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NOISE REDUCTION OF SPIRAL DUCTS

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ABSTRACT

The paper presents noise reduction (NR) as result of computational modeling of acoustic wave propagation in spiral ducts. 3D models were created by the use of the Finite Elements Method (FEM) in computer application COMSOL Multiphysics. 9 models of spiral ducts with increasing from 1 to 9 number of spiral leads are considered. Time harmonic analysis was used to predict noise reduction, which is shown in spectral and interval frequency band. Spiral duct performance can be observed as a comparison between noise reduction before and after change from circular into spiral duct.

1. INTRODUCTION

An Archimedean screw is very popular solution in many industrial applications. Usefulness and practical aspects of applicability of this solution can be found in many utilities and machines, for example in: screw pump, sewage treatment, an auger in a snow blower or grain elevator, screw conveyor etc. [1,2,3]. Although, authors could not find any information about acoustic properties of that structural element, which will be called spiral duct for further considerations. Due to that, it seems to be important to know the acoustical properties of the screw leads inserted into the duct of circular cross section.

2. MODEL PARAMETERS

Due to inability to find any acoustic premises and research results of size and construction, 9 models of spiral ducts with increasing number from 1 to 9 number of spiral leads are considered. All spiral ducts in our case are inserted into circular pipe of length 1m and **125mm** diameter (one of the typical length and diameter of pipes used for ventilation systems). A **30mm** diameter mandrel is placed in axis of every spiral duct. This is necessary, because of the fact, that technologically is impossible to manufacture spiral screw without any internal diameter. Thickness of our spiral lead is assumed about 5mm.

The elements constructed as described above will be called here spiral ducts. The Figure 1 shows few representative examples of spiral ducts.

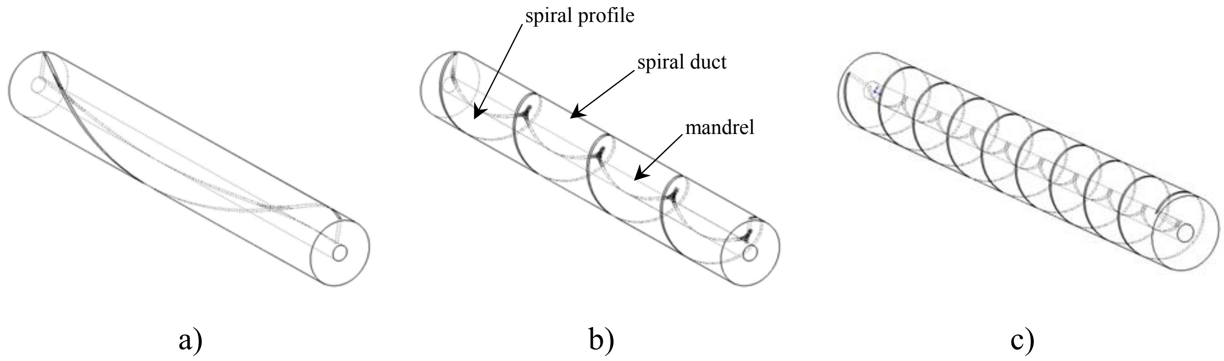


Fig.1. Examples of spiral ducts inside 1m long pipe ϕ125mm with ϕ30mm mandrel in axis:
a) 1 spiral lead, b) 4 spiral leads, c) 9 spiral leads

3. PARAMETERS OF COMPUTATIONAL ENVIRONMENT

For the simulation of acoustical properties the spiral duct was designed in engineering program called **Solidworks** as 3D solid models. In a next step they were imported to software environment **COMSOL Multiphysics** [6]. This application uses the Finite Element Method (FEM) for computing sound wave propagation through ducts as depicted below (see Fig. 2).

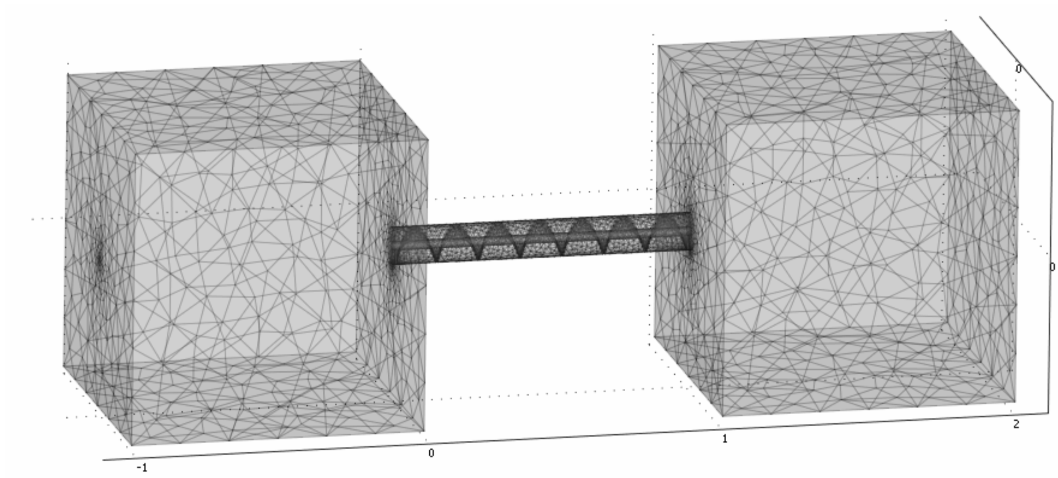


Fig.2. An example view of investigated acoustic system in **COMSOL Multiphysics** with generated 3D mesh of finite elements

Figure 2 shows computational system, which bring us closer to real conditions. It consists two boxes of volume $1m^3$, air filled, with impedance boundary conditions of characteristic impedance ($\rho_0 c$=1,25 [kg/m^3]*343[m/s]) were applied [4]. Ducts were placed between them, as it is shown on figure 2. Circular surface of 1cm diameter was a harmonic sound source, which has generated plane wave of acoustic pressure of **1Pa**. Sound source was located in geometrical center of one box wall, placed opposite the duct inlet.

To solve such defined problem in the frequency domain it was used so called time-harmonic Pressure Acoustics application mode [6]. In the case of COMSOL Multiphysics the model equation is a slightly modified version of the Helmholtz equation [4,5,6] for the acoustic pressure, ***p***:

$$\nabla \cdot \left(-\frac{\nabla p}{\rho} \right) - \frac{\omega^2 p}{c_S^2 \rho} = 0, \qquad (1)$$

where:

p – acoustic pressure [Pa] depends on x – distance [m] and frequency $\omega = 2\pi f$, where f[Hz]; ∇ - gradient operator; ρ – air density (1,25 kg/m^3); c_S – sound speed in air(343m/s).

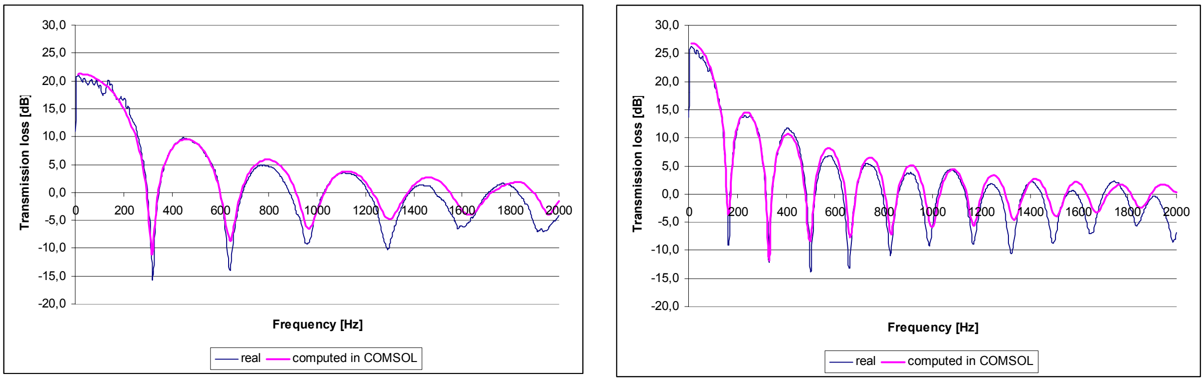
To determine sound attenuation authors made use of noise reduction (**NR**) formula [4,6]. The noise reduction is given by:

$$NR = L_{in} - L_{out} \ \ \textbf{[dB]} \qquad (2)$$

that is, it is the difference between the sound pressure levels L_{in} and L_{out} measured at two points in silencer system located upstream (inlet) and downstream (outlet) of the silencer, respectively.

4. COMPARISON: REAL DUCT VS SIMULATION

To prove that virtual computing is very similar to reality there was made a comparison between real measurements and results computed in COMSOL Multiphysics. There were compared two circular tubes ø125mm of length 1m and 0,5m. Noise reduction (**NR**) was examined. Fig. 3 shows results of that comparison.



a) 0,5m b) 1m

Fig.3. Comparison of noise reduction of circular tubes ø125mm computed in COMSOL Multiphysics and measured in real laboratory conditions. Length of tubes: a) 0,5m , b) 1m

As we can see on Fig.3 real experiment gives almost identical results as computed in COMSOL. Also for further consideration, we can be sure that real application of spiral ducts will get almost the same results as numerically computed.

5. CALCULATION OF NOISE REDUCTION IN SPIRAL DUCTS

Due to fact that in practice an engineer needs concrete directions and parameters of technical object, we will use noise reduction NR [4,5] as a practical determinant of sound attenuation. Moving forward for better utility of our technical solution we need detailed parameters. Therefore, every duct will be analyzed in parametric frequency dependent attenuation, and also averaged over some frequency band. Here we define so called **band noise reduction**, from lower frequency limit f_{low} [Hz] to higher frequency limit f_{high} [Hz], and this will be designated as $NR_{(f_{low} \div f_{high})}$,

$$NR_{(f_{low} \div f_{high})} = L_{in(f_{low} \div f_{high})} - L_{out(f_{low} \div f_{high})}, [dB] \tag{3}$$

where:

L_{in} – sound pressure level equivlent at inlet of the duct [dB],

L_{out} – sound pressure level equivlent at outlet of the duct [dB],

$f_{low} \div f_{high}$ – frequency band [Hz],

The numerical calculation of averaged band noise reduction $NR_{(f_{low} \div f_{high})}$ (3) is expressed as:

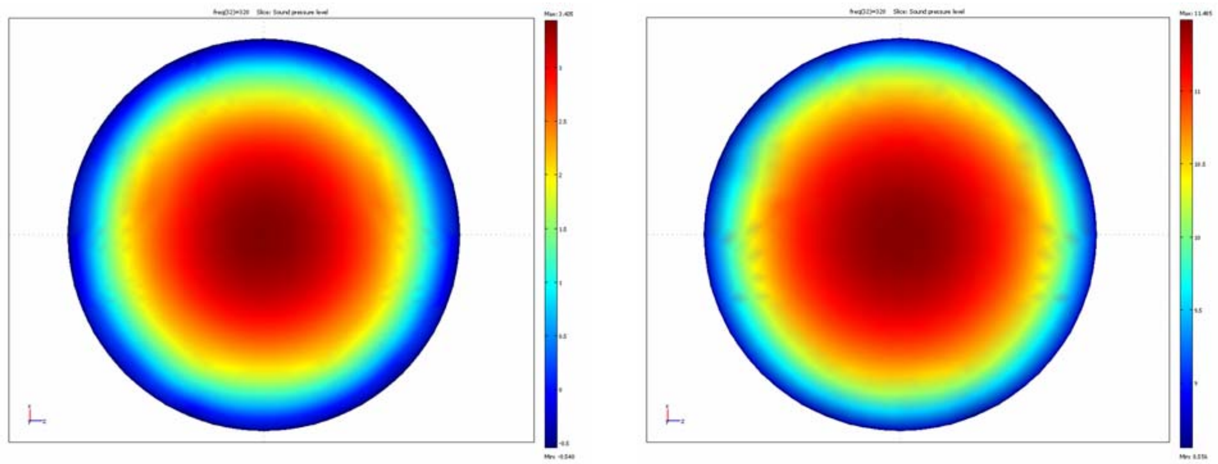
$$NR_{(f_{low} \div f_{high})} = 10 \log \left(\frac{\sum_{i=1}^{n} 10^{0,1 \cdot L_{in,i}}}{\sum_{i=1}^{n} 10^{0,1 \cdot L_{out,i}}} \right), [dB] \tag{4}$$

where:

n – number of calculation intervals (calculation steps), $n = \frac{f_{low} - f_{high}}{\Delta f}$,

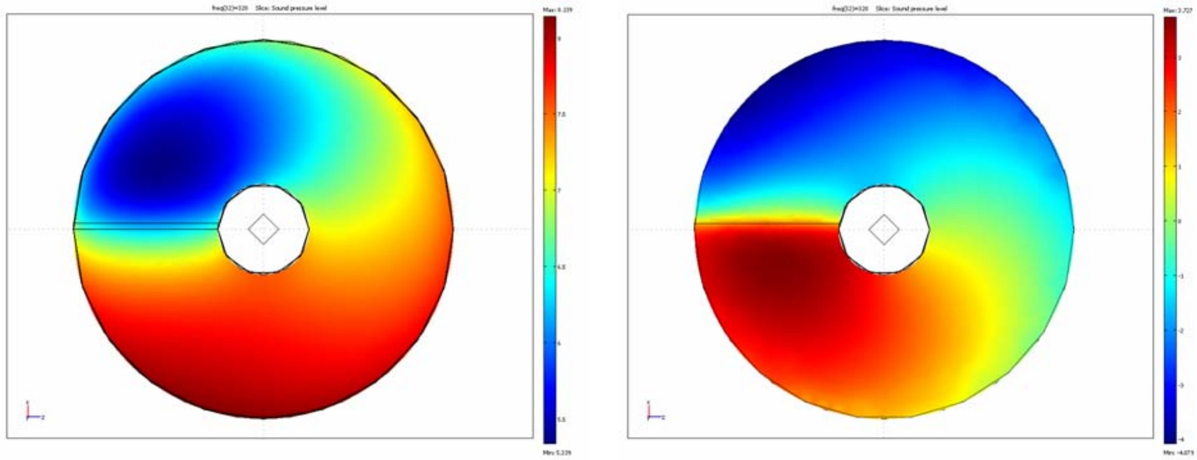
Δf – frequency interval [Hz], as a step of numerical calculation (*for our calculations* *Δf =10Hz*).

As it is presented on Fig.4 sound pressure level distribution at the inlet and the outlet surfaces of circular tube allows to make measurements directly in one point in central axis. Instead of that inlet and outlet surfaces of spiral ducts are different - Fig.5. Therefore band noise reduction $NR_{(f_{low} \div f_{high})}$ was calculated on the base of arithmetic average of sound pressure levels in 8 points at the inlet and outlet surfaces, as presents Fig.6.



inlet of tube *outlet of tube*

Fig.4. An example of sound pressure levels at inlet and outlet surfaces of circular 1m long tube ø125mm in example frequency 320Hz



inlet of spiral duct *outlet of spiral duct*

Fig.5. An example of sound pressure levels at inlet and outlet surfaces of spiral duct with 6 spiral leads in example frequency 320Hz

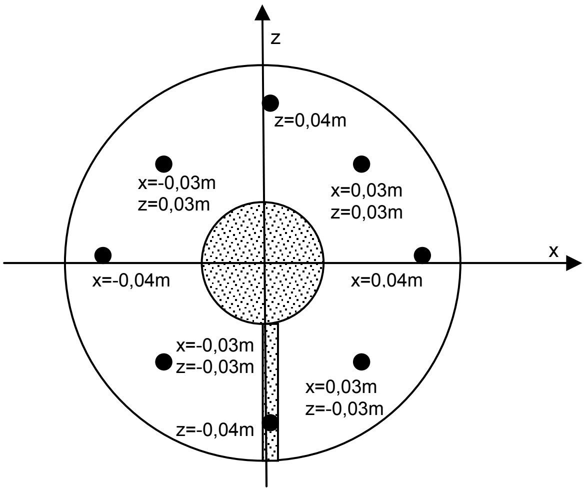


Fig.6. Location of 8 points at the inlet and outlet surfaces of spiral ducts for arithmetic average of sound pressure levels

Fig.7 presents spectral and band noise reduction $NR_{(f_{low} \div f_{high})}$ for circular 1m long tube of the diameter ø125mm. Figures 7, 9, 10 show spectral and band NR for few types of spiral ducts. Frequency band for band NR are divided into sections 20Hz to 1kHz with interval 100Hz, and 1kHz to 2kHz with interval 200Hz.

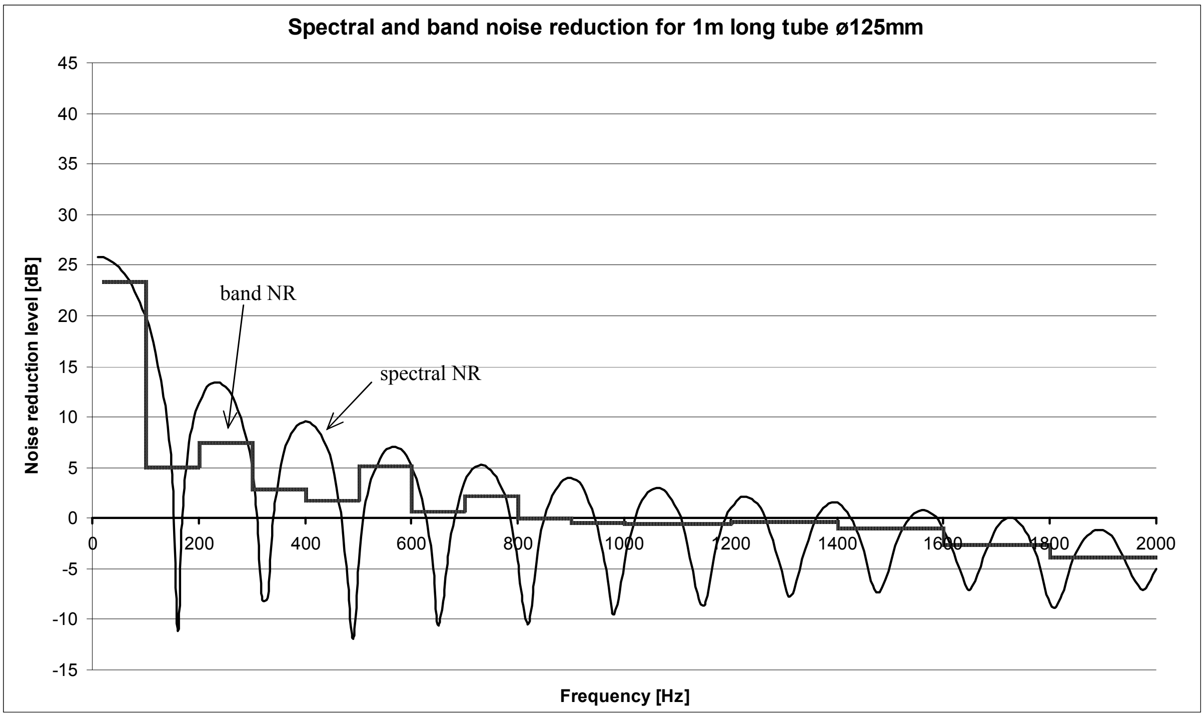


Fig.7. Spectral and band NR for 1m long tube ø125mm

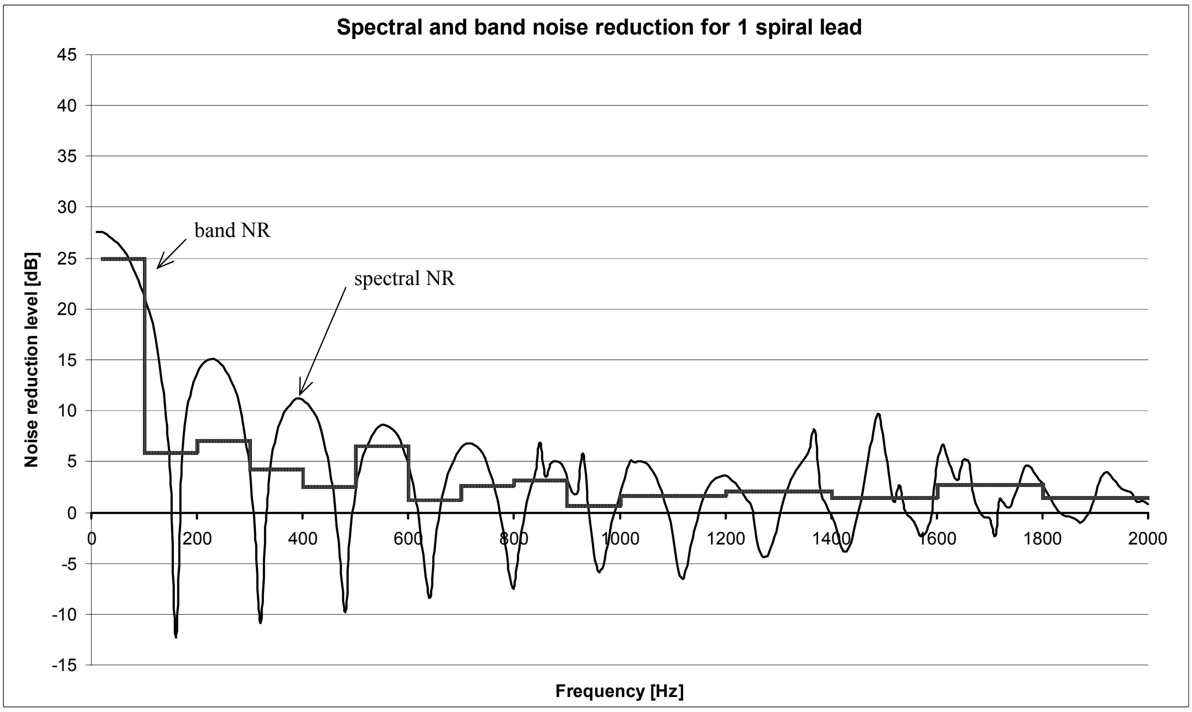


Fig.8. Spectral and band NR for 1 spiral lead in the tube

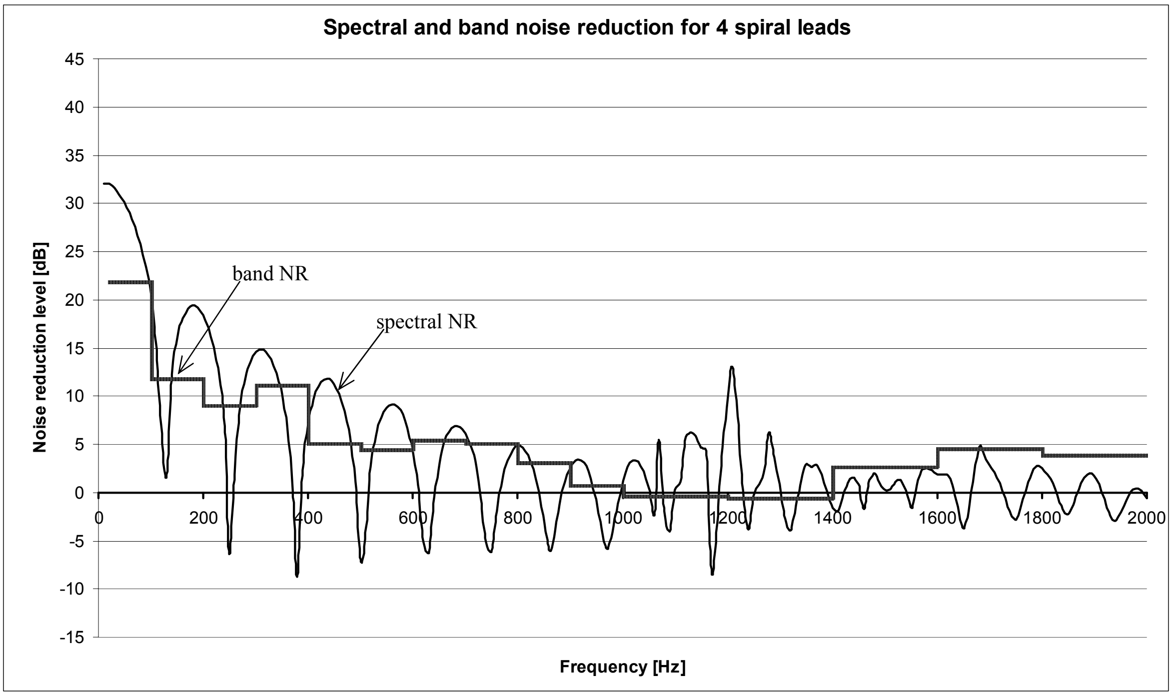


Fig.9. Spectral and band NR for 4 spiral leads in the tube

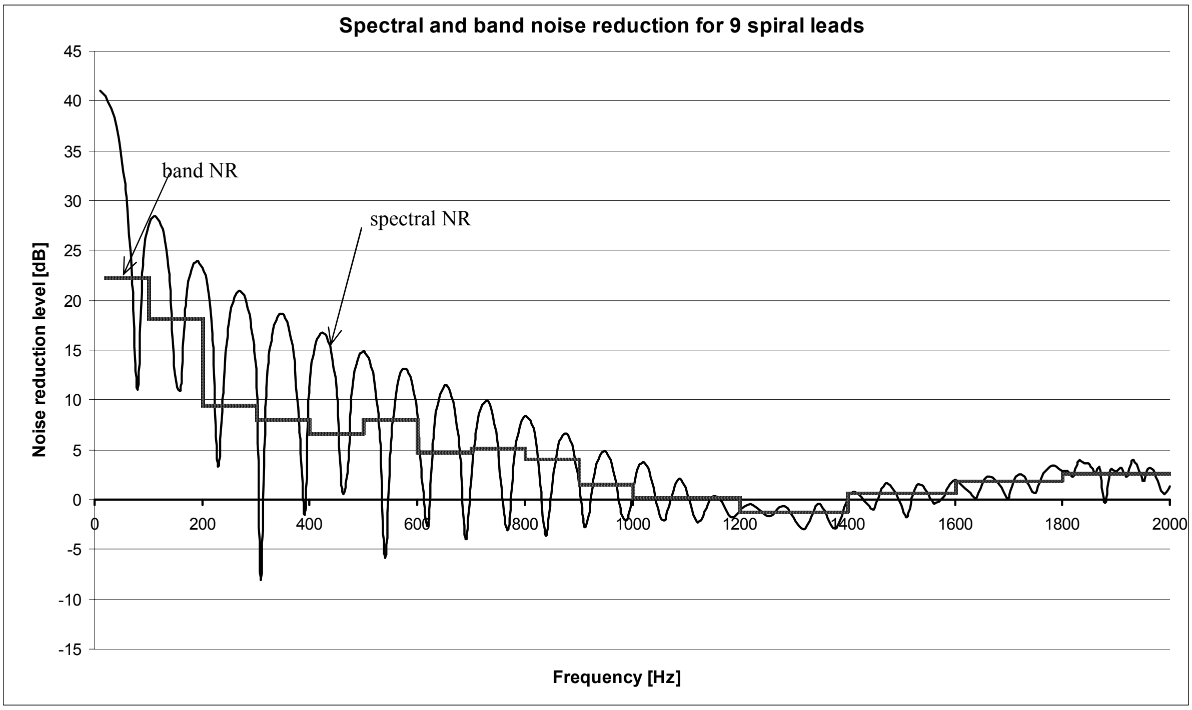


Fig.10. Spectral and band NR for 9 spiral leads in the tube

Table 1 consists a synthesis of the accurate values of band noise reduction levels (NR) in particular frequency bands for all modeled spiral ducts. There are included two additional frequency bands: from 20Hz to 2kHz, which gives a global information about sound NR, and the second band from 20Hz to 800Hz, which gives the information about sound NR in the low- and mid- frequencies.

Table 1. Band noise reduction levels (NR) for spiral ducts and 1m long tube ø125mm

	Noise reduction level [dB]									
		Number of spiral leads								
Frequency band [Hz]	**Tube 1m**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
20-100	23,4	25,0	25,6	26,2	26,3	24,6	11,6	16,1	21,9	22,2
100-200	5,0	5,9	7,4	9,7	11,8	11,7	8,7	12,4	11,8	18,2
200-300	7,5	7,1	3,3	3,2	5,9	10,6	8,3	8,4	9,0	9,5
300-400	2,8	4,3	8,2	6,8	3,6	6,7	7,5	6,0	11,1	8,0
400-500	1,8	2,6	2,7	4,2	4,3	4,8	5,9	5,7	5,2	6,6
500-600	5,1	6,5	3,4	2,8	4,9	4,1	4,5	5,6	4,4	8,0
600-700	0,6	1,3	3,5	3,0	2,5	3,6	3,2	5,1	5,5	4,7
700-800	2,2	2,7	1,4	2,9	2,0	2,7	1,9	4,0	5,1	5,2
800-900	-0,1	3,2	1,4	1,2	1,1	1,0	1,0	2,0	3,0	4,1
900-1k	-0,5	0,7	2,2	1,4	0,4	0,0	-0,1	0,2	0,8	1,5
1k-1,2k	-0,5	1,7	1,6	2,7	2,8	0,2	-0,5	-0,6	-0,4	0,2
1,2k-1,4k	-0,3	2,1	0,8	4,4	1,8	2,3	2,5	0,8	-0,5	-1,3
1,4k-1,6k	-1,0	1,4	2,6	1,4	0,8	3,1	2,6	3,6	2,6	0,6
1,6k-1,8k	-2,6	2,7	2,1	1,0	1,1	3,0	3,4	3,7	4,5	1,9
1,8k-2k	-3,8	1,5	1,0	1,3	-0,1	0,4	1,8	2,2	3,8	2,7
20-800	**2,1**	**3,0**	**3,1**	**3,3**	**3,5**	**3,8**	**4,5**	**4,9**	**5,5**	**6,0**
20-2k	**-1,3**	**2,0**	**1,7**	**1,8**	**1,3**	**2,1**	**2,3**	**2,3**	**2,3**	**1,7**

It follows from the table, in comparison to the tube alone, that the addition of spiral lead gives additional noise reduction. What is more important, this property is almost linear - i.e. more leads more noise reduction (NR), (see Fig.11).

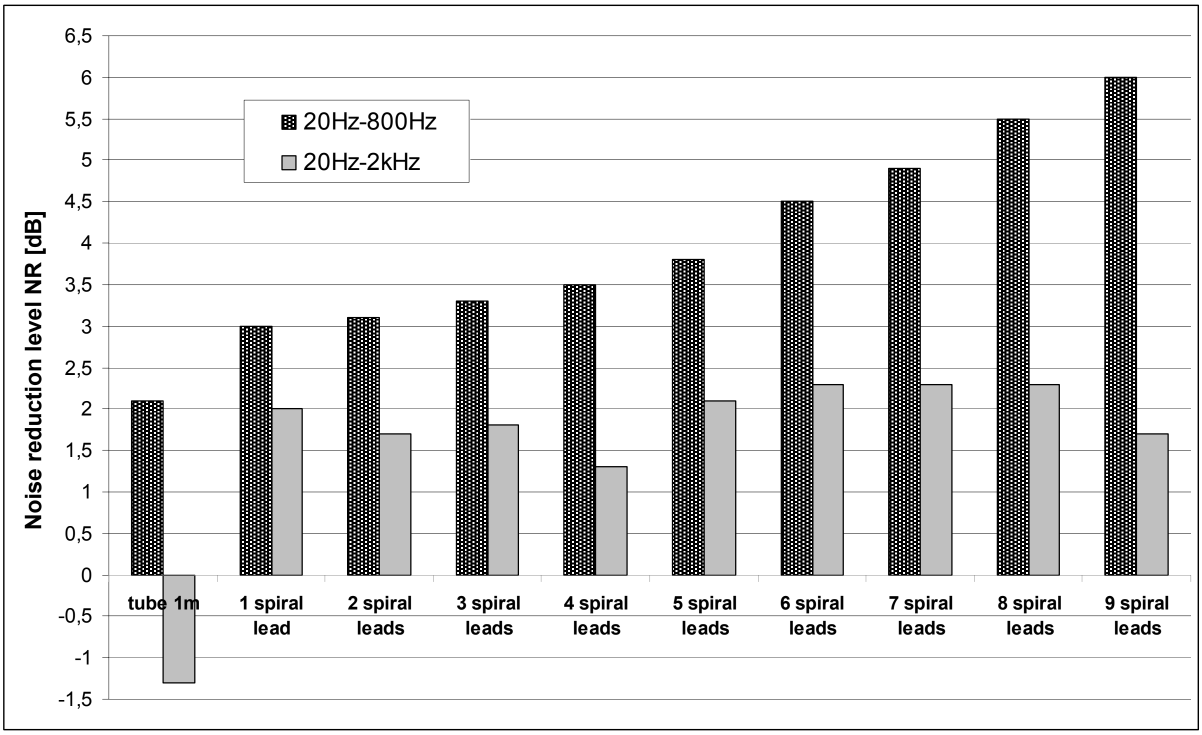


Fig.11. Noise reduction levels (NR) for 9 spiral ducts and 1m long tube ø125mm in frequency band 20Hz – 800Hz

6. CONCLUSIONS

In conclusion, to consideration of the whole paper we can stress once more:

- Spiral ducts have better acoustic performance than circular ducts in examined frequency range 20Hz to 2kHz,
- Increasing number of spiral leads gives bigger NR in low- and mid- frequencies 20Hz to 800Hz.
- Newly defined band noise ratio seems to be a good measure of averaged acoustical properties

7. REFERENCES

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