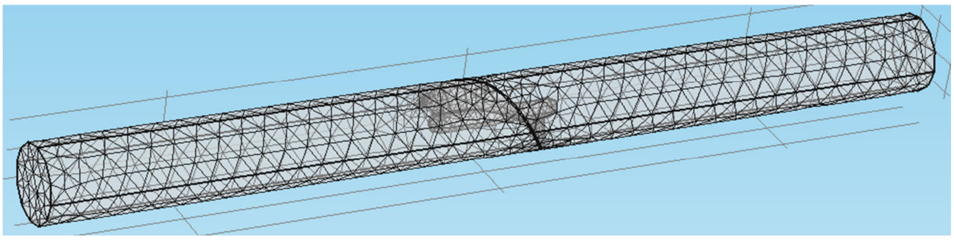

Figure 2. Example view on free tetrahedral mesh of investigated acoustic system

2.2. CFD turbulent flow model

The CFD turbulent flow model was analyzed as the single-phase flow k-ω turbulence RANS model [14, 17, 18] with compressible flow (Mach number less than 0,3). The main feature is fluid properties**,** which adds the Navier-Stokes equations and the transport equations for the turbulent kinetic energy k and the specific dissipation ω, and provides an interface for defining the fluid material and its properties [14]. The fluid properties are: temperature T=20ºC, reference atmospheric pressure p_a=1atm, density and dynamic viscosity of air were calculated automatically from COMSOL material library [14]. The boundary conditions were described as follows:

- wall slip - there are no viscous effects at the slip wall at all surfaces of cylindrical duct and helicoidal resonators,
- normal inflow velocity at the inlet in the air flow velocities 1m/s, 5m/s, 10m/s ,15 m/s and 20m/s,
- no viscous stress at the outlet, pressure equaled 0Pa.

Finite element mesh was automatically generated as a free tetrahedral and controlled by physics-fluid dynamics. The stationary solver was used. The investigated range of numbers of helicoidal turns n was analyzed in the range from 0 to 1.0 with the step of 0.1.

3. Results

This chapter contains the results of solved 3D pressure acoustics and fluid dynamics problems for investigated models of helicoidal resonators with constant ratio s/d=1,976 and different numbers of helicoidal turns n. Due to the acoustic attenuation performance is the most important parameter of helicoidal resonators the TL characteristics as a surface plot are contained in subchapter 3.1. On this basis were performed computations for fluid dynamics of helicoidal resonators with numbers of helicoidal turns n from 0 to 1.0 as it is presented in subchapter 3.2.

3.1. Transmission Loss

The surface plot of *TL* of helicoidal resonators with ratio *s/d*=1,976 and the range of numbers of helicoidal turns *n* from 0 to 2.0 for the frequency range from 10Hz to 2000Hz with the calculation step of 10Hz, are presented in Figure 3.

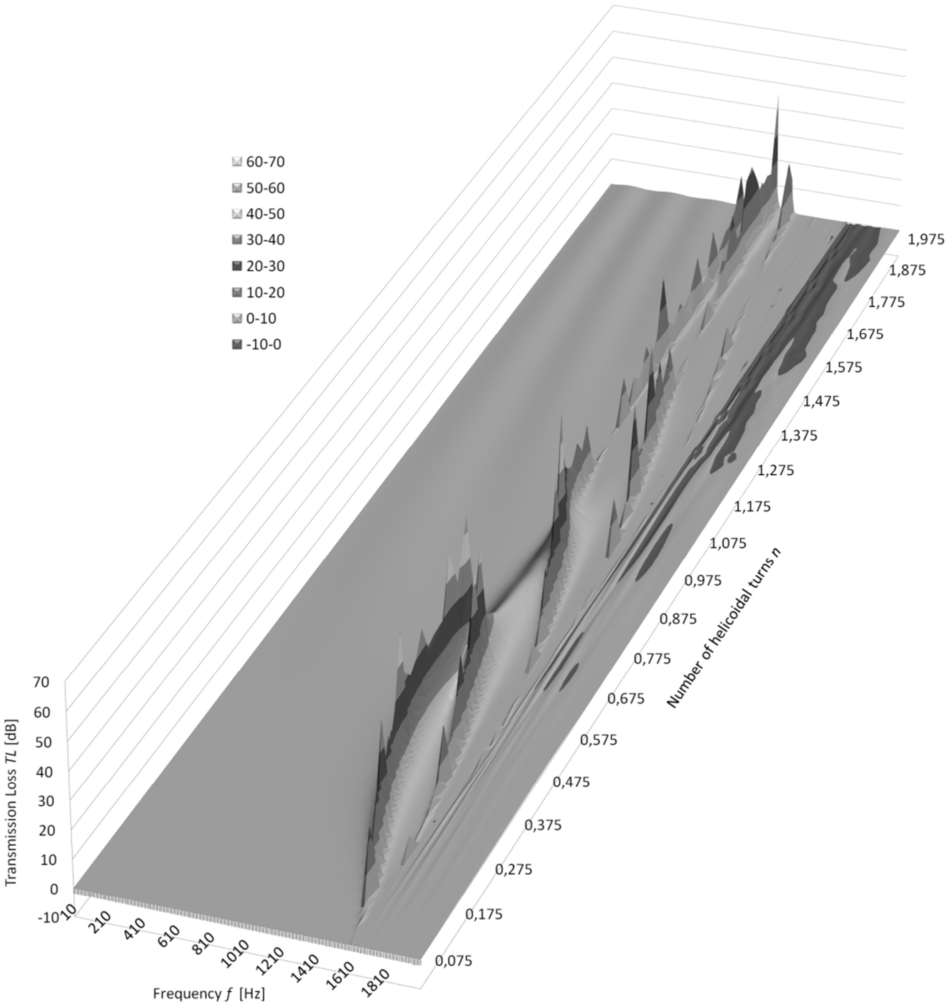

Figure 3. Surface plot of *TL* [dB] of helicoidal resonators with ratio *s/d*=1,976 and the range of numbers of helicoidal turns *n* from 0 to 2.0

As it can be observed from Figure 3 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 *n*=1.0. Globally the attenuation range of TL=1dB starts from about 1000Hz for n=0.55, and it ends on about 1580Hz for few numbers of helicoidal turns n.

3.2. CFD turbulent flow

The pressure drop Δp [Pa], as a difference between pressure at the inlet and outlet of the duct, of helicoidal resonators with ratio s/d=1,976 and the range of numbers of helicoidal turns n from 0 to 1.0 with the step of 0.1 are presented in Figure 4.

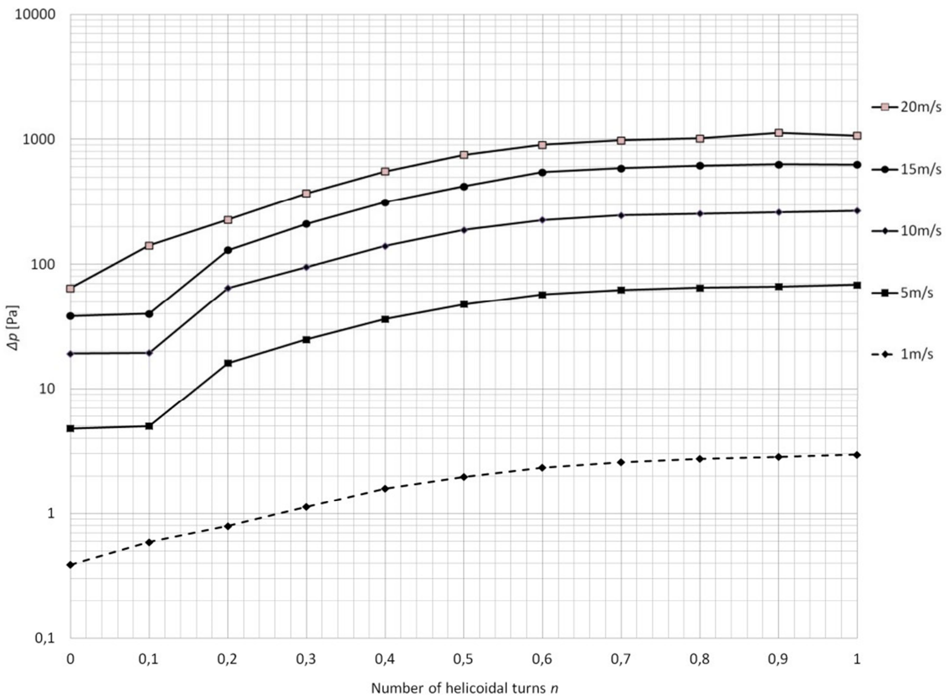

Figure 4. Pressure drop Δp [Pa] of helicoidal resonators with ratio s/d=1,976 and the range of numbers of helicoidal turns n from 0 to 1.0

As it can be observed from Figure 4, 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.

4. Conclusions

The numerically calculated transmission loss and pressure drops of helicoidal resonators with constant ratio s/d=1.976 and different numbers of helicoidal turns n were presented.

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. Globally the attenuation range of *TL*=1dB starts from about 1000Hz for *n*=0.55, and it ends on about 1580Hz for few numbers of helicoidal turns *n*. Also for investigated models the frequency range of sound attenuation equals nearly 580Hz.

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.

Acknowledgments

The author gratefully acknowledges that this paper was financially supported in the year 2014 by the research project 02/21/DSPB/337.

References

1. Łapka W., Cempel C., *Acoustic filter for sound attenuation in ducted systems*, Polish Patent Office, PAT.216176, Date of grant 25.07.2013.
2. Łapka W., Cempel C., *Noise reduction of spiral ducts*, International Journal of Occupational Safety and Ergonomics (JOSE), Vol. 13 (4), pp. 419-426, 2007.
3. W. Łapka, *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.
4. 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), pp. 65-70, 2008.
5. Łapka W., Cempel C., *Acoustic attenuation performance of Helmholtz resonator and spiral duct*, Vibrations in Physical Systems, Vol. 23, pp. 247-252, 2008.
6. Łapka W., *Insertion loss of spiral ducts - measurements and computations*, Archives of Acoustics, Vol. 34 (4), pp. 407-415, 2009.
7. Łapka W., *Substitutional transmittance function of helicoidal resonator*, Vibrations in Physical Systems, Vol. 24, pp. 265-270, 2010.
8. Łapka W., *Comparison of numerically calculated pressure drop for selected helicoidal resonators*, Polskie Towarzystwo Akustyczne - Oddział Poznański, tytuł monografii: 59th Open Seminar on Acoustics joint with Workshop on Strategic Management of Noise including Aircraft Noise, pp. 145-148, 2012.
9. 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, pp. 267-272, 2012.
10. Łapka W., *Multi resonant helicoidal resonator for passive noise control in ducted systems*, Experimental Mechanics - New Trends and Perspectives, Editors J.F. Silva Gomes, Mario A.P. Vaz, Proceedings of the 15th International Conference on Ex-

perimental Mechanics, ICEM15, Porto, Portugalia, 22-27 lipiec 2012, 995-996, 2012.

11. Łapka W., *Helicoidal resonators for passive noise control in ducted systems with practical application*, Proceedings of Internoise 2012, New York, USA, 2012.
12. Łapka W., *Numerical study of acoustic-structure interaction of selected helicoidal resonator with flexible helicoidal profile,* rozdział w j. ang. w monografii pt. Postępy Akustyki, Polskie Towarzystwo Akustyczne - Oddział w Rzeszowie, Rzeszów, pp. 194-205, 2013.
13. Łapka W., M. Szymański, R. Górzeński, *Badania oporów przepływu w zależności od strumienia objętości powietrza w kanale dla wybranych rezonatorów helikoidalnych,* rozdział w monografii pt. Postępy Akustyki, Polskie Towarzystwo Akustyczne - Oddział w Rzeszowie, Rzeszów, pp. 168-180, 2013.
14. COMSOL Multiphysics version 4.2.a*, User's Guide and Model Library Documentation Set*, COMSOL AB, www.comsol.com, Stockholm, Sweden, 2011.
15. Munjal M. L., *Acoustics of Ducts and Mufflers with Application to Exhaust and Ventilation System Design*, Inc., Calgary, Canada, John Wiley & Sons, 1987.
16. Marburg S., Nolte B., *Computational Acoustics of Noise Propagation in Fluids – Finite and Boundary Element Methods*, 578, Springer-Verlag, Berlin, Germany, 2008.
17. Wilcox, D. C., *Turbulence Modeling for CFD*, 3rd edition, DCW Industries, Inc., La Canada CA, 2006.
18. Wilcox, D. C., *Formulation of the k-omega Turbulence Model Revisited*, AIAA Journal, Vol. 46, No. 11, 2823-2838, 2008.