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Visualization of Automotive Power Seat Slide Motor Noise

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Automotive Power Seat Motors

Front view

Bottom view

Power seat with three motors
(Some other power seats have four motors)
INTRODUCTION

• Automotive power seat slide motor
  - Power seats have different but similarly shaped motors
  - Relatively compact in size, similar to small cylinder
  - Noise sources of motor are closely spaced: e.g., motor shell, bearings, and brushes
  - Span wide frequency range: e.g., 592 Hz ~ 8 kHz
  - Limited position for reference measurement

• Statistically Optimized Nearfield Acoustical Holography
  - High resolution and no truncation effects
  - Multi-reference acoustical holographic procedure
  - Cylindrical surfaces
Visualization of Power Seat Motor Noise

- SONAH formulation (1)

• The sound pressure, $p(r)$, can be expressed as linear combination of the measured sound pressure $p(r_n)$,

$$p(r) \approx \sum_{n=1}^{N} c_n(r) p(r_n)$$

• If a good representation of the sound field can be obtained by using a finite subset of wave functions, the coefficients $c_n$ can be determined.

$$\Phi_{Km}(r) \approx \sum_{n=1}^{N} c_n(r) \Phi_{Km}(r_n), \quad m = 1 \ldots M$$
Visualization of Power Seat Motor Noise

- SONAH formulation (2)

\[ p(r, \phi, z) = \frac{1}{(2\pi)^2} \sum_{m=-\infty}^{m=\infty} \int_{-\infty}^{\infty} P_m(r_h, k_z) \Phi_{km} dk_z \]

• Defining wave function,

\[ \Phi_{km} \equiv 2\pi \frac{H_m^{(1)}(k_r r)}{H_m^{(1)}(k_r r_h)} e^{im\phi} e^{ik_z z} , \]

where:

\[ k_r = \begin{cases} \sqrt{k^2 - k_z^2} & \text{for } |k| \geq |k_z| \\ i\sqrt{k_z^2 - k^2} & \text{for } |k| < |k_z| \end{cases} \]
- SONAH formulation (3)

\[ A \equiv \left[ \Phi_{Kq,m} (r_{h,j}) \right], \quad \alpha (r) \equiv \left[ \Phi_{Kq,m} (r) \right], \quad \mathbf{c} (r) \equiv \left[ c_j (r) \right]. \]

- Estimated pressure \( \rho (r) \) is,

\[ \rho (r) \approx \sum_{n=1}^{N} c_n (r) \rho (r_n) = \mathbf{p}^\top \mathbf{c} (r) = \mathbf{p}^\top \left( A^+ A + \theta^2 \mathbf{I} \right)^{-1} A^+ \alpha (r) \]

where, \( \mathbf{p}^\top \) is measured pressure vector at \( r_n \)

- Estimated normal particle velocity \( u_z (r) \) is,

\[ u_z (r) \approx \mathbf{p}^\top \left( A^+ A + \theta^2 \mathbf{I} \right)^{-1} A^+ \beta (r) \]

where, \( A^+ \beta (r) \) is a correlation vector that relates measured pressure and particle velocity.
Visualization of Power Seat Motor Noise

- Power seat motor measurement
  - Number of field microphones: \( N_z = 11 \)
  - Microphone spacing in \( z \) direction: \( z_{inc} = 2 \text{ cm} \)
  - Radius of hologram: \( r_h = 4 \text{ cm} \)
  - Radius of motor shell: \( r = 2 \text{ cm} \)
  - Total aperture size: 22 cm, \( N_\Phi = 24 \)
  - Motor rotating speed: 3552 rpm (13.5V)
Visualization of Power Seat Motor Noise

- Power seat motor measurement result

Singular values of reference measurement

- Difference between first and second singular values > 10 dB
- First singular values are used for reconstruction
- Since the motor is rotating at 3552 Hz, and armature has ten poles, 3552/60*10=592 Hz, is brush passage frequency and the motor has two pairs of magnets, so motor housing shell is excited at 592*2=1184 Hz.
Visualization of Power Seat Motor Noise

- Power seat motor measurement result

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Sound power (dB) (Ref.: 10^{-12} W)</th>
<th>Rank</th>
<th>Major noise origin</th>
</tr>
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<tr>
<td>592</td>
<td>52.0</td>
<td>7</td>
<td>Shell vibration and lower bearing</td>
</tr>
<tr>
<td>1184</td>
<td>86.6</td>
<td>1</td>
<td>Shell vibration</td>
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<td>1736</td>
<td>47.1</td>
<td>8</td>
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<td>2360</td>
<td>55.3</td>
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<td>67.8</td>
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<td>64.8</td>
<td>4</td>
<td>Lower bearing</td>
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<tr>
<td>4032</td>
<td>67.5</td>
<td>3</td>
<td>Shell vibration and lower bearing</td>
</tr>
<tr>
<td>8288</td>
<td>61.5</td>
<td>5</td>
<td>Shell vibration and lower bearing</td>
</tr>
</tbody>
</table>

SONAH Sound power estimate and major noise origin of motor.

Shell vibration

Lower bearing
Visualization of Power Seat Motor Noise

- Cylindrical shell vibration

Cylindrical mode shapes

$n=1$ mode    $n=2$ mode    $n=3$ mode    $n=4$ mode
Visualization of Power Seat Motor Noise

- Power seat motor measurement result: Eight major frequencies

592 Hz

Motor shell vibration and lower bearing
Sound power: 52.0 dB (Ref.: $10^{-12}$ W), 7th/8th frequencies
Visualization of Power Seat Motor Noise

- Power seat motor measurement result: Eight major frequencies

1184 Hz

Motor shell vibration ($n=2$ mode) and lower bearing
Sound power: 86.6 dB (Ref.: $10^{-12}$ W), 1st/8 frequencies
Visualization of Power Seat Motor Noise

- Power seat motor measurement result: Eight major frequencies

1736 Hz

Motor shell vibration (n=2 mode)

Sound power: 47.1 dB (Ref.: 10^{-12} W), 8th/8 frequencies
Visualization of Power Seat Motor Noise

- Power seat motor measurement result: Eight major frequencies

2360 Hz

Particle velocity

Sound intensity

Motor shell vibration ($n=3$ mode)

Sound power: 55.3 dB (Ref.: $10^{-12}$ W), 6th/8 frequencies
Visualization of Power Seat Motor Noise

- Power seat motor measurement result: Eight major frequencies

2944 Hz

Particle velocity

Sound intensity

Motor shell vibration \((n=3\text{ mode})\) and lower bearing

Sound power: 67.8 dB (Ref.: \(10^{-12}\) W), 2nd/8 frequencies
Visualization of Power Seat Motor Noise

- Power seat motor measurement result: Eight major frequencies

3536 Hz

Lower bearing
Sound power: 64.8 dB (Ref.: $10^{-12}$ W), 4th/8 frequencies
Visualization of Power Seat Motor Noise

- Power seat motor measurement result: Eight major frequencies

**4032 Hz**

Motor shell vibration (n=3 mode) and lower bearing

Sound power: 67.5 dB (Ref.: $10^{-12}$ W), 3rd/8 frequencies
Visualization of Power Seat Motor Noise

- Power seat motor measurement result: Eight major frequencies

8288 Hz

Motor shell vibration and lower bearing

Sound power: 61.5 dB (Ref.: $10^{-12}$ W), 5th/8 frequencies
Visualization of Power Seat Motor Noise

- Power seat motor measurement result: Shell modes

1196 Hz

Motor shell vibration ($n=2$ mode)
Visualization of Power Seat Motor Noise

- Power seat motor measurement result: Shell modes

3100 Hz

Particle velocity

4720 Hz

Particle velocity

Motor shell vibration ($n=3$ mode)

Motor shell vibration ($n=4$ mode)
Visualization of Power Seat Motor Noise

- Power seat motor measurement result: Summary

Motor shell vibration, $n=2$
Lower bearing

Motor shell vibration, $n=3$
Lower Bearing
Visualization of Power Seat Motor Noise

- Conclusions

• Possible to visualize closely located sources on compact cylindrical machine accurately by using high resolution, multi-reference acoustical holographic procedure over a wide range of frequencies

• Sound radiation from motor shell vibration and lower bearing were clearly visualized over wide range of frequencies

• Clearly shown that sound radiation around 1184 Hz is primarily from motor shell vibration of $n=2$ mode

• Sound radiation from automotive power seat slide motor was clearly visualized, and also other power seat motors with similar geometry can be clearly visualized