Numerical Analysis of Pressure Drop and Acoustic Attenuation Performance of Two Helicoidal Resonators Arranged in Parallel Ducts with Different Rotation Angles

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Abstract

The paper presents a numerical analysis of pressure drop and acoustic attenuation performance (transmission loss) of two identical acoustic helicoidal resonators arranged in parallel ducts with different rotation angles. The air stream is divided from one cylindrical duct of a diameter D=140mm to a two parallel cylindrical ducts of diameter d=125mm with two helicoidal resonators inside – one per one duct. The ratio of helicoidal pitch s of helicoidal resonators to a cylindrical duct diameter d equals s/d=1,976. Other geometrical relationships of helicoidal resonators, as a mandrel diameter d_m to duct diameter ratio d_m/d=0.024, thickness g of helicoidal profile g/d=0.0024, and the number of helicoidal turn n=0,695 for both resonators. The investigated range of rotation angles covered the three characteristic positions of helicoidal resonators gaps, when considering the air stream distribution from central large duct with diameter D. The value of normal inflow velocity v[m/s] equaled 1 for all investigated cases.

Keywords: helicoidal resonators, pressure drop, acoustic attenuation, parallel ducts, flow distribution, numerical analysis

1. Introduction

The newly patented solution of acoustical helicoidal resonator [1] has a specific feature of a narrowband sound attenuation and multi resonances. The acoustical properties of this solution and basic dimensions are quite well described in many publications [2-7, 9-12, 14-17]. The flow properties of this solution were described mainly for one helicoidal resonator inside cylindrical duct [8, 9, 13, 14, 16]. In the paper [15] were mentioned the possibilities of inserting a few ducts with acoustically tuned helicoidal resonators for the same blade-passing frequency of fan in ducted system. From the acoustical point of view it is determined by the plane wave propagation condition, which must be satisfied for a proper work of helicoidal resonator (acoustical resonance). From the fluid dynamics point of view the pressure drop depends on many conditions of inserted helicoidal resonators, as example most important here relationship between helicoidal pitch $s$and numbers of helicoidal turns n. But the transition of air flow stream into few ducts induces more complications, as example distribution inside duct of helicoidal resonators and other obstacles.

Also this work presents the numerical analysis of transmission loss (TL) characteristics and pressure drop for specific three cases of rotation angles of two identical helicoidal resonators with constant s/d ratio that equals 1,976 and numbers of helicoidal turns $n=0,695$ arranged in parallel cylindrical ducts.

2. Description of investigated models

In this chapter are characterized investigated acoustical (2.1) and CFD turbulent flow (2.2) models of two identical helicoidal resonators placed inside a cylindrical ducts arranged in parallel just past the transition from one duct with larger diameter D=140mm to two parallel ducts with diameters d=125mm, as presented in Figure 1. In both subchapters the three dimensional (3D) models were analysed.

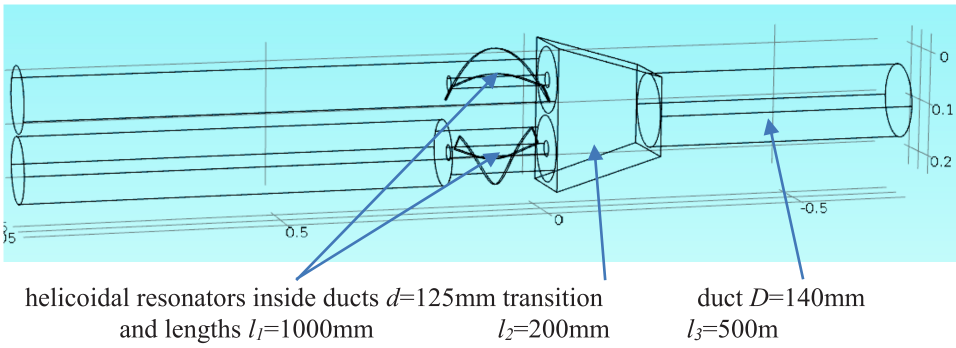

Figure 1. Example view on numerically represented and considered ducted system with two identical helicoidal resonators with s/d=1,976 and n=0,695 arranged in parallel ducts past the transition from one larger duct

The ducted system consists of a straight cylindrical ductsand the transition with lengthl_2=200mm. The ratio of helicoidal pitch s of helicoidal resonators to cylindrical duct diameter d equals s/d=1,976, and the number of helicoidal turns n=0,695. The 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 with diameter D at the inlet sideequaled 500mm, and the outlet parallel ducts with diameter d=125mm equaled 1000mm.As it is presented in figure 1 the helicoidal resonators were placed right past the transition, and the closest edges of helicoidal profiles were situated in the distance of 10mm from the end of transition.

Three cases of rotation of helicoidal resonators were analyzed in this paper, as it is presented in Figure 2. Case 1 represents the situation when helicoidal resonators are placed in the same way inside cylindrical ducts. Case 2 represents the situation when the characteristic gaps of the rest part 0,305 of helicoidal turns are placed externally, and Case 3 represents the situation when those gaps are placed internally.

Case 1: rotation angles
- both resonators 70°,
- gaps oriented on the same side,

Case 2: rotation angles
- left resonator 60°,
- right resonator 240°.
- gaps oriented externally,

Case 3: rotation angles
- left resonator 240°,
- right resonator 60°,
- gaps oriented internally.

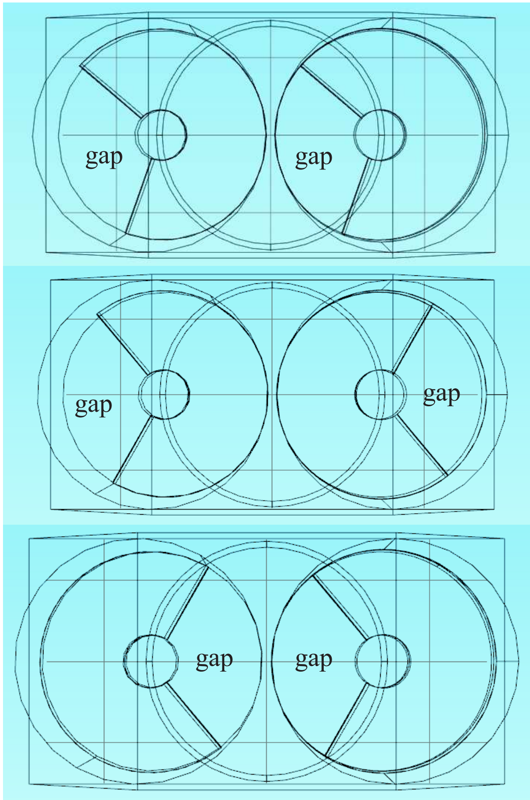

Figure 2. Investigated three cases of rotation angles of two identical helicoidal resonators arranged in parallel ducts

2.1. Acoustical model

Investigated in this paper acoustical models have the same parameters as in previous, well described studies under helicoidal resonators, as in example papers [2-7, 9-12, 14-17]. It was used the finite element method in Comsol Multiphysics-Acoustic Module numerical environment [18]. The transmission loss (*TL*) [19] was computed as the acoustic attenuation performance parameter. It was considered the sound propagation in air with temperature 20ºC without flow. The boundary conditions were established, as follows:

- hard walls of all elements of helicoidal resonators (perfect reflection) and cylindrical ducts,
- plane waves radiation - inlet (incident pressure p=1Pa) of a duct with diameter D=140mm and outlet surfaces of two cylindrical ducts with diameters d=125mm - that satisfies the anechoic terminations to calculate *TL*.

Free tetrahedral mesh [18] was created with satisfying the rule of minimum 5 finite elements per sound wave length [20] for maximum frequency- here it is f_{max}=2000Hz at

20 Celsius degrees. The considered speed of sound in air c_s=343m/s. Maximum finite element size equalled $h_e=0{,}2(c_s/f_{max})$. Example view on generated free tetrahedral mesh of investigated model is presented in Figure 3.

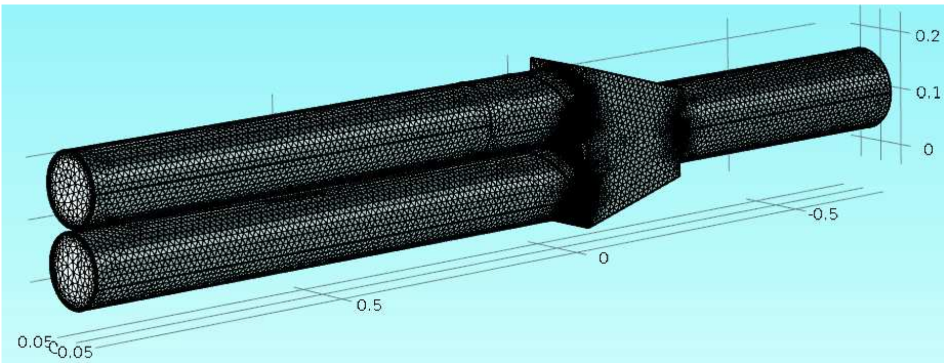

Figure 3. Example view on free tetrahedral mesh of investigated ducted acoustical system with two identical helicoidal resonators arranged in parallel

2.2. CFD turbulent flow model

CFD Module of Comsol Multiphysics [18] was used to solve investigated CFD turbulent flow model of ducted system analyzed as a single-phase flow k-ω turbulence RANS model [18, 21, 22] with compressible flow (Mach number lower than 0,3), as it was similarly considered in papers [8, 14, 16]. The main feature is fluid properties, that adds the Navier-Stokes equations and the transport equations for the turbulent kinetic energy k and the specific dissipation ω, and provides interface for defining the fluid material and its properties [14]. The basic fluid properties are: temperature T=20ºC, reference atmospherical pressure p_a=1atm, density and dynamic viscosity of air were calculated automatically from COMSOL material library [18]. 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 equaled 1m/s,
- no viscous stress at the outlet, pressure there equaled 0 Pa.

Finite element mesh was generated automatically as a free tetrahedral and controlled by physics-fluid dynamics. The stationary solver was used.

3. Results

This chapter contains the results of solved pressure acoustics in frequency domain (subchapter 3.1) and fluid dynamics problems (subchapter (3.2) for investigated models of two identical helicoidal resonators with constant ratio s/d=1,976 and numbers of helicoidal turns n=0,695 arranged in parallel ducts past the transition from one larger duct with diameter D.

3.1. Transmission Loss

Figure 4 presents the three *TL* characteristics of two identical helicoidal resonators with ratio *s/d*=1,976 and numbers of helicoidal turns *n*=0,695for three cases of rotation the helicoidal resonators and localisation of gaps.
The numerical calculation were made in the frequency range from 10Hz to 2000Hz with the calculation step of 10Hz.

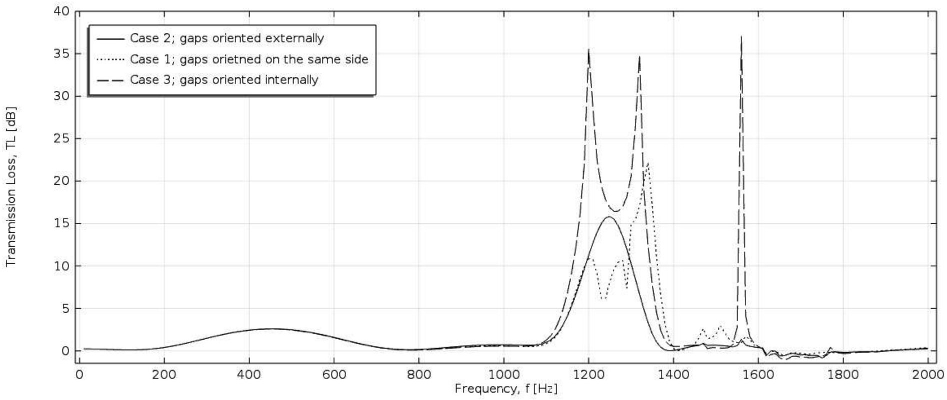

Figure 4.Transmission Loss of two identical helicoidal resonators with *s/d*=1,976 and *n*=0,671 arranged in parallel ducts for three cases of rotation.

As it can be observed from Figure 4 the specific narrow-band attenuation of sounds for investigated two identical helicoidal resonators arranged in parallel ducts is visible for all investigated cases. But only for case 3, when the gaps are oriented internally, there were obtained the highest *TL* levels (TL_1≈35dB and TL_2≈34dB) for characteristic resonance frequencies (f_1≈1200Hz and f_2≈1350Hz) of this type of helicoidal resonators (see results of researches in several authors publications, as for example in [9,12,16]).

For case 1 with gaps oriented on the same side it is observed, near the second resonance frequency of about 1350Hz,*TL* level of about 22dB. And for the case 2, when the gaps are oriented externally, there are visible only nearly symmetrical *TL* distribution for one characteristic frequency of about 1250Hz with *TL* level of about 17dB.

3.2. CFD turbulent flow

The numerically calculated pressure drop *Δp* [Pa],as a difference between surface average pressure in [Pa] at the inlet and outlet of the ducted system for three cases of investigated two identical helicoidal resonators with ratio *s/d*=1,976 and number of helicoidal turns *n*=0,695 arranged in parallel cylindrical ducts with diameter d past the transition from cylindrical duct with diameter D, are presented in Figure 5.

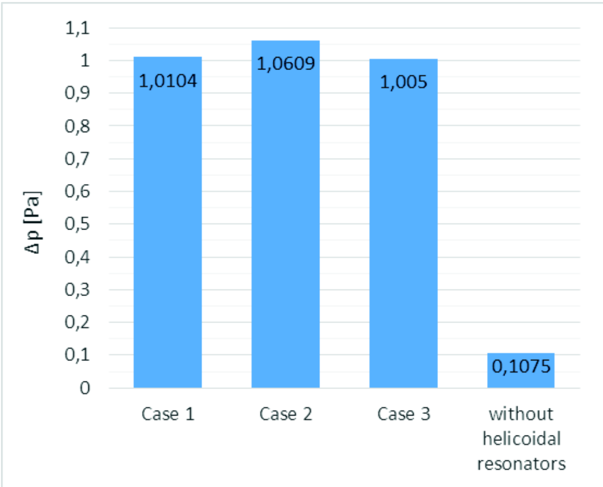

Figure 5. Pressure drop *Δp* [Pa] of investigated three cases of two identical helicoidal resonators with ratio *s/d*=1,976 and number of helicoidal turns *n=0,695*arranged in parallel ducts with different rotation angles

On the basis of performed CFD numerical analysis, there were calculated a total pressure drop coefficients ζ for three investigated cases in the same way as in previous papers [13,16], presented in Table 1.

Table 1. Total pressure drop coefficients ζ for three investigated cases

Case No.	ζ
1	1,4993
2	1,5832
3	1,4904

As it can be observed from Figure 5, the highest pressure drop *Δp*= 1,0609Pa (ζ=1,5832)occurs for case 2, when the gaps of two helicoidal resonators are oriented externally. The lowest pressure drop *Δp*= 1,005Pa (ζ=1,4904)occurs for case 3, when the gaps of two helicoidal resonators are oriented internally.

4. Conclusions

A numerical analysis of pressure drop and acoustic attenuation performance of two identical acoustic helicoidal resonators with *s/d*=1,976 and *n*=0,695 arranged in parallel cylindrical ducts with diameter *d*=125mm and different rotation angles past the transition from one cylindrical duct of a diameter *D*=140mm,was performed in this paper. Three cases of rotation angles and orientation of helicoidal resonators gaps were considered.

On the base of acoustical analysis, it can be found, that the specific narrow-band attenuation of sounds for investigated two identical helicoidal resonators arranged in parallel ducts with different rotation angles is visible for all investigated cases. But only for case 3, when the gaps are oriented internally, there were obtained the highest *TL* levels for (TL_1≈35dB and TL_2≈34dB) for characteristic resonance frequencies (f_1≈1200Hz and f_2≈1350Hz) of this type of helicoidal resonators.

On the base of fluid dynamics analysis, it can be found, that the lowest pressure drop Δp=1,005Pa(ζ=1,4904)occurs for case 3, when the gaps of two helicoidal resonators are oriented internally.

Obtained results are surprising, due to a fact that the case 3, when the helicoidal resonators gaps are oriented internally, provides the best acoustical attenuation performance and the lowest pressure drop.

Considered in this paper the three cases of rotation angles and orientation of gaps were selected intuitive in the manner of practical applications. There should be performed more acoustical and CFD analysis for ducted systems with helicoidal resonators placed past the transition to find the best solution.

Acknowledgments

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