Characterization of Mufflers

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Motivation

- Mufflers are devices used to reduce noise emitted from different fluid machines.
- They have to be tailored to each machine.
- Tailoring means that we need simulation tools and measurement techniques to validate the models.
Motivation

- Measurements are done in universities, Research Institutes and Companies
- They are repeated regularly
- Requirements:
  - Standardize the procedure
  - Minimize the time to conduct one measurement
  - Make it easy for everyone to do the test
The wave propagation inside an acoustic element (muffler) can be described by the scattering matrix formulation:

\[
\begin{bmatrix}
  p_{a+} \\
  p_{b+}
\end{bmatrix} = \begin{bmatrix}
  R_{11} & T_{12} \\
  T_{21} & R_{22}
\end{bmatrix} \begin{bmatrix}
  p_{a-} \\
  p_{b-}
\end{bmatrix} + \begin{bmatrix}
  p_{a+}^s \\
  p_{b+}^s
\end{bmatrix}
\]
Two source technique

- It is a technique which is widely used to characterize mufflers using stepped sine excitations especially in the presence of flow.

Fig. 1: Typical two source setup
The two source technique

Fig. 2: Two-source setup schematic

\[
\begin{bmatrix}
  p_{a+} \\
  p_{b+}
\end{bmatrix} =
\begin{bmatrix}
  R_{11} & T_{12} \\
  T_{21} & R_{22}
\end{bmatrix}
\begin{bmatrix}
  p_{a-} \\
  p_{b-}
\end{bmatrix} +
\begin{bmatrix}
  p_{a+}^s \\
  p_{b+}^s
\end{bmatrix}
\]
Wave Decomposition
Two-microphone Technique

- Two-microphone wave decomposition techniques used to determine downstream and upstream propagating waves.

Frequency Range?
- Limitation 1: Plane waves inside the pipe $\Rightarrow f_u < 0.58 \frac{c_0}{d}$
- Limitation 2: Microphone spacing $\Rightarrow 0.1\pi(1-M^2) < ks < 0.8\pi(1-M^2)$
It can be used to estimate the acoustic performance of a muffler by measuring the:

- Elements of the scattering matrix
- Transmission loss

\[
TL = 10\log_{10}\left(\frac{(1 + M_k)^2 Z_l}{(1 + M_l)^2 4Z_k}\right)T_{red,11} + \frac{T_{red,12}}{Z_l} + Z_k T_{red,21} + \frac{T_{red,22}Z_k}{Z_l}\]

- Insertion loss

\[
IL = 10\log_{10}\left[\frac{T_{red,11}Z^{ls} + T_{red,12} + Z^{ks}\left(T_{red,21}Z^{ls} + T_{red,22}\right)}{T_{ref}Z^{ls} + T_{ref} + Z^{ks}\left(T_{ref}Z^{ls} + T_{ref}\right)}\right]^2\]

- Noise reduction

\[
NR = 20\log_{10}\left[T_{red,11} + \frac{T_{red,12}}{Z^{ls}}\right]\]
Problem statement

- The evaluation of the acoustic performance of a muffler using stepped sine measurements takes a considerable amount of time.
- We introduce a new platform to automate the two-source technique which:
  - Reduces the time required to perform stepped sine measurements.
  - Maintain the accuracy provided by traditional platforms.
The measurement time is reduced by developing a new platform which:
- Introduces a new acquisition algorithm to optimize the measurement time
- Implements simultaneous upstream and downstream stepped sine excitation
Construction of the new platform

User Interface (JAVA)

Data Handling (JAVA)

Measurement logic (MATLAB)

Acquisition logic (ANSI C)

User Input

Measurement Parameters

Estimated Acoustic Properties

Mic Transfer functions

Excitation Signals

Raw Mic readings

Acquisition Hardware (NI)

Measurement Parameters

Acquisition logic (ANSI C)

Acquisition Hardware (NI)

Excitation Signals

Mic Transfer functions

Measurement logic (MATLAB)

Data Handling (JAVA)

User Interface (JAVA)
Optimized acquisition algorithm

Reference algorithm:

- The sampling rate is fixed and depends on the maximum frequency to be excited
- The data window size is determined by the desired frequency step size
- The excitation is stopped between each two frequency steps

Optimized algorithm:

- The sampling rate depends on the frequency being excited
- The data window size is fixed
- The excitation is kept between each two frequency steps, only the frequency is changed
• Traditionally only one speaker (upstream or downstream) is excited at a time

• Simultaneous excitation involves exciting both upstream and downstream speakers at the same time but at different frequencies:

<table>
<thead>
<tr>
<th>Frequency spectrum</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>Start Freq.</td>
</tr>
<tr>
<td>Minimum spacing</td>
</tr>
<tr>
<td>End Freq.</td>
</tr>
<tr>
<td>Down</td>
</tr>
</tbody>
</table>

**Simultaneous excitation**
Conventional vs. Optimized Acquisition

(a) Conventional Acquisition

1. Start
2. Setup the input channels
3. Start Excitation
4. Wait for the response to settle
5. Acquire mic signals
6. Convert to frequency domain and select the current frequency
7. \( f = f_{\text{max}} \)?
   - No: Increment \( f \) by \( f_{\text{step}} \)
   - Yes: Average data and calculate the transfer functions
8. End

(b) Optimized Acquisition

1. Start
2. Start Excitation
3. Adjust the sampling time
4. Wait for the response to settle
5. Acquire mic signals
6. Convert to frequency domain and select the current frequency
7. \( f = f_{\text{max}} \)?
   - No: Increment \( f \) by \( f_{\text{step}} \)
   - Yes: Average data and calculate the transfer functions
8. End
The results obtained by the following methods were compared:

- The new platform with:
  - Optimized acquisition algorithm
  - Optimized algorithm and simultaneous excitation
- SIDLAB commercial software
- Analytic simulations using the acoustic two port theory
Validation setup

Test Cases:
- Straight pipe ($L=1 \ m, \ D=50 \ mm$)
- Dissipative muffler ($L=0.5\ m, \ D_i=50 \ mm, \ D_o=99 \ mm, \ 20\% \ porosity$)

Fig. 3: Schematic for the dissipative muffler

Fig. 4: The used test setup for validation
Straight pipe results

(a) Without flow

(b) With flow (M=0.1)

Fig. 5: Real and imaginary components of $S_{12}$ estimated using simultaneous stepped sine (Real part and Imaginary part), white noise (Re and Im), optimized single-sided stepped sine (Re and Im), conventional stepped sine excitations (Re and Im) and analytically (Re and Im)
Dissipative muffler results

Fig. 6: TL of the dissipative muffler estimated using simultaneous stepped sine, white noise, optimized single-sided stepped sine, conventional stepped sine excitations and analytically.

(a) Without flow

(b) With flow (M=0.1)
The total acquisition time \( t_a \) taken by the different acquisition algorithms within a frequency range between 200 and 1100 Hz, a step of 10Hz and 100 averages was measured to be:

<table>
<thead>
<tr>
<th>Acquisition algorithm</th>
<th>( t_a ) (min)</th>
<th>Speed Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>32.0</td>
<td>-</td>
</tr>
<tr>
<td>Optimized</td>
<td>9.1</td>
<td>3.5</td>
</tr>
<tr>
<td>Optimized with simultaneous excitation</td>
<td>6.0</td>
<td>5.3</td>
</tr>
</tbody>
</table>
Summary

- A new platform for the automation of two source acoustic measurements is introduced and validated.
- The new platform minimizes the time needed to perform the measurements without affecting their quality.
- The new platform can be as much as 5 times faster than reference implementations.