POLITECNICO MILANO 1863	051483 Musical Acoustics Module 2: Modeling of musical instruments Academic Year 2023/2024	Homework Laboratory IV Brass instrument simulation

Assignment: Brass instrument simulation

Implement the model of a trumpet in COMSOL Multiphysics in order to simulate its acoustic response. Through FEM simulation compute the input impedance of the trumpet in the frequency domain, its radiated sound pressure and directivity pattern. Describe in detail the implementation and your choices for setting the simulation, you can use screenshots of the software.

The the theory is described in the set of slides:

- 09_brass_instrument_simulation

- Implement a COMSOL Multiphysics model (.mph) that solves:
  - **Exercise 1 to exercise 4.**

NOTE: The submitted model must be compatible with COMSOL 6.1

Simulation setup:

- **Follow the suggestions on the set of slides** 09_brass_instrument_simulation
- **Take advantage of 2D axisymmetric simulation**
  - **Reduced complexity**
  - **Reduced computation time**
- **The physics involves acoustic pressure**
- **We are interested in the input impedance:** $\boldsymbol{Z(\omega) = \frac{P(\omega)}{U(\omega)}}$
- **We are interested in the directivity pattern**
  - **Hint: exploit the appropriate boundary condition**
- **Progressively add components (bell and mouthpiece)**

Exercise 1

Impendance of a tube

- Implement a simple tube that simulates the body of a trumpet
  - Use the parameters in **Error! Reference source not found.**
  - Input pressure is 1.1[Pa]
  - Set the meshing to satisfy the 5 points per wavelength condition

Name	Expression	Value	Description
rT	0.6[cm]	0.006 m	Tube radius
rS	2[m]	2 m	Air sphere radius
N	255	255	Number of frequencies
Lt	1.37[m]	1.37 m	Tube length
Lspace	20[mm]	0.02 m	Length empty space
lambdaMax	c0/fMax	0.08575 m	Wave length max frequency
fMin	50[Hz]	50 Hz	Min Frequency
fMax	4000[Hz]	4000 Hz	Max Frequency
c0	343[m/s]	343 m/s	wave speed

Figure 1 Simulation parameters

Name	Expression	Value	Description
Lh	0.2[m]	0.2 m	Bell length
m	28	28	Bell exponent
St	rT^2*pi	1.131E-4 m²	Surface tube

Figure 2 Bell parameters

- Set the PML in order to simulate the free field conditions
- Store the sound pressure and the velocity at the input boundary in two variables
- The frequency study goes from a minimum frequency $f_{\min}$ to maximum frequency $f_{\max}$ in N steps.
- Plot the modulus of the input impedance in dB scale
- Show the polar plot of the directivity pattern in dB scale at relevant frequencies

- Comment the obtained results.

Exercise 2

Tube with bell

Using a new 2D axisymmetric element implement a tube with a bell at one end

- Starting from a simple tube model modify the geometry:
  - Include an exponential bell $r = \sqrt{\frac{St}{\pi} e^{mz}}$
  - Use the parameters in Fig. 2
  - Set the meshing to satisfy the 5 points per wavelength condition
  - Set the PML in order to simulate the free field conditions
  - Store the sound pressure and the velocity at the input boundary in two variables
  - The frequency study goes from a minimum frequency $f_{\min}$ to maximum frequency $f_{\max}$ in N steps.
  - Plot the modulus of the input impedance in dB scale

Name	Expression	Value	Description
rM	rT+0.3[cm]	0.008 m	Mouthpiece radius
Lm	10[cm]	0.1 m	Length mouthpiece

Figure 3 Parameters of the mouthpiece

- Show the polar plot of the directivity pattern in dB scale at relevant frequencies
- Compare and comment the simulation results with respect to the one of a simple tube.

Exercise 3

Mouthpiece

Using a new 2D axisymmetric element implement the mouthpiece of the trumpet.

- Model only the mouthpiece using two elements
  - A circle and a polygon with short side equal to one eighth of the tube radius
  - Use the parameters in **Error! Reference source not found.**
  - Set the meshing to satisfy the 5 points per wavelength condition
  - Set the PML in order to simulate the free field conditions
    - use a smaller domain
  - Store the sound pressure and the velocity at the input boundary in two variables
  - The frequency study goes from a minimum frequency $f_{\min}$ to maximum frequency $f_{\max}$ in N steps.
  - Plot the modulus of the input impedance in dB scale
- Compare and comment the simulation results with respect to the previous models

Exercise 4

Complete model

Using a new 2D axisymmetric element implement the complete model of a trumpet (mouthpiece + tube with bell)

- Combine the previously defined models to simulate the complete instrument
  - Set the meshing to satisfy the 5 points per wavelength condition
  - Set the PML in order to simulate the free field conditions
  - Store the sound pressure and the velocity at the input boundary in two variables
  - The frequency study goes from a minimum frequency $f_{\min}$ to maximum frequency $f_{\max}$ in N steps.
  - Plot the modulus of the input impedance in dB scale
  - Show the polar plot of the directivity pattern in dB scale at relevant frequencies
- Compare and comment the simulation results with respect to the simplified models.

Please provide the answers in a report as a PDF file which explains how the simulation have been developed, your implementation choices for the estimation of the acoustic input impedance and comments on the obtained results. Complete the report with plots and everything you find useful for better explain your results. In addition, you have to provide Comsol Multiphysics model (file .mph with solutions, mesh and geometries removed to keep it lightweight).
All the files must be included in a .zip file named:

yourIDnumber_surname_homework_4.zip

Upload the required file using the WeBeep platform in the “Assignment HL4” delivery folder.
One file for each student must be uploaded. If more than one student participated to the assignment, write on the cover page of the assignment the name, surname and ID of the participating students.