What does this seminar offer?

- Overview on loudspeaker part measurements
  - B-Field Testing
  - Temperature / Power Testing
  - Suspension Part Measurement
    - Low frequencies (lumped K(x))
    - Cone break up range (distributed)
  - Material Parameter Measurement
  - RMA – Rocking Mode Analysis
- Relation to measurements at final loudspeaker
- Theory on measurement principles
- Available Industry Standards
Measurement of magnetic Flux density

Abstract

Measurement of magnetic Flux density (B Field Scanner)
The flux density $B(\phi, z)$ in the gap is automatically measured versus angle $\phi$ and height $z$ by using a B-Field Probe and a mechanical scanning technique. This technique is the basis for predicting the force factor $B_l(x)$ and for detecting problems in the design, assembling and magnetization causing rocking modes and voice coil rubbing.
Example: Static Measurement of B-field in the gap and force factor characteristic $B_l(x)$

- Hall sensor
- Cylindrical Coordinates: $z$-axis, angle $\phi$

Scanning Process

Cylindrical Coordinates
**Magnetic Flux Density**

on the scanned surface

\[
B(z_i, \varphi, \tau_k) \quad \{ i = 1, ..., N_i \}
\]

\[
k = 1, ..., N_k
\]

**Force Factor Nonlinearity** \( \text{Bl}(x) \)

Integration of the B field versus coil length \( l \)

\[
\text{Bl} = e_i \int \left[ B(r_i) \times dr_i \right]
\]

\[
\text{Bl}(x) = m \int_{-e}^{e} B(x + \frac{D}{2} + z_i, \varphi) \cdot d\varphi
\]

\[
= m 2 \pi \sum_{i=0}^{N_i} B'(x + \frac{D}{2} + z_i)
\]
Asymmetrical Field Distribution

Flux Density Variation

\[ V_d(\phi) = \frac{B'(\phi) - B''}{B''} \times 100\% \]

Variation of Force Factor Distribution

\[ V_{df}(x,\phi) = \frac{2\pi B'(x,\phi) - B''(x)}{B''(x)} \times 100\% \]

\[ B''(x) = \int\frac{B'(x,\phi)}{\phi} d\phi \]

Asymmetries of the Magnetic Field

Causes:

- Geometry is not axially symmetrical
- Position of the magnet
- Position of the pole piece
- Magnetization process

Consequences:

- Tilting of the voice coil former
- Rocking modes
- Rubbing coil
- Higher-order distortion
- Damage
Causes of Rocking Modes

- Stiffness asymmetries
- Mass Unbalances
- Asymmetric acoustic loads

B field Asymmetries

How to assess the Force Factor Nonlinearity?

Magnetic System
- Geometry + Material
  - STATIC FEM
  - Static Flux Density \( \vec{B}(x, l_{coil} = 0) \)
  - Integration over Coil length

Voice Coil
- Geometry + Material
  - Parameter Identification

Transducer
- + Stimulus
  - Force Factor \( B(x, l_{coil} = 0) \)
  - Force Factor \( B(x, l_{coil} > 0) \)
  - Force Factor agreement?
Temperature Monitoring (Power Test)

![Graph showing Increase of voice coil temperature DeltaTv (\(T\)) and electrical input power P (\(t\)).]

Static Temperature Tests

Standards:

- ALMA TM-324 (Draft): Test Method for Voice Coil Maximum Operating Temperature (Tmo):
  Find ratio (K) between hot and cold DCR for coil only (DC voltage).
**Conventional techniques:**

**Temperature Monitoring with DC source**

Disadvantages:
- Requires additional hardware (large capacitor)
- Causes Offset in voice coil displacement
- Slow monitoring of voice coil temperature
- Fails in measuring drivers with crossover
- Limited in speed and AC-rejection

**Temperature Measurement**

By Using a Steady-State Pilot Tone

Benefit of adding an additional tone:
- Quasi-dc measurement with ac-power amplifier possible (f < 4 Hz)
- High speed monitoring of variation of Re(t)
- Long term averaging using low amplitude
- No external stimulus required
- Active during cooling phase (OFF-cycle)
- Impedance measured at one frequency
- Power of pilot tone is negligible

**Transducer:** 1 - 4 Hz  
**Systems:** 0.01 ... 3 kHz

**KLIPPEL**

**Magnitude of electric impedance Z(f)**

**Frequency [Hz]**

**Impression of woofer, tweeter and crossover**

**Temperature**

**Increase of VC Temperature**

KLIPPEL, Sound Quality of Audio Systems, Part 7: Measurement of Nonlinear Parameters, 15
**Voice Coil Temperature**

Measured via Electrical Resistance $R_e(t)$

- Based on voltage and current measurement
- $R_e(t)$ corresponds with mean value of the temperature
- Local temperature varies in overhang coils

Indications of a thermal damage:
- loose windings $\rightarrow$ voice coil rubbing
- shortcut of windings with pole gap $\rightarrow$ reduced resistance
- open coil $\rightarrow$ maximal resistance limited by instrument

**Pilot Tone**

Internal mixing of the pilot tone

External mixing of internal pilot tone

External mixing of external pilot tone

2 Hz for woofer
20 Hz for tweeter
2 Hz for subwoofer
Assessing Maximal Power Handling

![Graph showing the increase of voice coil temperature (ΔTv) and electrical input power (P(t)) over time (t) for DUT 1 (01:35:54). The graph indicates a failure at 190 K and 13 W, marking the permissible increase of VC temperature.]

**Failure Detection ("Death Report")**

- High sampling of state (X, Tv) and parameters (Kms) period just before destruction
- Allows to investigate cause of failure
Suspension Part Measurement

Abstract

Linear Suspension Part Testing for QC (LST)

http://www.klippel.de/our-products/qc-system/additional-modules/linear-suspension-test.html

The QC LST is dedicated to the quality control of suspension parts (spiders, cones, surrounds) and passive radiators (drones). Linear mechanical parameters like resonance frequency, stiffness (LST Lite) or relative mass and stiffness deviation (LST Pro) are determined dynamically from the displacement frequency response. The device under test is stimulated pneumatically while displacement is measured by a cost effective triangulation laser.

Test objects with circular geometry are easily attached to the measurement bench without time consuming mounting effort by using a set of mounting parts (rings, cones). The fast loading mechanism is designed to change DUTs as fast as possible while ensuring stable and robust measurement conditions. For quality control limits can be calculated based on reference units to provide pass/fail verdicts.
Static Suspension Measurement

Standards:
- ALMA TM-438 Measurement of the Stiffness of Loudspeaker Driver Suspension Components
- EIA RS-438 (ANSI C83.116-1976)

Tonwel: Elasticity of Spider Measurement System based on EIA RS-438


Quasi-Static Measurement of $K_{ms}(x)$

Method:
- Sample the working range
- Generate DC displacement $x_{DC}$
- Measure associated state signals $F_{DC}$
- Calculate instantaneous parameters
- Repeat the measurement at other working points

Results depend on measurement time
Hysteresis has no importance for audio band

$K_{ms}(x) = \frac{F_{DC}}{x_{DC}}$

→ Dynamic measurement preferred
Practical Realization of Quasi-Static Method

Ringlstetter Harman Becker Straubing, Germany

Quasi-Static non-linear Measurement of $K_{ms}(x)$

Tonwell:
Compliance of Loudspeaker
Spider and Cone Test System

Quasi-Static non-linear Measurement of $K_{ms}(x)$

Dr. Kurt Müller - R&D Tester

- used for the development of any kind of suspensions during early design of components.

Hysteresis curves are basically used for interpretation or evaluation.

- There are various opportunities to study the behaviour of suspension parts during their movement in a large range.
- It's an quasi static measurement and comparable with conventional tensile strength tests.
- All samples have to be fixed during measurement at the neck (or inner diameter) and pressed down at the OD with pneumatic clamping force.
- For analysis, the R&D-Tester has to be linked to a computer.

Weight Range: +/- 25 kg
Precision: +/- 0.1 mm, +/- 1 mN
Max Excursion: +/- 100 mm

Dynamic, Linear Suspension Measurement

Standards:
- IEC 62459/Ed.1

Figure 2 – Measurement of lowest cone resonance $f_0$

http://www.tonwel.com/b-en/03.php

Tonwel:
The Test System for the Resonance Frequency of Loudspeaker Cones
Linear Suspension Test (LST)
Fast quality control of suspension parts and passive radiators

- Objective: check driver and system parts before assembly (spiders, cones, domes, passive radiators) → early quality control
- Software and optional hardware set for the QC System (Basic & Standard)
- Fast and easy mounting of DUT → time efficient testing
- Fits a wide variety of DUT sizes

Mounting Suspension Parts

![Diagram of Linear Suspension Test (LST) and mounting suspension parts](image-url)
Processing of displacement response

Simple processing, only based on displacement amplitude response (laser signal)

**Assumptions**
- Constant driving force
- Constant moving mass \( m \) (dominated by inner clamping)

\[
Q = \frac{1}{\Delta F} = \frac{f_r}{f_2 - f_1}
\]

| Resonance Frequency | \( f_r = \frac{1}{2\pi \sqrt{\frac{k_e f}{m}}} \leq \arg \max \{|X(f)|\} \)
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Stiffness (small signal)</td>
<td></td>
</tr>
</tbody>
</table>
\[
k_0 \leq k_m(x_{\text{peak}}, x_d) = m(2\pi f_r)^2 \quad \text{for} \quad x_{\text{peak}}, x_d \to 0
\]

**Operator View**

Displacement Response

Test Verdicts

Temperature/Humidity

Detailed Result Table
Testing in Operator Mode

• Passive system element – difficult to test before loudspeaker assembly
• Most important parameter: moving mass
• Resonance frequency result of both suspension stiffness and moving mass
• Added mass method may be used to determine moving mass – inappropriate for QC

• Solution: monitoring relative deviation to „golden” reference unit

Testing Passive Radiators
**Monitoring Mass & Stiffness Deviation**

using displacement response only

\[
\frac{M'_n(f)}{M_n(f)} = \left| \frac{f^2}{f_0^2} \right| \frac{|x(f)|}{\text{abs}(|x(f)|)} \left( 1 - \frac{f}{f_0} + j \frac{f}{f_0} \frac{1}{Q} \right)
\]

PASS

<table>
<thead>
<tr>
<th>Test: LST Passive Radiator</th>
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<tr>
<td>Q factor</td>
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<tr>
<td>Mass deviation ( \Delta m )</td>
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<tr>
<td>Amplitude limit ( \Delta m )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
<th>Min. Limit</th>
<th>Max. Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q factor</td>
<td>3.2</td>
<td>2.9</td>
<td>3.6</td>
</tr>
<tr>
<td>Mass deviation ( \Delta m )</td>
<td>1.5</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Amplitude limit ( \Delta m )</td>
<td>0.6</td>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Note: Signal characteristics (LST)

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**Hardware Platforms**

**LST Bench** with internal laser (QC System)
- Linear Suspension Test

**MSPM Bench (RnD System)**
- MSMP Pro for linear and nonlinear testing
- MSMP Lite for linear testing

**SPM Bench (RnD System)**
- SPM Pro for linear and nonlinear testing
- SPM Lite for linear testing

**LST Bench with external laser (RnD System)**
- SPM Lite for linear testing
Non-linear Suspension Part Measurement

Abstract

Suspension Part Measurement (SPM)

http://www.klippel.de/our-products/rd-system/modules/suspension-part-measurement.html

Suspension Part Measurement features a dynamic identification of the small and large signal spider parameters (Force deflection curve, Stiffness curve, resonance, damping factor...) using an audio like ac-stimulus. This measurement can also be performed as an accelerated life test for separating fatigue from break-in and assessing the long term stability of the suspension.
Problem: Suspension at Low Frequencies

Different approaches to describe this effect:

\[ C(f) = C_0 \left( 1 - \lambda \log_{10} \left( \frac{f}{f_0} \right) \right) \]

Kundsen and Jensen, JAES 1993

\[ C(f) = C_0 \left( 1 - \lambda \log_{10} \left( \frac{f}{f_0} \right) \right) \left( 1 + \left( \frac{f}{f_{\text{min}}} \right)^2 \right) \]

Ritter, 2010

Compliance \( C_{\text{md}}(f) \) and resistance \( R_{\text{md}}(f) \) increases to lower frequencies below resonance \( f \ll f_0 \)

Static and Quasi-Static Measurement of \( K_{\text{ms}}(x) \)

Disadvantages:

- Stiffness measured at very low frequencies is much smaller than the stiffness found in the audio band
- Static displacement of the suspension affects the rest position
- Creep, relaxation, hystereses only occur at low frequencies
- Time consuming
**Full dynamic Measurement**

**Method:**

- Excite speaker with large AC-signal
- Measure a state variables $X_{AC}(t)$ and $F_{AC}(t)$
- Estimate $K_{MS}(x)$ to describe relationship between input $F_{AC}$ and output $X_{AC}$

$$K_{MS}(x) = \frac{F}{X}$$

---

**How to measure the Large Signal Parameters of Suspension Parts**

**Example: SPM System**

Advantages:

- dynamical method
- vertical operation
- robust, easy to use
- inexpensive

Set up according to IEC Standard 62459
Dynamic Measurement of the Mechanical Stiffness of Suspension Parts

Need for a Dynamic Measurement of Suspension Parts

→ significant variation of $K_{ms}(x=0)$ at the rest position $x=0$
→ small variation of $K_{ms}(x_{peak})$ at the maximal displacement $X_{peak}$
Variation of Suspension Stiffness $K(t)$ versus Measurement Time $t$

Performing a power test with pink noise of constant amplitude

Stiffness ratio after 1 h and 100 h power testing

$$R_{100h} = \frac{K(t=100\text{h})}{K(t=1\text{h})}$$

Disadvantages of:
- measurement results depend on the properties of the stimulus
- assumes constant excitation during power test
- can not be transferred to other stimuli
- neglects the slope of the stiffness variation

Idea:
Replacing time $t$ by a quantity describing the dosage of the mechanical load

Performing a power test with pink noise of constant amplitude

Accumulated Load Model

Measurement Condition:
same stimulus of constant amplitude during the power test

Stiffness of loudspeaker suspension versus accumulated work $W$

$$K(W) = K(W=0) - \Delta K(W)$$

$$\Delta K(W) = \sum_{i=1}^{N} C_i \left(1 - e^{-\frac{W}{W_i}}\right)$$

$N=2$ sufficient for most cases
Example: Poor Spider
Suffering from Long-Term Fatigue

- 50% of initial stiffness decay during life-cycle
- Only 50% of stiffness decay during break in
- High fatigue ratio - permanent but slow decay of the stiffness

Measurement Technology
Suspension Parts

apparent mechanical power
\[ P(t) = K(x) \frac{dx(t)}{dt} \]

Measurement of spiders, surrounds and passive radiators using a laser sensor and system identification
How to measure Micro Suspension Parts

**Preparation**
- Diaphragm glued or clamped in panel
- Diameter < 40mm

**Measurement**
- Passive excitation by pressure chamber below
- Laser measurement of displacement
- Microphone measurement of pressure

---

Linear Parameter Identification

**Measurement Signal**
- Sweep Signal
- Measurement of Transfer function
  \[ H(f) = \frac{X(f)}{P(f)} \]

**Calculation of Results**
- Mass perturbation with known mass
- Fitting modelled Transfer function to the measurement
  \[ H(f) = \frac{X}{P} = \frac{S_{0}/K}{1 + \frac{s}{R} + \frac{s^2}{C} + \frac{s^3}{m}} \]

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f_{\text{res}} )</td>
<td>896.2</td>
<td>Hz</td>
<td>Resonance Frequency</td>
</tr>
<tr>
<td>Q</td>
<td>3.756</td>
<td>–</td>
<td>Quality Factor</td>
</tr>
<tr>
<td>m</td>
<td>.105</td>
<td>g</td>
<td>Moving Mass</td>
</tr>
<tr>
<td>C</td>
<td>1.787</td>
<td>mm/N</td>
<td>Mechanical Complance</td>
</tr>
<tr>
<td>K</td>
<td>550</td>
<td>N/mm</td>
<td>Stiffness</td>
</tr>
<tr>
<td>R</td>
<td>.025</td>
<td>kg/s</td>
<td>Mechanical Resistance</td>
</tr>
</tbody>
</table>
Nonlinear Parameter Identification

**Measurement Signal**
- Low frequency Multitone signal
- Measurement of displacement
- Generated distortion results from nonlinear K(x)

**Calculation of Results**
- Model Force $F_{DUT}$ from the measured Displacement
- Minimize error between measured Force $(P \times S_D)$ and modelled Force
- Verification: Fitting Error <20%

$$F_{DUT} = P \times S_D = K(x) \times x + R \times x' + m \times x''$$

Comparing LSI vs. MSPM Results

Small differences possible
- Different time and temperature conditions
  - LSI: 5-10min
  - MSPM: 2-5s
- Different application of force
  - LSI: at voice coil position
  - MSPM: distributed over membrane area
Application

MSPM in Operation
Laser positioning by clamping MSPM bench at

LST or SPM Bench
Pro Driver Stand

SCN - Scanning Vibrometer
Challenges in Suspension Design

Critical examples are flat and slim transducers used over the full audio band (headphone, micro-speaker, TV-Speaker)

**PROBLEMS:**
1. Suspension centers the coil in the gap → sufficient clearance to avoid coil rubbing
2. Suspension determines the rest position of the coil in the gap → coil offset
3. No spider is used or distance between spider and surround is small → Rocking mode → coil rubbing
4. Surround contributes significantly to the effective radiation area $S_d$ → acoustical output
5. Suspension determines the peak displacement $x_{\text{max}}$, required for bass reproduction → large geometry → significant material deformation
6. Air pressure in the enclosure affect the stiffness of the suspension
7. Displacement (bass) affects modal vibration of the surround → strong intermodulation

Objectives of the Suspension

- **Suppressing tilting and rocking**
- **Defining coil's rest position**
- **Solved by nonlinear control with active stabilization**

**Conclusion:**
- Decreasing stiffness in the direction of intended coil movement!
- Increasing stiffness in all other directions!
Suspension Characteristics
for describing optimal properties in the particular application

Compliance $X_c(x=0)$ at rest position which is important for resonance frequency $f_s$

Note: Symmetrical nonlinearities of the suspension are usually beneficial

What is a Bad Suspension Part?
Properties which are not acceptable – k.o. criteria

Stiffness asymmetry $A_k$ (> 20 %) measured at high excursion

Significant loss (> 30 %) of stiffness $K(x=0,t)$ versus time after break-in

Significant dc displacement generated dynamically by stiffness asymmetry
Bad Spider
Suffering from Long-Term Fatigue

- 50% of initial stiffness decay during life-cycle
- Only 50% of stiffness decay during break in
- High fatigue ratio - permanent but slow decay of the stiffness

Spider - Weakest Part of the Loudspeaker

Tupperware® gives lifetime warranty

Research activity:
Replacement of impregnated fabric by new materials
How to Specify the Suspension Part

**R&D Measurement (e.g. SPM module)**
- Vertical operation
- Clamping similar to final application
- Dynamic measurements
- Small and large signal domain
- Long-term Measurement (ageing, fatigue)

**End-of-line Testing (QC System)**
- Horizontal operation
- Minimal clamping
- Dynamical Measurement
- Small Signal Domain
- Fast measurement (< 1s)

**Important Characteristics**
- Dynamic stiffness $K(x=0)$ measured at small amplitudes
- Loss of stiffness $K(x=0,t)$ versus time $t$
- Stiffness asymmetry $A_k$ measured at high excursion
- DC-displacement generated dynamically
- Maximal peak displacement $X_{cg}$ giving decay of compliance to 75 %

More details in IEC Standard 62458 and 62459

Material Parameter Measurement

2014
Stefan Irrgang
Klippel GmbH
Abstract

- **Temperature Monitoring (Power Test)**
- [http://www.klippel.de/our-products/rd-system/modules/power-testing.html](http://www.klippel.de/our-products/rd-system/modules/power-testing.html)
- A fast and reliable measurement of the instantaneous voice coil temperature of woofer, tweeter, micro-speakers and active systems can be realized by using a small ac pilot tone added to the stimulus. This technique reveals the thermal dynamics (heating and cooling process) of voice coils with a small or large thermal capacity.

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**Measurement of Young’s E-modulus and loss factor of material samples**

**Method:**
- simple beam technique (Standard ASTM E 756-93)
- acoustical excitation (applicable to thin foils)

**Requirements:**
- Planar (flat) material samples
- Isotropic material
- Constant thickness and density

**Application:**
- Communication between driver and softpart manufacturer
- Checking production consistency
- Not applicable to FEM at high frequency

**Modal loss factor**

\[
\eta = \frac{\Delta f}{f_0}
\]

**Youngs E-modulus**

\[
E = 38.29 \frac{m b^3 h^2}{l^2}
\]

- \(m\) ... mass
- \(b\) ... width
- \(d\) ... height
- \(l\) ... length
Operation of the MPM Measurement hardware

Parameter Measurement of Loudspeaker Materials

Measurement of Youngs modulus and loss factor by fitting FEM to Scanner

Problem:
- FEM requires accurate material material parameters for simulation
- Compound materials are used in loudspeakers
- Influence of glue and processing (variation of thickness and density)

⇒ Table or standard values for materials are not applicable

⇒ Material parameters are highly frequency dependent (factor 10 over audio band)

⇒ The first prototype of the transducer is the best test measurement setup for exciting the material and measurement the mechanical vibration at high frequencies.
Identification Process

Iterative Parameter Identification

Optimal 'fitting' of the material parameters by minimizing the error between FEM and SCANNER

Residual modeling error caused by:
- Geometry (cone thickness)
- Density variation
Results

![E-Modulus Graph](image)

Scanning Vibrometer System
Abstract

Scanning Vibrometer System

The SCN Vibrometer measures the vibration and geometry of radiators, enclosures and mechanical structures used in loudspeakers, micro-speakers, headphones and other electro-acoustical or electro-mechanical transducers. The SCN Analysis Software performs visualization, animation and a modal analysis of the mechanical vibration using the scanned data which is provided by the vibrometer.

More Comprehensive Assessment

Motor

F

Voice coil

V

Vibration

X(r)

Cone’s surface

Radiation

F(r)

soundfield

near field

far field

Electrical Measurement

Impedance

Z_e(f)=U(f)/I(f)

Electrical

Lumped Parameters

Mechanical Measurement

H_v(f)=X(f)/U(f)

mechanical

Cone Vibration + Geometry

Acoustical Measurement

Far Field SPL Response

mechanical

Distributed Parameters
Cone Scanning Techniques

- Amplitude
- Amplitude + phase
- Amplitude + phase + geometry

Doppler Interferometry
(Polytech, 1995)

Triangulation Laser Scanner
(Klippel, 2007)

Olson, 1950
Frankort 1978

Velocity distribution on the cone

Intensity

Features:
- measures reflected laser light
- provides displacement
- Also black, transparent surface
- 0 Hz ... 25 kHz (dc component !!!)
- robust

PRO
- cost effective alternative to the Doppler Interferometry
- Accurate measurement of cone geometry
- dc component generated by driver nonlinearities

Cons
- Short working distance
- Needs robotics for scanning
Measurement of Cone Displacement ?!

Transfer function between electrical input voltage and displacement of a point on the diaphragm

How to measure displacement at 20 kHz?

Amplitude of displacement is almost constant (less than a micro meter)
Automatic Scanning Process

Mechanical scanning system with one rotational (φ) and two linear actuators (r, z)

- Special control software
- Secure scanning of unknown driver geometry
Resolution of the Scanning Grid

- Profile Scan (27 points)
  - Assuming axial-symmetrical vibration
- Sₜ Scan (100 points)
  - Good for measurement of effective radiation area and other lumped parameters
- Explore Scan (226 points)
  - Good for vibration analysis and sound pressure prediction of round speakers
- Rectangular Scan (2000 points)
  - Good for TV and microspeakers
- Detailed Scan (2900 points)
  - Good for searching for irregularities

Scanning Time:
- 8 min
- 1 hour
- 8 hours

Visualization of Vibration Data

- 3D Animation
- Cross-sectional Cut
- Phase Distribution
- Amplitude Distribution
Sound-Pressure-Related Decomposition

\[ \mathbf{v}(\mathbf{r}) = \mathbf{v}_{\text{in}}(\mathbf{r}) + \mathbf{v}_{\text{red}}(\mathbf{r}) + \mathbf{v}_{\text{quad}}(\mathbf{r}) \]

generates sound \quad reduces sound \quad no sound

Three Important Responses

Example: woofer

Maximal possible sound pressure output
Acoustical cancellation
On-axis
Directivity
Index
Power
Practical Examples
discussed in Journal AES 2008

Smooth On-axis SPL Response?

Woofer A with paper cone

Woofer B with magnesium cone

Woofer C with flat radiator

Klippel, Sound Quality of Audio Systems, Part 7: Measurement of Nonlinear Parameters, 83

Klippel, Sound Quality of Audio Systems, Part 7: Measurement of Nonlinear Parameters, 84
Sufficient Cone Vibration?

Woofer A with paper cone:
→ low Q factor of cone resonances

Woofer B with magnesium cone:
→ natural modes cause high peaks in SPL

Woofer C with flat radiator
→ dips are not visible in AAL
→ AAL cause peak at 0.8 kHz

What Causes Excessive Peaks?

• low modal density → reduce bending stiffness (cone thickness)
• low loss factor → apply damping
• longitudinal mode → increase longitudinal stiffness
Sufficient Damping of the Material?

Woofer C with flat radiator

Read 3dB bandwidth in AAL!

\[ \eta_i(f_1) = \frac{f_2 - f_1}{f_1} = \frac{80}{840} \approx 0.1 \rightarrow \text{Increase loss factor of material} \]

Where to apply additional damping?

Woofer C with flat radiator

Find places of high deformation!

View the shape of the modes!
Where to apply additional damping?

Woofe B Magnesium cone

Rubber surround has sufficient losses

Cone requires damping

Effective Radiation Area $S_D$

Definition

The effective radiation area $S_D$ is an important lumped parameter describing the surface of a rigid piston moving with the mean value of the voice coil velocity $v_{coil}$ and generating the same volume velocity $q$ as the radiator’s surface. The integration of the scanned velocity can cope with rocking modes and other asymmetrical vibration profiles.
Effective Radiation Area

Method:
1. Measurement of vibration and radiators' geometry
2. Integration over surface and voice coil position
3. Calculation of effective radiation area $S_D(\omega)$
4. Reading $S_D(\omega_s)$ at fundamental frequency $\omega_s$

$$S_D(\omega) = \sum \frac{\alpha(\omega, r_x)}{S_{rad}(\omega)}$$

Problems:
- Surface is covered by grill (surface is not visible for laser)

Benefits

- Measurement of geometry and mechanical vibration
- Visualization of vibration behavior
- Shows contribution to sound pressure output
- Directivity pattern
- Accurate $S_d$ calculation
- Analysis of actively radiating cone regions
Root cause analysis of Rocking modes

Scanning Vibrometer can make Rocking Modes visible. But it gives no clue on the root cause of the Rocking Mode.
Imbalances?

PROBLEMS:
- Mechanical limit due to rub&buzz
- Reduction of the acoustic output
- Can be highly excited at large amplitudes
- Asymmetric radiation pattern

Root Causes

Where are the asymmetries and Inbalances located?

Example:

Dominant Stiffness Asymmetry is causing rocking mode
For more details on RMA, see separate presentation on ALMA 2016