BROADBAND ABSORPTION
USING
COUPLED QUARTER WAVELENGTH TUBES
INTRODUCTION
**Motive**

*Personal interest*

*Curiosity*

*Balance in knowledge*

*Extra dimension*
Quarter wavelength tube

Resonator tube

Absorber tube
Quarter wavelength tube = Resonator tube

Resonator tube + Resonator tube = Absorber tube
ACOUSTICS
Sound wave
\[ \lambda = \frac{c}{f} = \frac{340}{f} \]
\[ \lambda = \frac{c}{f} = \frac{340}{f} \]
Speech

- Soprano Voice
- Alto Voice
- Tenor Voice
- Bass Voice

Frequencies:
- 32 Hz
- 63 Hz
- 125 Hz
- 250 Hz
- 500 Hz
- 1000 Hz
- 20000 Hz
Speech

FOCUS

SOPRANO VOICE
ALTO VOICE
TENOR VOICE
BASS VOICE

32 Hz 63 Hz 125 Hz 250 Hz 500 Hz 1000 Hz

20000 Hz
Reverberation time

GRAPH:
- X-axis: Time
- Y-axis: Sound Level
- GUNSHOT
- FIRST REFLECTIONS
Reverberation time

- Gunshot
- Second reflections
Reverberation time
Absorption material

- Porous absorber
- Perforated panel (Helmholtz)
- Unperforated panel

Absorption coefficient vs. Frequency
Quarter wavelength tube
A + B = ZERO ENERGY

Quarter wavelength tube
Broadband absorption

- Porous absorber
- Perforated panel (Helmholtz)
- Unperforated panel

**FREQUENCY Hz**

**ABSORPTION COEFFICIENT α**

**SINGLE FREQUENCY**
Broadband absorption

- Porous absorber
- Perforated panel (Helmholtz)
- Unperforated panel
Broadband absorption

- Porous absorber
- Perforated panel (Helmholtz)
- Unperforated panel
ADDITIVE MANUFACTURING
ADDITIVE MANUFACTURING
ADDITIVE MANUFACTURING

RAPID MANUFACTURING

RAPID PROTOTYPING

3D PRINTING
Production process

- CAD
- STL
- Product
- Create file
- Post process
- Check for errors
- Extract
- Set-up machine
- Print
ADDITIVE MANUFACTURING

LIQUID POLYMER SYSTEMS          DISCRETE POLYMER SYSTEMS

MOLTEN MATERIAL SYSTEMS          SOLID SHEET SYSTEMS
# ADDITIVE MANUFACTURING

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<thead>
<tr>
<th>LIQUID POLYMER SYSTEMS</th>
<th>DISCRETE POLYMER SYSTEMS</th>
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<tr>
<td>1. SLA</td>
<td>1. SLS</td>
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<tr>
<td>2. DLP</td>
<td>2. 3DP</td>
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<td>3. Polyjet printing</td>
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<tr>
<th>MOLTEN MATERIAL SYSTEMS</th>
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<td>1. DED</td>
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<td>2. FDM</td>
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ADDITIVE MANUFACTURING

DISCRETE POLYMER SYSTEMS
1. SLS
2. 3DP
RESEARCH QUESTION
To what extent can coupled quarter wavelength tubes create broadband absorption, utilizing additive manufacturing production techniques; producing acoustic devices for indoor use
Develop a working prototype with coupled quarter wavelength tubes that provides broadband absorption optimized for the case analyzed, produced by means of AM
Develop a working prototype with coupled quarter wavelength tubes that provides broadband absorption optimized for the case analyzed, produced by means of AM
Design a product with coupled quarter wavelength tubes that provides broadband absorption for indoor use, produced by means of AM.
Research design

**PART 1**
- Literature research
- Research Definition

**PART 2**
- Acoustics
- Additive Manufacturing
- Measurements

**PART 3**
- Precedent sample analysis
- Design of experiment
- Design of measurement
- Field measurement
- Design of samples

**PART 4**
- Measurement of samples
- MatLab

**PART 5**
- Design of prototype
- Verification of prototype

**PART 6**
- Evaluation
MEASUREMENTS
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<td>Measurement types</td>
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**Measurements** ↔ **Simulations**
MEASUREMENTS

IMPEDANCE TUBE
MEASUREMENTS

- Impedance Tube
- Field Measurement

Physical measurements
MEASUREMENTS

- Impedance Tube
- Field Measurement
- Reverberation Chamber

Physical measurements
MEASUREMENTS

- IMPEDANCE TUBE: Verify MatLab
- FIELD MEASUREMENT: Case study
- REVERBERATION CHAMBER: Experiment
SIMULATIONS

MANUAL

Computer simulations
SIMULATIONS

MANUAL

OPTIMIZATIONS
SIMULATIONS

- MANUAL
- OPTIMIZATIONS
  - LOCAL MAXIMUM
SIMULATIONS

- MANUAL
- LOCAL MAXIMUM

- OPTIMIZATIONS
- OCTOPUS
SIMULATIONS

- MANUAL
  - LOCAL MAXIMUM: Group of resonators
- OPTIMIZATIONS
  - OCTOPUS: One resonator
CLOSEST MAXIMUM

OCTOPUS
680 - 900 HZ RANGE

MatLab simulations
MEASUREMENTS

- IMPEDANCE TUBE: Verify MatLab
- FIELD MEASUREMENT: Case study
- REVERBERATION CHAMBER: Experiment
Results

- Studio
- Classroom
- Cinema
- Theatre
- Concert
Results

\[ L = \frac{343}{(4 \times 200)} \]
Results

\[ L = \frac{343}{(4 \times 200)} + \frac{343}{(4 \times 220)} \]
$L = \frac{343}{(4 \times 200)} + \frac{343}{(4 \times 220)} + \frac{343}{(4 \times 240)} = 1.17 M$
\[ L = \frac{343}{(4 \times 200)} + \frac{343}{(4 \times 220)} + \frac{343}{(4 \times 240)} = 1.17 M \]
### MEASUREMENTS

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<th>IMPEDANCE TUBE</th>
<th>FIELD MEASUREMENT</th>
<th>REVERBERATION CHAMBER</th>
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<td>Verify MatLab</td>
<td>Case study</td>
<td>Experiment</td>
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INTRODUCTION

ACOUSTICS

AM

RESEARCH QUESTION

MEASUREMENTS

- Impedance tube

DESIGN

---

**MICROPHONES**

**SPEAKER**

**EXTENDABLE SEGMENT 200 MM**

---

TOM SCHOLTEN | 25-01-2018 | P5 PRESENTATION
Sample sizes

- 50 - 1600 Hz
- 500 - 6400 Hz
- 100 mm
- 29 mm
- MAX 200 mm
50 - 1600 Hz

500 - 6400 Hz

MAX 200 mm

100 mm

29 mm
Sample design
DOWELS
Any bends in the internal channels can obstruct the removal of powder.

The combination of the above mentioned warning, combined with a channel diameter of 5mm results is a situation that does not guarantee powder removal.
Sample design

CONSTRAINT

THRESHOLD r=2.5 MM
New samples
Revised simulations

- Tube 1
  - Length: 125 mm
  - Radius: 12.2 mm
  - End correction: 2.4 mm

- Tube 2
  - Length: 125 mm
  - Radius: 2.8 mm

- Tube 3
  - Length: 118 mm
  - Radius: 0.5 mm

Initial simulation

- Tube 1
  - Length: 125 mm
  - Radius: 30.6 mm
  - End correction: 2.3 mm

- Tube 2
  - Length: 123 mm
  - Radius: 8.75 mm

- Tube 3
  - Length: 118 mm
  - Radius: 2.5 mm
Measurement results

# 1

# 2

# 3
Comparison

Simulated curve

# 1

# 2

# 3
Revised simulations

Initial simulations

Revised simulations
Tube 1
- Length: 125 mm
- Radius: 40.1 mm

Tube 2
- Length: 123 mm
- Radius: 10 mm

Tube 3
- Length: 118 mm
- Radius: 2.5 mm

End correction: 7 mm
**Acoustics**

**Research Question**

**Measurements**

**Design**

**Geometry thresholds**

---

**Tube 1**
- **Length**: 125 mm
- **Radius**: 40.1 mm

**Tube 2**
- **Length**: 123 mm
- **Radius**: 10 mm

**Tube 3**
- **Length**: 118 mm
- **Radius**: 2.5 mm

**End correction**: 7 mm

---

2 resonators

---

3 resonators

---

End correction: 5.7 mm

---

Tube 1
- **Length**: 123 mm
- **Radius**: 10 mm

---

Tube 2
- **Length**: 118 mm
- **Radius**: 2.5 mm

---

Calculated sound absorption coefficient

---

End correction: 7 mm
MEASUREMENTS

- Impedance Tube: Verify MatLab
- Field Measurement: Case study
- Reverberation Chamber: Experiment
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<td>360 degree rotation</td>
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<td>Reverberation chamber</td>
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</table>
All results
Target frequency

\[ d = \frac{3}{8} \times \frac{c}{f} \]

\[ d = \frac{3}{8} \times \frac{343}{f} \]

\[ d = 0.011 \, \text{m} \]

\[ L = c \sqrt{\frac{4}{f} - \frac{d}{0.495}} \]

\[ L = 343 \sqrt{\frac{4}{f} - 0.011} \]

\[ L = 168 \, \text{Hz} \]

\[ S = \frac{A_{\text{max}}}{d} \]

\[ S = \frac{0.23}{0.011} \]

\[ S = 206 \, \text{m}^2 \]

\[ A_{\text{circle}} = \pi r^2 \]

\[ A_{\text{circle}} = 0.23 \, \text{m}^2 \]

\[ r = \frac{0.23}{\pi} \]

\[ r = 0.27 \, \text{m} \]
Surface area needed per 1/3 octave band

Measure

Analyze and pick target frequencies

Calculate required area to add

Pick target frequencies (1/3 octave bands)

Python script

Octopus evolutionary algorithm

Count

Diameter

Length
DESIGN
DESIGN

PLACEMENT
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INTRODUCTION | ACOUSTICS | AM | RESEARCH QUESTION | MEASUREMENTS | DESIGN

Structure

DESIGN

| PLACEMENT | RATIONALE | PRODUCTION |
**Absorption Cross Section Area**

\[ A_{\max} = \frac{\lambda^2}{4\pi} = \frac{c^2}{4\pi f_{\text{peak}}^2} \]
Rationale
CLOSEST PACKING

DIFFICULT TO MODEL

ACOUSTICALLY INCORRECT

TOTAL POPULATION

1

2

3

Rationale

CLOSEST PACKING

DIFFICULT TO MODEL

ACOUSTICALLY INCORRECT

TOTAL POPULATION
INTRODUCTION

ACOUSTICS

AM

RESEARCH QUESTION

MEASUREMENTS

DESIGN

Closest packing

BOUNDARY AREA

ABSORPTION CROSS SECTION AREA

ATTRACTOR
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OVERLAP

TOP VIEW

Bounding Box: 700x580x380 mm

Print process
INTRODUCTION

ACOUSTICS

AM

RESEARCH QUESTION

MEASUREMENTS

DESIGN

Print process
Absorber cylinder
Light cylinder
Light cylinder
**INTRODUCTION**

- **ACOUSTICS**
  - **AM**
  - **RESEARCH QUESTION**
  - **MEASUREMENTS**
  - **DESIGN**

**Workflow**

- **Output from optimization**
  - **Length**
  - **Count**
  - **Diameter**

- **Model light tubes as Brep**
- **Model absorber tubes as Brep**
- **Closest packing**
- **Collection of curves**
- **Wrap outer boundaries**
- **Edge curves with planar surface**
- **Extrude surface as Brep**
- **Join Breps**
- **Place absorber & light cylinders**

- **Print & post process**
- **STL**
- **Product**
- **Insert components**
- **Lasercut components for light tube**
To what extent can coupled quarter wavelength tubes create broadband absorption, utilizing additive manufacturing production techniques; producing acoustic components for indoor use.
To what extent can coupled quarter wavelength tubes create broadband absorption, utilizing additive manufacturing production techniques; producing acoustic devices for indoor use.

At this moment, the capability of coupled quarter wavelength tubes to create broadband absorption cannot be verified fully.
To what extent can coupled quarter wavelength tubes create broadband absorption, utilizing additive manufacturing production techniques; producing acoustic devices for indoor use.

The resolution of SLS is not high enough to print geometry small enough to effectively absorb sound.
THANK YOU