FEATURES

The harmonic distortion component of an excitation tone varied in frequency and voltage is measured with the DIS module (3D distortion measurement) of the KLIPPEL R&D SYSTEM. The 3D measurement reveals the complicated relationship between the excitation amplitude (voltage) and the amplitude of the harmonic distortion components which depends on the heating of the voice coil and other nonlinear effects. The connection between common speaker nonlinearities (motor, suspension, etc.) and the harmonic distortion components is discussed.

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# 1 Method of Measurement

## Excitation signal
A sinusoidal signal with variable frequency and amplitude is applied to the terminals of the loudspeaker.

**Voltage Sweep:**
A series of \( n_U \) subsequent measurement with different excitation voltages is performed. The \( n_U \) voltages are spaced linearly or logarithmically between the starting voltage \( U_{\text{start}} \) and final voltage \( U_{\text{end}} \).

**Frequency Sweep:**
A series of \( n_f \) subsequent measurement with different excitation frequencies is performed. The \( n_f \) frequencies are spaced linearly or logarithmically between the starting frequency \( f_{\text{start}} \) and final frequency \( f_{\text{end}} \).

For example:
\[
U_{\text{start}} = 0.1 \text{ V}_{\text{rms}}, \quad U_{\text{end}} = 2 \text{ V}_{\text{rms}} \quad (\text{8 points linearly spaced})
\]
\[
f_{\text{start}} = 20 \text{ Hz}, \quad f_{\text{end}} = 1 \text{ kHz} \quad (50 \text{ points linearly spaced})
\]

## Loudspeaker setup
Free-field or half-space free-field conditions are recommended for the measurement. The microphone should be placed in 1 meter distance from the speaker (on axis).

## Total harmonic distortion
The IEC standard 60268 defines the total harmonic distortion as:
\[
d_{ht} = \frac{P(2f)^2 + P(3f)^2 + \ldots + P(Nf)^2}{P(f)^2 + P(2f)^2 + P(3f)^2 + \ldots + P(Nf)^2} \times 100\%
\]
in percent and
\[
L_{ht} = 20 \log \left( \frac{d_{ht}}{100} \right) \text{ dB}
\]
in decibels.

## 2\textsuperscript{nd} order harmonic distortion
The second-order harmonic distortion is defined as:
\[
d_{h2} = \frac{P(2f)}{P(f)^2 + P(2f)^2 + P(3f)^2 + \ldots + P(Nf)^2} \times 100\%
\]
in percent and
\[
L_{h2} = 20 \log \left( \frac{d_{h2}}{100} \right) \text{ dB}
\]
in decibels.

## 3\textsuperscript{rd} order harmonic distortion
The third-order harmonic distortion is defined as:
\[
d_{h3} = \frac{P(3f)}{P(f)^2 + P(2f)^2 + P(3f)^2 + \ldots + P(Nf)^2} \times 100\%
\]
in percent and
\[
L_{h3} = 20 \log \left( \frac{d_{h3}}{100} \right) \text{ dB}
\]
in decibels.
2 Using the DIS Module

Requirements

The following hardware and software is required
- Distortion Analyzer + PC
- DIS software module + dB-Lab
- Microphone

Setup

Connect the microphone to the input IN1 at the rear side of the Distortion Analyzer. Set the speaker in the approved environment and connect the terminals with output Speaker 1. Switch the power amplifier between the connectors OUT1 and Amplifier.

Preparation

Create a new object.
Add a new DIS operation based on the template DIS 3D Harmonics AN 9.

Measurement

1. Start the measurement DIS 3D Harmonics AN 9
2. Open the windows 2nd Harmonics, % and 3rd Harmonics, %
3. Open the window Harmonic (n) and select order n on property page Display
4. Print the results or create a report

3 Relationship between speaker nonlinearities and harmonic distortion

<table>
<thead>
<tr>
<th>Nonlinearity</th>
<th>Distortion Measure</th>
<th>Critical Frequency Range</th>
<th>Relationship Between Input voltage and amplitude of Distortion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offset of coil in equal-length configuration</td>
<td>$d_{h2}(f)$</td>
<td>$f &lt; f_s$</td>
<td>quadratic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$f \approx 2f_s$</td>
<td>quadratic</td>
</tr>
<tr>
<td>Symmetric Bl(x) in equal-length configuration</td>
<td>$d_{h3}(f)$</td>
<td>$f &lt; f_s$</td>
<td>cubic</td>
</tr>
<tr>
<td>Symmetric Bl(x) due long coil overhang</td>
<td>$d_{h3}(f)$</td>
<td>$f &lt; f_s$</td>
<td>negligible distortion</td>
</tr>
<tr>
<td>Asymmetric pot spider</td>
<td>$d_{h2}(f)$</td>
<td>$f \approx f_s$</td>
<td>quadratic</td>
</tr>
<tr>
<td>Symmetric spider</td>
<td>$d_{h3}(f)$</td>
<td>$f \approx f_s$</td>
<td>cubic</td>
</tr>
<tr>
<td>Asymmetric surround limiting</td>
<td>$d_{h2}(f)$</td>
<td>$f \approx f_s$</td>
<td>negligible distortion</td>
</tr>
<tr>
<td>Symmetric surround limiting</td>
<td>$d_{h3}(f)$</td>
<td>$f \approx f_s$</td>
<td>negligible distortion</td>
</tr>
<tr>
<td>Inductance asymmetry</td>
<td>$d_{h3}(f)$</td>
<td>$f \approx 2f_s$</td>
<td>quadratic</td>
</tr>
</tbody>
</table>
4 Setup parameters for the DIS module

Template

Create a new Object, using the operation template DIS 3D Harmonics AN 9 in dB-Lab. If this database is not available you may adjust the default DIS setup as described below. You may also modify the setup parameters according to your needs.

Default setting for harmonic measurement

- Open the property page Stimulus.
- Select Harmonics in the drop down box Mode.
- Select Sweep in group Voltage U₁.
- Set $U_{\text{start}}$ to 1 V rms, $U_{\text{end}}$ to 8 V rms, Points to 4 and Spaced to lin. Make sure the signal level is appropriate for loudspeaker.
- Select Sweep in group Frequency $f₁$ and specify a sweep with 50 points spaced logarithmically between 20 Hz and 1000 kHz.
- Select Additional excitation before measurement and set it to 0.01 s.
- Set maximal order of distortion analysis to $N = 16$.
- Open property page Protection.
- Select Monitoring: Voice coil temperature and amplifier gain.
- Select Abort measurement if: increase of voice coil temperature (Speaker 1) exceeds and set the temperature to 100 K.
- Open property page Input. Select IN 1 (Mic). Select Off in group Y2 (Channel 2).
- Open property page Display. Select Signal at IN1 in drop down box State signal.

5 Example

Fundamental

The result window Fundamental shows the fundamental of the sound pressure versus frequency $f₁$ and voltage $U₁$ if 3D plot is selected in property page Display.

<table>
<thead>
<tr>
<th>Voltage $U₁$ [V]</th>
<th>IN1 [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00 V</td>
<td>0 dB = 4.47e-006 V (rms)</td>
</tr>
<tr>
<td>1.41 V</td>
<td>2.5 dB</td>
</tr>
<tr>
<td>2.00 V</td>
<td>5.0 dB</td>
</tr>
<tr>
<td>2.83 V</td>
<td>7.5 dB</td>
</tr>
<tr>
<td>4.00 V</td>
<td>10 dB</td>
</tr>
<tr>
<td>5.66 V</td>
<td>12.5 dB</td>
</tr>
<tr>
<td>8.00 V</td>
<td>15 dB</td>
</tr>
</tbody>
</table>

2nd-order harmonic component

The result window Harmonic (n) shows the 2nd order harmonic component of the sound pressure in decibels versus frequency $f₁$ for voltages $U₁$ increased between $U_{\text{start}}$ and $U_{\text{end}}$ if 2D plot versus $f₁$ is selected in property page Display. Change order $n$ in property page Display.

<table>
<thead>
<tr>
<th>Voltage $U₁$ [V]</th>
<th>2nd-order harmonic distortion component [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00 V</td>
<td>120 Hz 1.41 V 2.00 V 2.83 V 4.00 V 5.66 V 8.00 V</td>
</tr>
<tr>
<td>1.41 V</td>
<td>140 Hz 1.41 V 2.00 V 2.83 V 4.00 V 5.66 V 8.00 V</td>
</tr>
<tr>
<td>2.00 V</td>
<td>160 Hz 1.41 V 2.00 V 2.83 V 4.00 V 5.66 V 8.00 V</td>
</tr>
<tr>
<td>2.83 V</td>
<td>180 Hz 1.41 V 2.00 V 2.83 V 4.00 V 5.66 V 8.00 V</td>
</tr>
<tr>
<td>4.00 V</td>
<td>200 Hz 1.41 V 2.00 V 2.83 V 4.00 V 5.66 V 8.00 V</td>
</tr>
<tr>
<td>5.66 V</td>
<td>220 Hz 1.41 V 2.00 V 2.83 V 4.00 V 5.66 V 8.00 V</td>
</tr>
<tr>
<td>8.00 V</td>
<td>240 Hz 1.41 V 2.00 V 2.83 V 4.00 V 5.66 V 8.00 V</td>
</tr>
</tbody>
</table>

At low and medium voltages the 2nd order distortion component raises by 6 dB revealing a quadratic relationship. The increase stagnates at the last voltage step.
### 3D Harmonic Distortion Measurement

Total harmonic distortion

The result window *Total Harmonic, %* shows the total harmonic distortion $d_{ht}$ in percent according to IEC 60268 versus frequency $f_1$ for voltages $U_1$ increased between $U_{start}$ and $U_{end}$ if 2D plot versus $f_1$ is selected in property page *Display*.

![Graph of total harmonic distortion](image)

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## 6 More Information

<table>
<thead>
<tr>
<th>Related application notes</th>
<th>3D Intermodulation Distortion Measurement, Application Note 8</th>
</tr>
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<tr>
<td></td>
<td>Multi-tone Distortion Measurement, Application Note 16</td>
</tr>
<tr>
<td>Related Specification</td>
<td>“DIS”, S4</td>
</tr>
<tr>
<td>Papers</td>
<td>W. Klippel, “Loudspeaker Nonlinearities – Causes, Parameters, Symptoms” preprint #6584 presented at the 119th Convention of the Audio Engineering Society, 2006 October 6-8, San Francisco, USA</td>
</tr>
<tr>
<td></td>
<td>Updated version on <a href="http://www.klippel.de/know-how/literature/papers.html">http://www.klippel.de/know-how/literature/papers.html</a></td>
</tr>
<tr>
<td>Software</td>
<td>User Manual of the <em>Klippel R&amp;D System</em>.</td>
</tr>
</tbody>
</table>

Find explanations for symbols at:  
[http://www.klippel.de/know-how/literature.html](http://www.klippel.de/know-how/literature.html)

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