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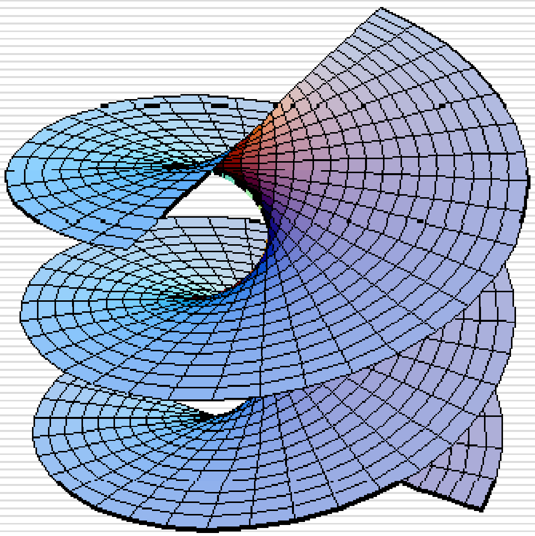
Sound Propagation through Circular Ducts with Spiral Element Inside



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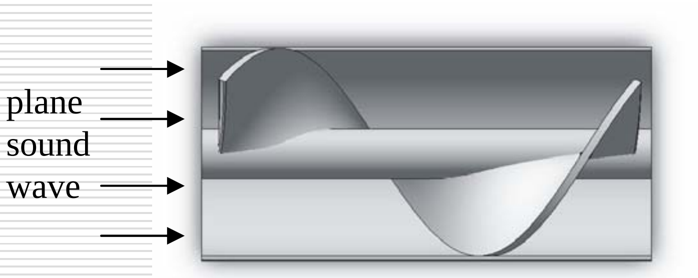
Presentation plan

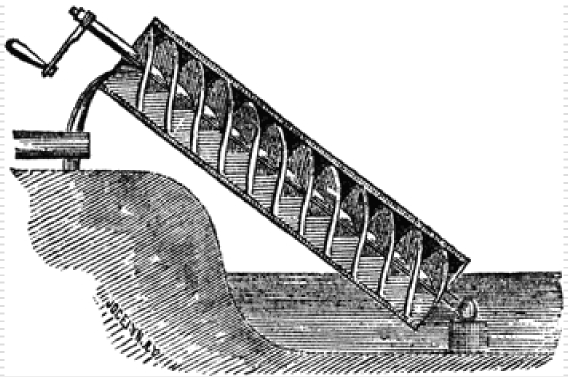
1. Introduction
2. General assumptions
3. Model definition
4. Equations
5. Boundary conditions
6. Results and discussion
7. Summary

1. Introduction

- This work presents results of computational modeling of a sound propagation through circular ducts with spiral element inside – it creates a similar solution to an Archimedean screw, which is a well-known technical solution for many applications (screw pump, screw conveyor, rotary feeder etc.),



Spiral element inside a circular duct



Archimedean screw

- Archimedean screw was historically used for transferring water from a low lying body of water into irrigation ditches.

1. Introduction

It’s already proven in presenters past research work that inserting just one spiral turn at the inlet circular duct of a round silencer can improve the sound attenuation performance of this silencing system.

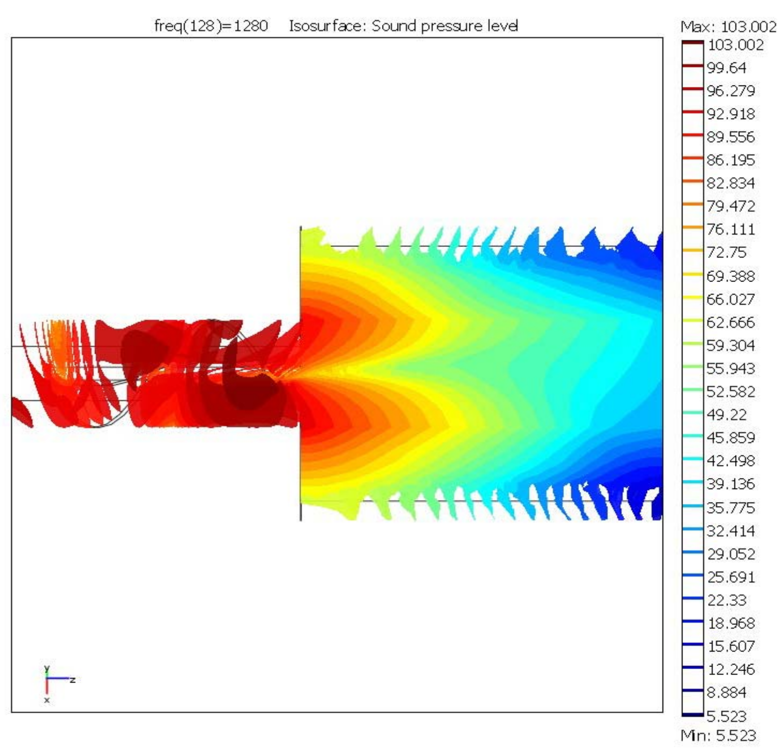


Fig. 1.Isosurface sound pressure level distribution for a resonance frequency of the spiral element placed at the inlet circular duct of the round silencer.

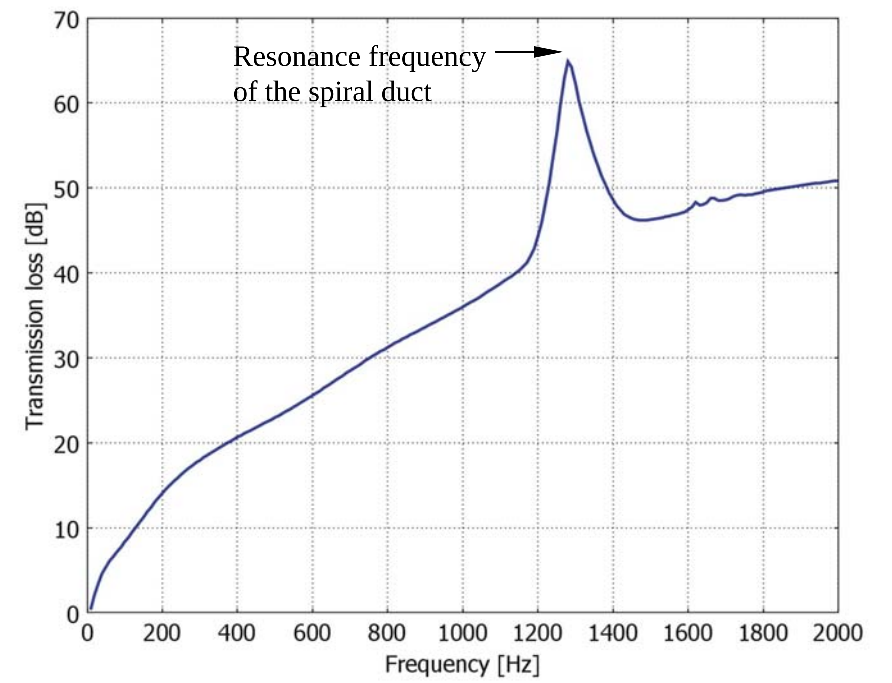


Fig. 2.Transmission loss of a round silencer with the spiral element placed at the inlet circular duct.

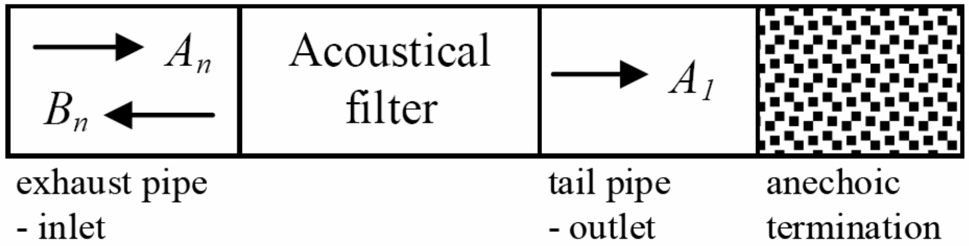
2. General assumptions

Three dimensional (3D) sound propagation without air flow in circular ducts with spiral element inside is numerically calculated by the use of COMSOL Multiphysics – Acoustic Module computational application.

Only transmission loss (TL) as an acoustical filter performance parameter is measured and in terms of the progressive wave components can be expressed as:

$$TL = 10\log_{10}\left|\frac{S_n A_n^2}{2}\frac{2}{S_1 A_1^2}\right|, \qquad B_1 = 0$$

$$TL = 20\log_{10}\left|\frac{A_n}{A_1}\right|, \qquad B_1 = 0.$$



Here S_n and S_1 denotes the cross-section areas of the exhaust pipe and tail pipe, respectively, which are equal in the experiments for transmission loss.

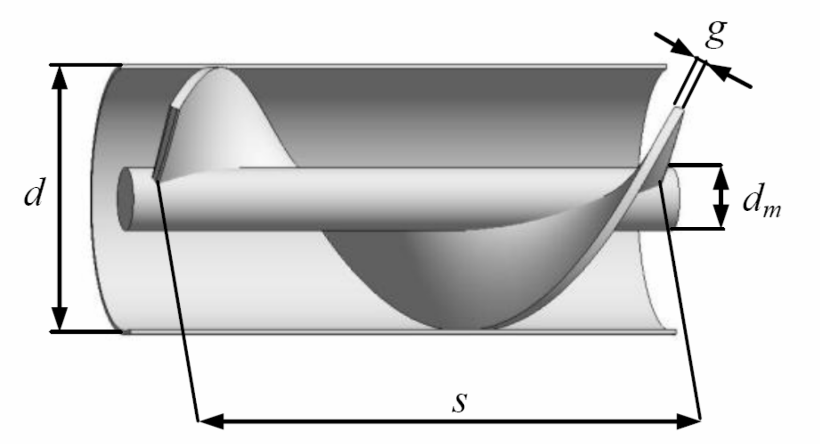
A_n and A_1 are the incident (in the exhaust pipe) and transmitted (in the tail pipe) wave pressures, respectively.

B_1 denotes the reflected wave pressure in the tail pipe. The anechoic termination ensures B_1=0

However, experimentally A_n cannot be measured in isolation from the reflected wave pressure B_n, computationally there is no difficulty.

3. Model definition

One spiral turn inside a circular duct:



Dimensionless ratios:

$s/d = 2$

$d_m/d = 0,24$

$g/d = 0,04$

s – spiral lead, [m]

d – circular duct dimension, [m]

d_m – circular mandrel dimension (placed axially), [m]

g – thickness of the spiral profile, [m]

4. Equations

The problem is solved in the frequency domain using the time-harmonic Pressure Acoustics application mode. The final solving parameter is the acoustic pressure *p* [Pa], which can be computed by the use of slightly modified Helmholtz equation:

$$\nabla \cdot \left(-\frac{\nabla p}{\rho_0} \right) - \frac{\omega^2 p}{c_s^2 \rho_0} = 0$$

$\nabla = \left(\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z} \right)$ - del operator in the three-dimensional Cartesian coordinate system,

ρ_0 - density of air (ρ_0=1,23 kg/m^3),
c_s - speed of sound in air (c_s=343m/s),
ω - angular frequency [rad/s],
$\omega=2\pi f$ where f [Hz] is the frequency.

4. Equations

For computational needs, the transmission loss TL is expressed as the difference between the outgoing power at the outlet w_o and the incoming power at the inlet w_i:

$$TL = 10\log_{10}\left(\frac{w_i}{w_o}\right), [dB]$$

Each of component quantities in equation above are calculated as an integral over the corresponding surface $\partial\Omega$ of circular ducts cross-sections S_n and S_1:

$$w_i = \int_{\partial\Omega} \frac{p_0^2}{2\rho_0 c_s} dS$$

⟶ p_0 is the source acoustic pressure at the inlet, [Pa]

$$w_o = \int_{\partial\Omega} \frac{|p_c|^2}{2\rho_0 c_s} dS$$

⟶ p_c is the transmitted acoustic pressure at the outlet, [Pa]

5. Boundary conditions

For investigated model the boundary conditions are of three types:

1. For acoustically hard walls at the solid boundaries, which are the walls of the spiral element profile, mandrel and circular duct, the model uses sound hard (wall) boundary conditions:

$$\left(\frac{\nabla p}{\rho_0}\right)\cdot \mathbf{n} = 0 \quad \longrightarrow$$

n is the natural direction vector for investigated circular duct

2. The boundary condition at the inlet surface (sound source) of circular duct is a combination of incoming and outgoing plane waves:

$$\mathbf{n}\cdot\frac{1}{\rho_0}\nabla p + ik\frac{p}{\rho_0} + \frac{i}{2k}\Delta_T p = \left(\frac{i}{2k}\Delta_T p_0 + \left(1-(\mathbf{k}\cdot\mathbf{n})\right)ik\frac{p_0}{\rho_0}\right)e^{-ik(\mathbf{k}\cdot\mathbf{r})}$$

where Δ_T denotes the boundary tangential Laplace operator, $k=\omega/c_s$ is the wave number, wave vector is defined as **k**=*k***nk**, where **nk** is the wave-direction vector, and **r** is the source axis direction (ex. z=1)

5. Boundary conditions

3. At the outlet boundary is set the radiation boundary condition which allows an outgoing wave to leave the modeling domain with no or minimal reflections:

$$\mathbf{n} \cdot \frac{1}{\rho_0} \nabla p + i \frac{k}{\rho_0} p + \frac{i}{2k} \Delta_T p = 0$$

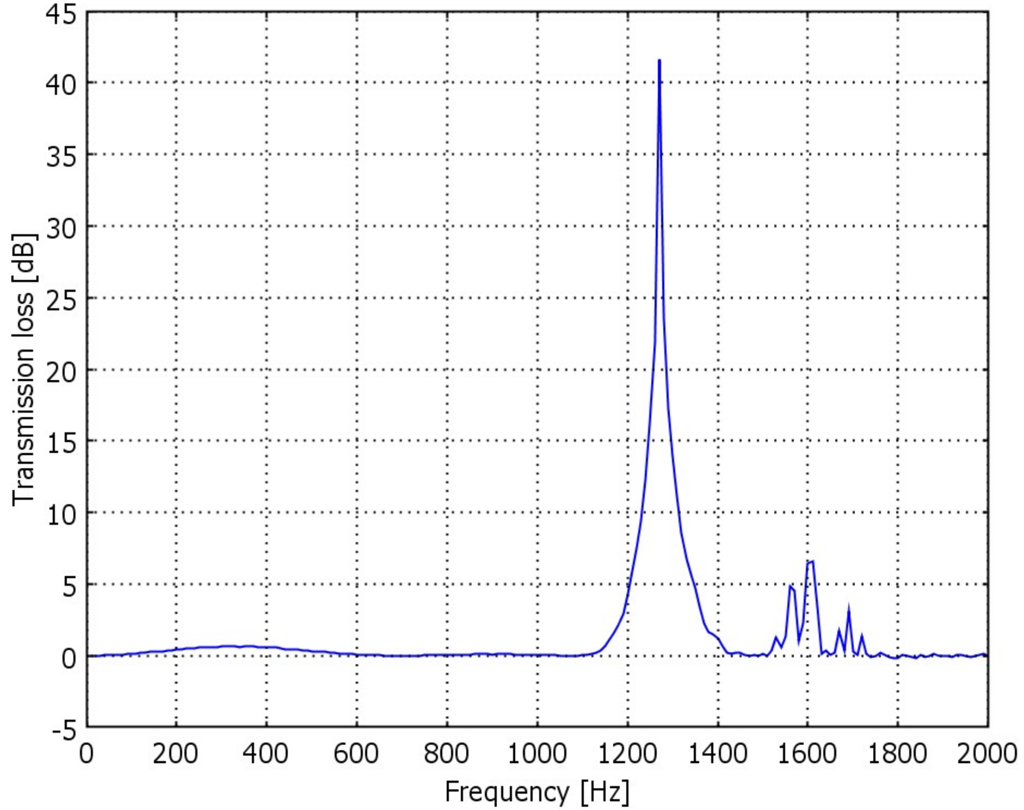
The numerical model is computed by the use of finite element method (FEM) by the terms of the element size and maximum element size equals

$$h_e = 0{,}2(c_s/f_{max}),$$

where f_{max} is the value of maximum investigated frequency (here f_{max}=2kHz)

6. Results and discussion

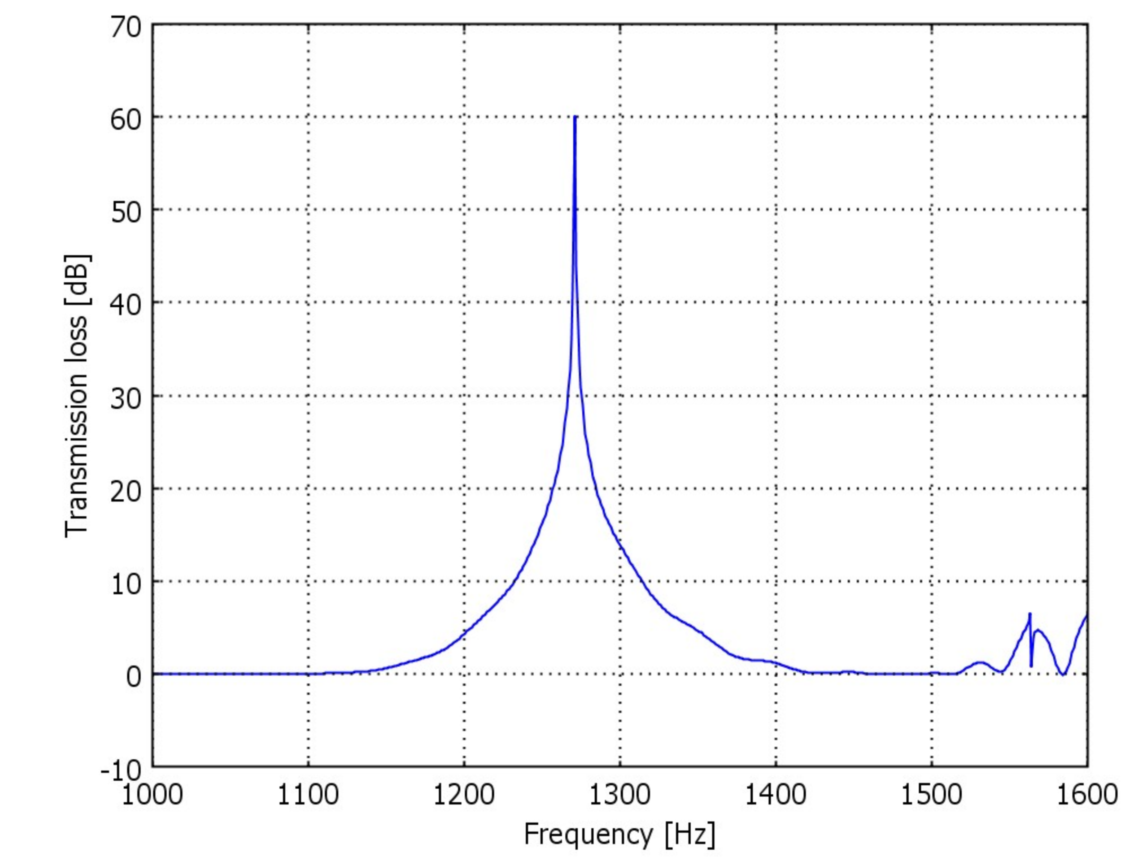
Transmission loss (TL) of the circular duct with spiral element inside with ratio *s/d*=2 for a frequency range from 10Hz to 2kHz with the computational step 10Hz.



- Maximum level of TL is about 42dB at the frequency 1270Hz,
- Sound attenuation considerably increases in a specified frequency range from about 1150Hz to about 1410Hz,
- Visible small growth (about 1dB) of the TL in low frequencies between about 150Hz and 550Hz,
- Variations of TL at frequencies higher than 1550Hz, what can be recognized as the influence of a transverse wave propagation in the circular duct.

6. Results and discussion

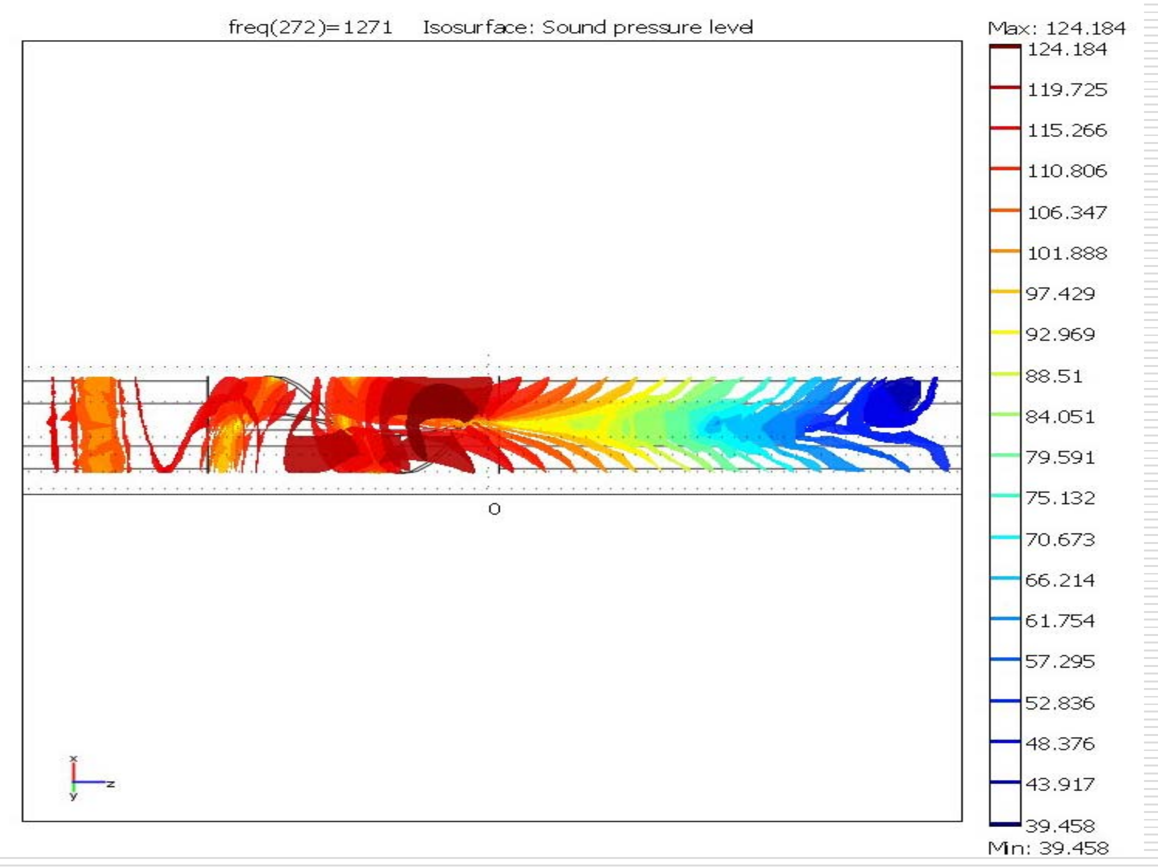
TL of the circular duct with spiral element inside with ratio *s/d*=2 for a frequency range from 1kHz to 1,6kHz with the computational step 1Hz.



- Maximum level of TL is about 60dB at the frequency 1271Hz, , which can be recognized as a resonance frequency of the spiral element,
- Sound attenuation considerably increases in a specified frequency range from about 1150Hz to about 1410Hz,
- Variations of TL at frequencies higher than 1550Hz, what can be recognized as the influence of a transverse wave propagation in the circular duct.

6. Results and discussion

Sound pressure level distribution at the resonance frequency 1271Hz of the spiral element inside a circular duct.



- At the outlet of the spiral element the major acoustic energy goes aside, and minor acoustic energy goes axially to the outlet.

6. Summary

- This study introduced the problem of modeling acoustic wave propagation without air flow in spiral shaped elements placed inside circular ducts.

- Suitable change of dimensions and mutually dependent *s/d*, *g/d* and d_m/d ratios can improve the sound attenuation performance in determined frequency range for any kind of circular duct.

- Characteristic SPL distribution at the outlet of spiral elements is their property.

- Newly discovered acoustical properties of attenuating sound in specified frequency band of spiral elements are a solid base to consider this solution as applicable for industrial systems. It can be applied as an alternative substitution of Helmholtz resonator – well known acoustic band stop filter.

- Spiral elements used for attenuating sound in ducted silencing system still need a lot of research work, but already done researches expand a new scientific knowledge in the domain of ducts and mufflers.

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Thank You for attention…