Tuning the Selected Acoustic Helicoidal Resonator with a Short Flat Bar – Numerical Analysis

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Abstract

This paper describes the possible way of tuning the selected acoustical helicoidal resonator placed in straight cylindrical duct by the use of a short flat bar. The acoustic attenuation performance (transmission loss) of helicoidal resonator has emphatically changed with the change of the length and the degree of rotation of a short flat bar placed close to the resonator. The finite element numerical calculations of the acoustical systems were made in COMSOL Multiphysics computational environment. The results show that the change of length and rotation of short flat bar can widely change the resonance frequencies of helicoidal resonator. So in this work were presented the possible simple tuning options for the acoustic helicoidal resonator applied in ducted systems.

Keywords: acoustic helicoidal resonator, tuning, sound propagation, flat bar, ducts and mufflers

1. Introduction

The helicoidal acoustic resonator belongs to the family of mufflers and resonators [1]. Its work is similar to the Helmholtz or a quarter-wave resonator. The acoustic resonance is achieved here by placing the helicoidal profile with proper dimensions inside a straight cylindrical duct [2, 4, 8-10]. There are a lot of different researches of this resonator. The most important works describe the experiments of using this device. The interactions between the helicoidal acoustical resonator and the dissipative silencer are presented in work [3]. The artice [5] describes the 90-degree duct elbow with the presented resonator. In the article [7], the authors wrote about a simple comparison to Helmholtz resonator. The behaviorof resonator when the helicoidal profile made from elastic material is presented in paper [6]. The last researches about interaction with 90-degree duct elbow [5] showed the possible way of tuning the helicoidal resonator by its rotation in the duct axis. The researches presented in this work show the new way of tuning the resonator. The mentioned method is basing on placing the short flat bar inside the resonator.

2. Investigated acoustical system and numerical model

Similarly to the previous researches [2, 5, 8] investigated acoustical system consist of a cylindrical duct with the diameter $d = 2a = 125$ mm, where a is a radius of the duct, with helicoidal resonator inside, which has the constant relationship $s/d = 1.976$, between helicoidal pitch s to the cylindrical duct diameter d, and the number of helicoidal turns n equals 0.671. The helicoidal profile thickness

g to the cylindrical duct diameter d, ratio g/d equals 0.04, and the value of relationship between mandrel diameter d_t and cylindrical duct diameter d, ratio d_t/d equals 0.24. The short flat bar thickness g_b has the same value as the thickness of helicoidal profile g, ratio g_b/d = 0.04, and its width w_b had the same value as radius a of the duct. The four radial positions of a short flat bar were considered as presented in Figure 1. The change in length of a short flat bar l_b was considered in the range from 0.16a to 1.6a with the step of 0.16a. The 0 degree position consisted in placing the beginning of the helicoidal profile directly at the beginning of the short flat bar.

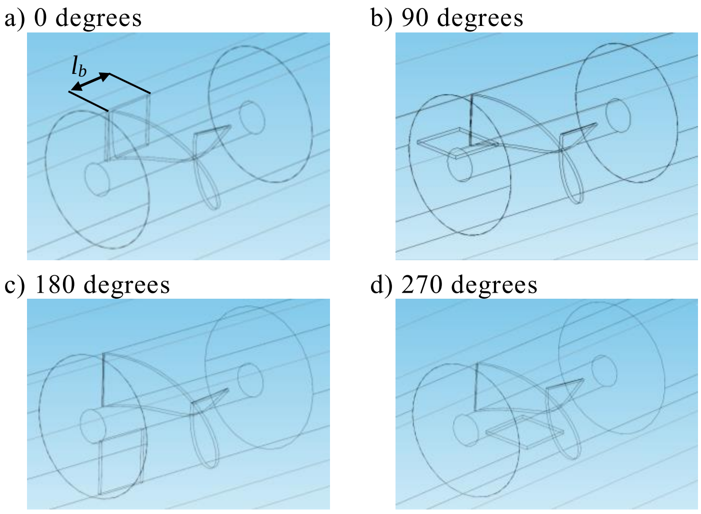

Figure 1. Visualisation of four radial positions of a short flat bar as a tuning element inside cylindrical duct of inner dimeter $d = 2a$ =125 mm (a–radius) with an acoustic helicoidal resonator inside with ratio s/d = 1.976 and number of turns n = 0.671, l_b is the length of a short flat bar

The COMSOL Multiphysics software was used to solve the Helmholtz equation [11] for the three dimensional models by the use of finite element method (FEM). The following parameters were used:

- type of medium - air with temperature 20ºC (speed of sound in air c = 343 m/s) without mean flow,
- computations in the frequency domain with the use of time-harmonic pressure acoustics physics,
- defined boundary conditions: hard walls with perfect reflection defined for all surface elements of helicoidal resonator, cylindrical duct walls and short flat bar walls; plane wave radiation defined for inlet (incident pressure p = 1 Pa) and outlet circular surfaces (anechoic termination) of the cylindrical duct,
- modeled finite element mesh was automatically generated with the rule of minimum five finite elements per wavelength [11] for the highest analyzed frequency.

The wave number $k = 2\pi f/c$ and Helmholtz number ka was used to present the non-dimensional frequency [12, 13]. The Transmission Loss (TL) [2, 11, 12] was calculated for the most interesting frequency range f [Hz] from 800 Hz (ka = 0.916) to 1.6 kHz (ka = 1.83) with the calculation step of 1 Hz.

3. Acoustical results – transmission loss

In Figure 2 to Figure 5 are presented the transmission losses of helicoidal resonator with respectively 0, 90, 180 and 270 degrees of radial position of a short flat bar with the length l_b range from 0.16a to 1.6a with the step of 0.16a.

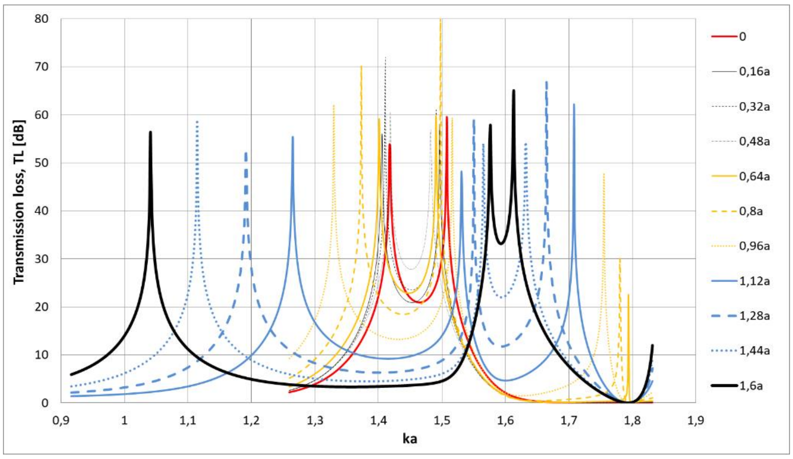

Figure 2. Transmission loss of helicoidal resonator for 0 degree of radial position of a short flat bar with the length l_b from 0.16a to 1.6a and the step of 0.16a

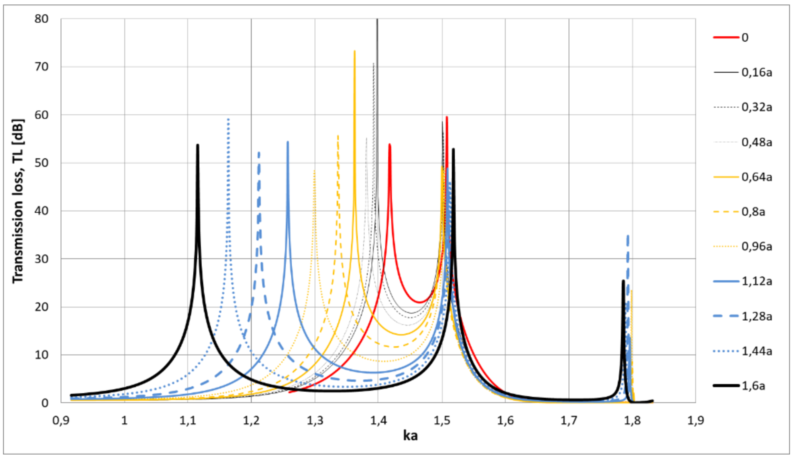

Figure 3. Transmission loss TL of helicoidal resonator for 90 degree of radial position of a short flat bar with the length l_b range from 0.16a to 1.6a and the step of 0.16a

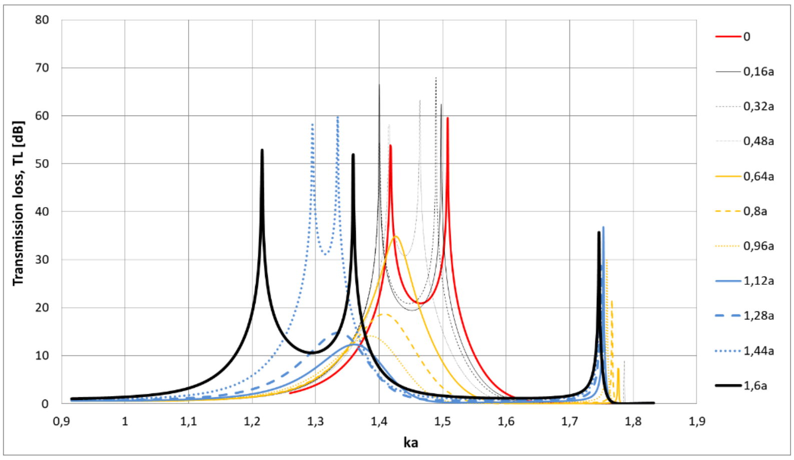

Figure 4. Transmission loss of helicoidal resonator for 180 degree of radial position of a short flat bar with the length l_b range from 0.16*a* to 1.6*a* and the step of 0.16*a*

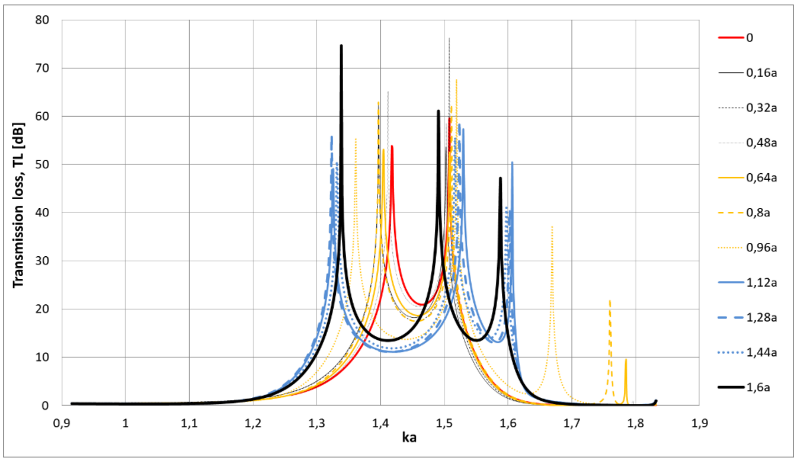

Figure 5. Transmission loss of helicoidal resonator for 270 degree of radial position of a short flat bar with the length l_b range from 0.16*a* to 1.6*a* and the step of 0.16*a*

Considered acoustical systems with a four radial positions of a short flat bar with different length placed at the beginning of the acoustic helicoidal resonator inside cylindrical duct, show that the widest range of Helmholtz number *ka* and so on the tuning possibilities for investigated helicoidal resonator was obtained for 0 degree of radial position of a short flat bar. In this case the highest values of narrowband sound attenuation can be obtained for Helmholtz number from *ka* = 1.04 to *ka* = 1.76. The smallest change of sound attenuation in *ka* range gives the 270 degree position of a short flat bar, from *ka* = 1.32 to *ka* = 1.61. But nearly every kind of obtained transmission loss characteristics are very interesting and tends to be implementable.

For the 0 degrees of radial positon the higher change in the length l_b of a short flat bar slightly changes the frequency of two resonances of investigated helicoidal resonator for l_b range from 0.16*a* to 0.48*a*, and then transforms into three resonance *TL* characteristics for the length l_b from 0.64*a* to 1.6*a*. All received transmission loss characteristics are saddled with the highest saddle level TL = 33 dB between second and third resonance for the longest flat bar with $l_b = 1.6a$, and the lowest saddle level TL = 3.3 dB between first and second resonance for the same flat bar with $l_b = 1.6a$.

For the 90 degrees of radial positon the higher change in length l_b of a short flat bar mainly changes the frequency of a first resonance of investigated helicoidal resonator, and the second resonance stays almost in the same value of *ka* – the inconsiderable change in the range from $ka = 1.5$ to $ka = 1.52$. All received transmission loss characteristics have two resonances and all are saddled with the highest saddle level TL = 18 dB for the shortest flat bar ($l_b = 0.16a$), and the lowest saddle level TL = 2.5 dB for the longest flat bar ($l_b = 1.6a$).

Very different and interesting results were obtained for the 180 degrees of radial positon of a short flat bar. For the length l_b from 0.16*a* to 0.48*a* the *TL* characteristics are saddled and consists of two resonances, which are getting closer to each other, and then for $l_b = 0.64a$ the highly resonant acoustical systems attenuation decreases and transforms into one resonance characteristics with lower *TL* levels for l_b range from 0.8*a* to 1.28*a*. For the last analysed two lengths l_b of the short flat bar, which equal 1.44*a* and 1.6*a*, the *TL* characteristics have three resonances, where the first and second resonance have high *TL* level between $ka = 1.21$ and $ka = 1.36$ with the *TL* saddle between them, and the third resonance appears for the Helmholtz number *ka* that equals about 1.75.

The 270 degrees of radial positon of a short flat bar with different length l_b gives the smallest change in sound attenuation in *ka* domain. For the range of lengths from 0.16*a* to 0.64*a* the *TL* characteristics doesn't change very much, first resonance changes in the range of *ka* from 1.39 to 1.42, and the second resonance changes in the range of *ka* from 1.5 to 1.51. For the range of lengths from 0.8*a* to 1.6*a* the *TL* characteristics have clearly visible three resonances in the range of Helmholtz numbers *ka* from 1.32 to 1.76. The interesting *TL* characteristics were obtained for short bar lengths l_b from 1.12*a* to 1.6*a*, where the lowest *TL* levels in the saddle obtain higher than 10 dB values on almost same level for both saddles between first and second resonance and a second and third resonance.

4. Conclusions

Presented paper described the numerical analysis of the acoustic system with helicoidal resonator inside a cylindrical duct with a short flat bar, as a tuning element. Undertaken research work showed that the widest tuning possibilities for investigated helicoidal resonator could be obtained for the 0 degree of radial position of a short flat bar. For this case the highest values of narrowband sound attenuation were obtained for Helmholtz number *ka* from 1.04 to 1.76. The smallest change of *ka* gives the 270 degree position of a short flat bar, from *ka* = 1.32 to *ka* = 1.61. But nearly every kind of obtained transmission loss characteristics are very interesting and tends to be implementable.

Acknowledgments

Author gratefully acknowledges that the study was financed by the Ministry of Science and Higher Education as a project 02/21/DSPB/3546 and 02/21/SBAD/3558.

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