薄膜型扬声器的声场和电声固多物理耦合模拟分析
by COMSOL Multiphysics

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25, Nov., 2011
大綱

1. 簡介

2. 駐極體揚聲器之結構建模與驗證

3. 駐極體揚聲器之指向性建模與驗證

4. 結論
1. 簡介
Flexible Thin-film Loudspeaker

http://www.soundtech.com/
http://www.dti.org.tw
http://www.jib.co.kr

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\[ F = \frac{\varepsilon r_1 S_c}{8\varepsilon_0} \left( \frac{2\varepsilon_0\varepsilon_r e_{in} + h\sigma_m}{\varepsilon_r (d + \delta) + \varepsilon r_1 h} \right)^2 \]

\[ = \frac{\varepsilon r_1 S_c}{2(\varepsilon_r (d + \delta) + \varepsilon r_1 h)^2} \left( \frac{h^2 \sigma_m^2}{4\varepsilon_0} + \varepsilon_r h\sigma_m e_{in} + \varepsilon_0 \varepsilon_r^2 e_{in}^2 \right) \]

Fabricate the flexible electret loudspeaker
SEM of PTFE/COC
2. 驗極體揚聲器之結構建模與驗證
Frequency response and THD of various speakers
Impulse response of various speakers

- Electret loudspeaker
- Mid speaker
- Tweeter
Different shapes and sizes of audio radiation area
# Material properties of the electret cell actuator

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Electret-based diaphragm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Geometry</strong></td>
<td>Square (Length) : 8mm, 10mm, 12mm</td>
</tr>
<tr>
<td></td>
<td>Circle (Radius) : 4mm, 5mm, 6mm</td>
</tr>
<tr>
<td></td>
<td>Hexagon (Edge) : 6mm, 8mm, 10mm</td>
</tr>
<tr>
<td><strong>Thickness (mm)</strong></td>
<td>20×10^{-3}</td>
</tr>
<tr>
<td><strong>Young’s modulus (Pa)</strong></td>
<td>553×10^{6}</td>
</tr>
<tr>
<td><strong>Poisson’s ratio</strong></td>
<td>0.33</td>
</tr>
<tr>
<td><strong>Density (kg/m^3)</strong></td>
<td>460</td>
</tr>
<tr>
<td><strong>Initial normal stress (Pa)</strong></td>
<td>( \sigma_{x_i}=47\times10^3 ), ( \sigma_{y_i}=47\times10^3 ),</td>
</tr>
</tbody>
</table>
Advanced vibrometer/interferometer device measurement system

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The schematics of the ESPI system
## First resonance frequency of electret cell actuator

<table>
<thead>
<tr>
<th>Shape</th>
<th>Square</th>
<th>Circle</th>
<th>Hexagon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size(mm)</td>
<td>Edge 8mm</td>
<td>Edge 10mm</td>
<td>Edge 12mm</td>
</tr>
<tr>
<td>Simulation(Hz)</td>
<td>1216.8</td>
<td>932</td>
<td>747</td>
</tr>
<tr>
<td>Experiment(Hz)</td>
<td>1120</td>
<td>966.67</td>
<td>706.67</td>
</tr>
</tbody>
</table>

[Images of 3D models of square, circle, and hexagon shapes with color gradients representing resonance frequencies]
First resonance frequency of the square shape by AVID

![Graph showing frequency vs. size for different shapes (Square, Hexagonal, Circular)].
The first mode shape by ESPI

Direct correlation → (5,1) Phase shifting

Phase unwrapping → Median filter

The first mode shape

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3. 驗極體場聲器之指向性建模與驗證
Beam patterns of the two shapes at 1k, 2k, and 4k Hz
The beam pattern of the array

The beam pattern of the array \( b(\theta) \equiv v^2(\theta) \)

\[
= \left( \frac{1}{N} \sin(N \cdot \frac{\pi d}{\lambda} \sin \theta) \right)^2 \left( \frac{\sin(\frac{\pi d}{\lambda} \sin \theta)}{\sin(\frac{\pi d}{\lambda} \sin \theta)} \right)
\]

where \( d \) is distance span of two electret cell elements, \( \lambda \) is wave length. Assume there are \( N \) elements of the array.
Simulation of Electret cell at 1st resonance

Structure

Acoustic

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Directivity of the electret loudspeaker
(10cm x 10cm)

at 1k Hz
Directivity of a electret loudspeaker
(10cm x 10cm)

at 4k Hz

at 8k Hz
Directivity influenced by size of array
Directivity influenced by weighting function

\[ b(\theta) \equiv \left\{ \frac{\sum_{m=0}^{N-1} C_m \cdot \alpha_m e^{i(k \cdot m \cdot d \cdot \sin \theta + \delta_m)}}{\sum_{m=0}^{N-1} C_m \cdot \alpha_m e^{i\delta_m}} \right\}^2 \]

\[ = \left\{ \frac{\sum_{m=0}^{N-1} C_m \cdot e^{i k \cdot m \cdot d \cdot \sin \theta}}{\sum_{m=0}^{N-1} C_m} \right\}^2 \]

**Ex. binomial shading**

\[ C_m = \frac{1}{10} \{1, 5, 10, 10, 5, 1\} \]

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**Schematic of two clusters of structures**
Directivity influenced by structure of array

結構  聲場  指向性

Simulations at 1kHz
Experiment at 1kHz

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4. 結論
4. CONCLUSIONS

- Built the FEA model of the electret Cell Actuator by COMSOL.
- Validated the FEA model by using AVID and ESPI measurement system
- Built the FEA model of the electret loudspeaker by COMSOL.
- Validated the FEA model by using acoustic measurement system
Thank you for your attention