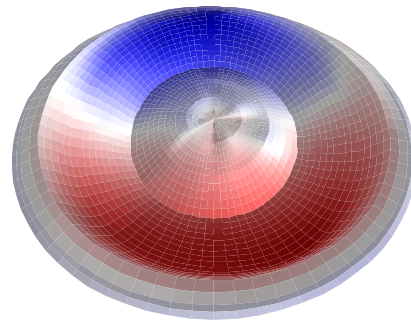


## FEATURES

- Identifies dominant root cause automatically
- Distinguishes mass, stiffness and BI problems
- Locates imbalances on the diaphragm
- Clear view on severity and excitation
- Based on fast scanner measurement

## BENEFITS

- Cope with voice-coil rubbing
- Counteract root causes of rocking
- Detect systematic production problems
- Optimize transducer stability



## DESCRIPTION:

The RMA module provides thorough analysis of rocking modes in loudspeaker transducer diaphragms. It automatically analyses the rigid-body tilting motion to

- Quantify the severity of a rocking mode problem
- Identify the contributions of mass, stiffness and BI imbalances in the excitation of rocking modes
- Indicate the position of the respective centers of imbalances on the diaphragm
- Provide the modal properties (damping, resonance frequency, gain) of each rocking resonator

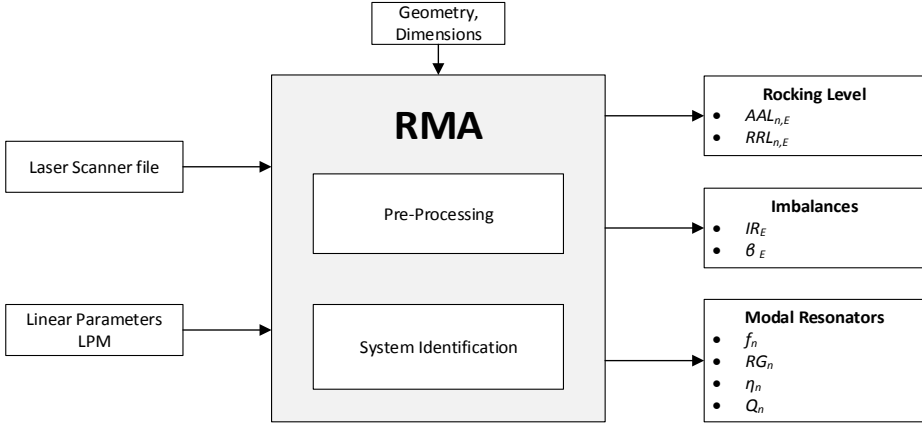
All important results are clearly summarized in a single result window. This information conforms the basis of the root cause analysis required for problem fixing and design improvements.

As input data, the module requires a quick (10-15 min) laser-scanner measurement with few points (50-100) and linear transducer parameters, ideally from Klippel's LPM. The vibrometric data can be directly used from the Klippel Laser Scanner System SCN or imported from finite element analysis via FEM2SCN or Polytec LDV devices via POLY2SCN.

**CONTENT**

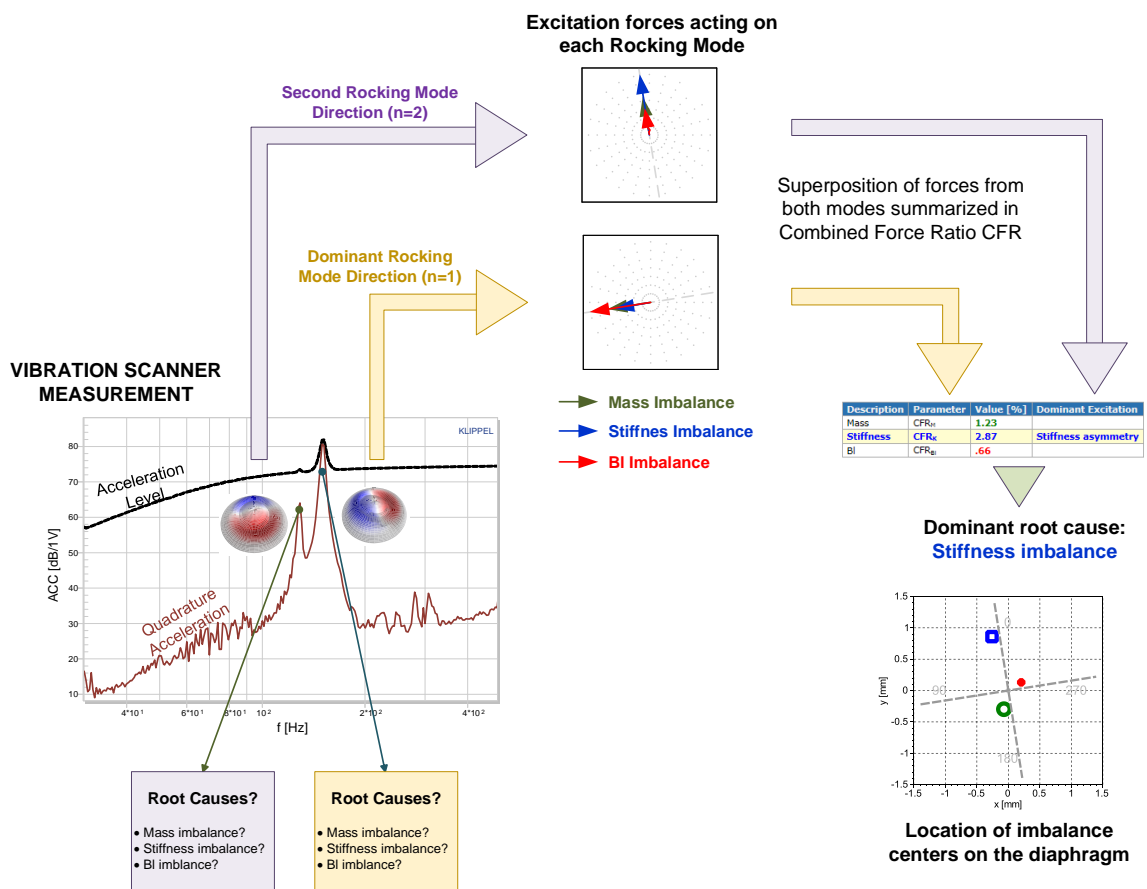
- 1 Principle - Overview ..... 3
- 2 Required components – How to get started ..... 6
- 3 RMA Root cause identification – How it works ..... 7
- 4 Setup parameters (input) ..... 10
- 5 Measurement results (output) ..... 11
- 6 Application examples / Use cases ..... 16

## 1 Principle - Overview

<p>Why this module exists</p>	<p>The market for portable devices including headphone and microspeaker transducers is constantly growing. The suspensions of such devices usually have to be constructed relatively simple due to restrictions of space and cost. Though the small diaphragm sizes may impose relatively large driving amplitudes, which in combination frequently triggers problems with rocking modes – undesired tilting motions of the diaphragm. These are usually highly undamped with large Q-factors, triggered already by tiny imbalances in the design.</p> <p>Since the amplitude of the tilting motion scales with voice-coil excursion and coil-gaps are narrow for efficiency reasons, the voice-coil will at a certain level hit the magnet, causing excessive impulsive distortion. The rubbing of the coil along the magnet wall also quickly breaks the coatings of the wires and causes the transducer to fail. This imposes strong limitations of usable output and lifetime of the product.</p> <p>With the RMA module, the root causes for these undesired effects can be analyzed thoroughly, allowing the designers and manufacturers to take the needed actions to improve the driver performance and quality with designs that are just right for the task.</p>
<p>Objective</p>	<p>The Rocking Mode Analysis (RMA) performs complete diagnostics of rocking modes.</p>  <pre> graph TD     G[Geometry, Dimensions] --&gt; RMA     LS[Laser Scanner file] --&gt; RMA     LPM[Linear Parameters LPM] --&gt; RMA     subgraph RMA [RMA]         direction TB         PP[Pre-Processing]         SI[System Identification]     end     RMA --&gt; RL[Rocking Level]     RMA --&gt; I[Imbalances]     RMA --&gt; MR[Modal Resonators]     RL --- RL_L["• AAL_{n,E}"]     RL --- RL_R["• RRL_{n,E}"]     I --- I_L["• IR_E"]     I --- I_R["• beta_E"]     MR --- MR_L["• f_n"]     MR --- MR_M["• RG_n"]     MR --- MR_D["• eta_n"]     MR --- MR_Q["• Q_n"]     </pre> <p>The user provides the RMA module with input data consisting of a linear parameter measurement, the distributed vibration scan data of the diaphragm and processing information (relevant analysis frequency range and diaphragm geometry). The rest of the process runs automatically.</p> <p>As a result, the module provides information about the energy levels of the rocking, alongside with magnitude of the unbalance forces caused by mass, stiffness and BI asymmetries. A complete set of modal parameters associated to the transfer resonators between these forces and the final tilting energy of the diaphragm (symptoms) is computed.</p>
<p>Symptoms and root causes of rocking modes</p>	<p>When an engineer detects rocking modes in laser-scanned loudspeaker data, the viewing software of the Klippel Scanning Vibrometer System SCN can be used to assess magnitudes and directions of the rocking. Raw-data from other sources of distributed vibration data like FEM (COMSOL, PAFEC) or Polytec LDV devices can be imported via our bridge tools FEM2SCN and POLY2SCN. A good approach is to check the <i>Quadrature component</i> and the <i>circular decomposition</i> provided by the SCN software.</p> <p>In the depicted example below, the quadrature component of the accumulated diaphragm acceleration level (AAL) clearly shows two strong peaks produced by the rocking modes of the analysed headphone. There are always two rocking modes whose main axes of tilting motion are oriented orthogonal to each other. These modes may though occur so close in frequency that they appear to be a single peak in the AAL plot.</p> <p>Inspecting the vibration shape in this manner allows assessment of how severe the problem is, but we do not yet have any information about the root causes for the rocking. This is where RMA comes into play. If all mechanical parameters (mass, stiffness, damping, electro-mechanical force factor) were distributed perfectly symmetrical over the diaphragm, no rocking would occur. Excitation only happens due to asymmetry (“imbalance”) of these parame-</p>


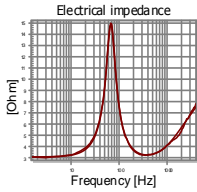
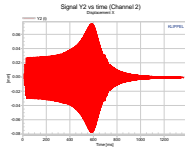
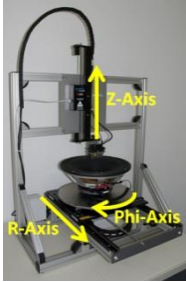
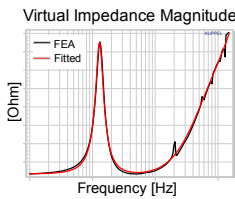
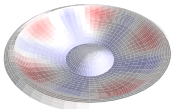
	<p>ters. If one side of the diaphragm is heavier than the other, then it is held back when the voicecoil moves the diaphragm in and out, creating asymmetrical forces. The same applies when the suspension is slightly stiffer on one side than on the other. Or when the motor does not push evenly on both sides. In all these cases, a tilting of the diaphragm (“rocking motion”) is induced. The imbalance causing it can be described by the offset of the center of gravity (or lumped stiffness or force factor respectively) relative to the geometrical center of the transducer. The Rocking Mode Analysis module RMA from Klippel determines these imbalances, indicates their location on the diaphragm and quantifies the resulting excitation strength.</p>
<p>Analysis of root causes for rocking modes with RMA</p>	<p>First RMA identifies the direction in which the vibration of the two modes is oriented and determines the excitation terms acting on them. After splitting up the excitation forces into the contributions from each identified root cause (imbalance of mass, stiffness or motor strength), both modes are summarized in the Combined Force Ratio CFR at the mean frequency between the two rocking resonances. This allows the engineer to assess the rocking problem globally, for both modes combined. The ranking of the CFR magnitude unveils which imbalance causes the strongest excitation of the rocking. This imbalance shall be addressed first in order to improve the transducer. To support this work, the RMA imbalance diagram indicates the position of the center of each imbalance on the diaphragm. The engineer will find guidance in which direction to search for the underlying mechanical issue, which might be caused either in the R&amp;D design itself or by imperfections in production.</p> <p>The analytical information described here is conveniently gathered in one single result window, providing a clear and simple overview over all relevant information.</p>

Workflow for analysis of rocking modes with Klippel RMA



Benefits, explained	<p>With RMA you can:</p> <ul style="list-style-type: none"><li>• <b>Reveal causes for Rub&amp;Buzz</b> By knowing the root cause of the coil rubbing, it is possible to perform design changes to reduce the imbalances. This helps to prevent QC rejected units.</li><li>• <b>Counteract the problem</b> The Combined Force Ratio magnitude helps to identify the dominant root cause. Using the information provided by the RMA imbalance diagram, its contribution can be counteracted.</li><li>• <b>Detect systematic errors</b> Several samples can be measured after production to detect systematic errors, by looking for some defect pattern (same root cause at same direction). After the problem is found, it can be solved by adjusting the production process.</li><li>• <b>Assess asymmetric acoustic loads</b> Performing parametric RMA measurements in vacuum and air, the effect of the acoustic load (cases, back-holes in headphones, etc.) on the transducer can be characterized to check for possible asymmetries or critical excitation conditions.</li><li>• <b>Optimize loudspeaker transducer stability</b> RMA measurements of different prototypes or FE simulations under different conditions can quantify the effect of parametric design changes on resonance frequencies and damping factors of the modal resonators.</li><li>• <b>Detect possible problems at high amplitudes</b> Some drivers using robust suspension mechanisms against rocking modes can have resonator characteristics with very low damping. If the stiffness or motor imbalances appear at high amplitudes, the undamped resonator can boost the rocking excitation terms producing substantial tilting, which in terms can cause rub&amp;buzz. RMA provides modal information to identify such cases.</li></ul>
------------------------	--

## 2 Required components – How to get started

<b>2.1 RMA analysis (minimum requirement, measurements externally provided)</b>		Spec#
<b>Klippel dB-Lab Software</b>	Version requirement > 210.270	
<b>RMA Software</b>	Rocking Mode Analysis software module for Klippel dB-Lab	S49
<b>SCN Scanning Vibrometer Analysis Software</b>	Analysis software for vibrometric laser data	C5 (2510-010)
<b>2.2 Additional components for self-performed measurements</b>		Spec#
<b>Measurement device</b>		Klippel Analyzer 3 (alternatively Distortion Analyzer 2) is the hardware platform for the measurement modules performing the generation, acquisition and digital signal processing in real time.
<b>LPM – Module</b>		Module to identify the electrical and mechanical parameters of electro-dynamical transducers by measuring the voltage and current at the transducer terminals.
<b>TRF</b>		The Transfer function (TRF) is a dedicated PC software module for measurement of the transfer behavior of a loudspeaker transducer.
<b>Scanning Vibrometer Hardware (SCN)</b>		The Scanning Vibrometer (SCN) performs a non-contact measurement of the mechanical vibration and the geometry data of cones, diaphragms, panels and enclosures.
<b>2.3 Additional alternative ways to gather SCN/LPM data</b>		Spec#
<b>FEM2SCN Module</b>		Module to identify the electrical and mechanical parameters of electro-dynamical transducers from finite element simulations in COMSOL and PAFEC and for importing surface vibration data to Klippel SCN format.
<b>POLY2SCN Module</b>		Module for importing surface vibration data to Klippel SCN format.

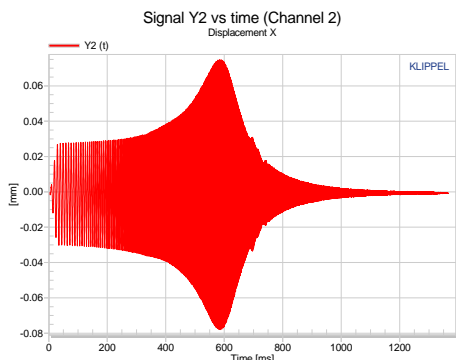
### 3 RMA Root cause identification – How it works

#### 3.1 Principle

Principle	Rocking mode analysis is applicable for electrodynamic drivers operated at low frequencies. In this context, only the suspension parts are deformed under the effect of applied forces and moments, while the center part of the diaphragm remains undeformed. This assumption is fulfilled by all kinds of electro-dynamical transducers composed by a rigid diaphragm, voice coil and former attached to slightly softer suspension parts. In the case of micro-speakers and headphones, the diaphragm and the surround are made of the same material and the diaphragm needs to be deformed to allow the rotational degree of freedom. In these special cases the “diaphragm” will be regarded as the part of the surface which is vibrating with only negligible deformation.
-----------	---

#### 3.2 Analysis Process

Vibrometer Scan

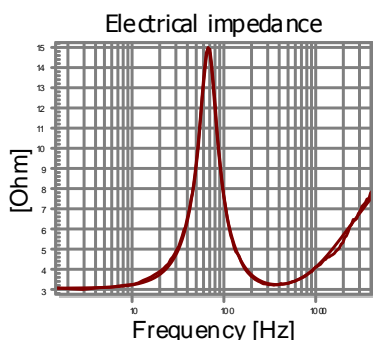


Fast scanner measurement (10-15 min) are suitable for RMA analysis.

The Rocking Mode Analysis is a post processing module applied to scanned vibration data. The difference between a normal “wide-band” scan and an optimized rocking mode scan is that the latter needs less measurement points (rigid body motion). The module requires sufficient excitation at low frequencies (moderate shaping: 5 dB are recommended).

1. **Spatial Grid:** There is no need for many scanning points for the Rocking Mode analysis, so the count can be reduced to achieve shorter scanning time. For a rough scan about **40-80 points** are suitable (10-15 minutes scan time). There should be **at least 3 radiuses in the rigidly oscillating part of the diaphragm (6 are recommended)** including the centre and an **angular resolution of 45 degrees**. For better analysis a manual grid scan will be convenient.
2. **TRF Setup:** RMA needs precise information in the lower frequency range. Therefore the following settings have to be considered.
  - The **frequency range** should conceal a frequency range from **at least one octave below fundamental piston resonance, up to 6 kHz**.
  - **Displacement:** Similar to the linear parameter measurement (LPM)
  - **Resolution:** 3 Hz or better
  - **Averages:** 4 or more, depending on the signal to noise ratio (optical access to diaphragm). More can be required for micro-speakers placed under screened cases
  - **Shaping:** 5 dB/oct, for sufficient voice coil displacement at lower frequencies and sufficient high-frequency S/N ratio
  - **Postprocessing Settings:** smoothing and log-reduce to: 40 points/oct.

LPM Measurement



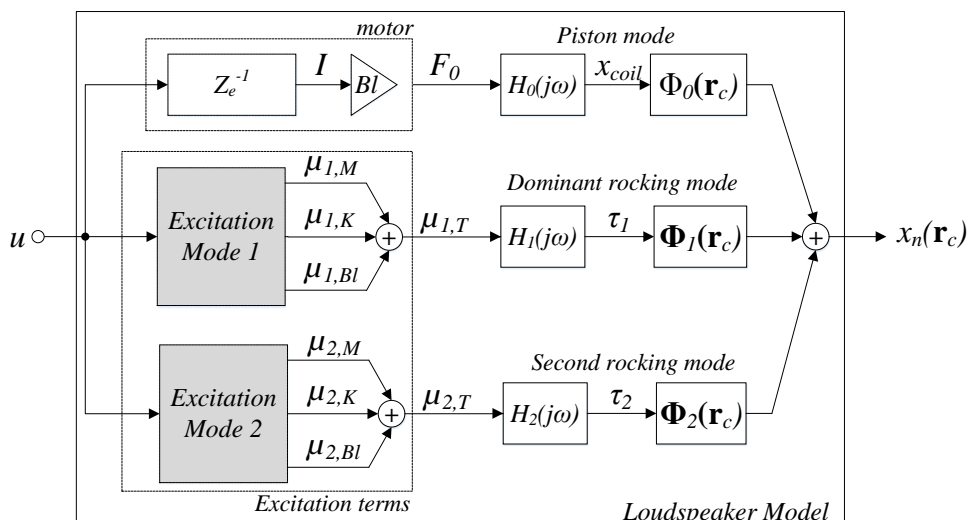
*Lumped parameter model*

For identification of the piston mode vibration of the loudspeaker transducer, the linear parameters are required.

The Thiele small parameters measured with the LPM module provide the **mechanical information** of the piston mode and the characteristics of the electrodynamic **motor**



Rocking Mode Analysis



**Modal Analysis**

At low frequencies, the complex vibration behavior of the loudspeaker transducer can be fully described by the superposition of three normal modes;

- *Piston mode*: Associated to the transversal displacement of the voice coil  $x_{coil}$ . Produced by the excitation of the modal resonator  $H_0(f)$  by the symmetric force  $F_0$  generated on the electrodynamic motor comprising the electrical impedance  $Z_e$  and the force factor  $Bl$  acting on the electrical current  $I$ . The mode shape  $\Phi_0(\mathbf{r}_c)$  transforms the lumped state variable  $x_{coil}$  into the distributed displacement contributing on the total vibration  $x_n$ .
- *Dominant rocking mode*: Associated to the rotation of the transducer diaphragm around a rotation axis (crossing the geometrical center of the driver)  $\tau_1$ . This tilting angle is generated by the excitation of the modal resonator  $H_1(f)$  by the total **dominant tilting moment**  $\mu_{1,T}$  composed by the excitation terms,  $\mu_{1,M}$ ,  $\mu_{1,K}$  and  $\mu_{1,BI}$  generated by mass, stiffness and  $Bl$  imbalances respectively. The mode shape  $\Phi_1(\mathbf{r}_c)$  transforms the lumped state variable  $\tau_1$  into the distributed displacement contribution of the mode in every point of the diaphragm, which is part of the total vibration  $x_n$ .
- *Second rocking mode*: Analogous to the dominant rocking mode, but usually less excited and for this reason of less importance. Denoted by subindex 2 in above diagram.

Knowing the excitation moments due to each of the root causes and the properties of the modal resonators form the basis of rocking modes diagnostics.

More information about the lumped parameter model can be found in

*W. Cardenas and W. Klippel, "Loudspeaker Rocking Modes (Part 1: Modeling), presented at the 139<sup>th</sup> Convention of the Audio Eng. Soc. 2015 October 29–November 1, New York, USA*

## 4 Setup parameters (input)

4.1 Input			
	Parameter Name	Parameter type	Description
Input Linear Transducer Parameters	LPM Operation	Link	Loudspeaker motor and mechanical transfer function determine the piston mode of the model
	or  Thiele-Small-Parameters from other source	or  Manual input (Poly2SCN license re-quired)	$R_e$ : Electrical Resistance $L_e$ : Voice coil Inductance $L_2$ : Para-Inductance of the voice coil $R_2$ : Electrical resistance due to eddy currents $Bl$ : Force factor at voice-coil rest position ( $Bl$ product) $M_{ms}$ : Mechanical mass $K_{ms}$ : Mechanical stiffness of the suspension $R_{ms}$ : Mechanical resistance $\lambda$ : Suspension creep factor
Input Distributed Vibration Data	Exported SCN file*.sce or SCN Datacontainer Operation	Link	Exported Klippel Scanner interpolated vibration/geometry data as ASCII file. See RMA Manual for details
Input Measurement Setup Metadata	Specification of device used for recording of distributed vibration data	Dropdown list, value	Klippel SCN or other (e. g. Polytec LDV) For other devices a function to compensate the amplifier gain factor in the signal generation chain is included (manual or automatic)
	Delay of measurement laser head	Dropdown list, value	Automatic or manual specification of laser delay [ms]
Input Values	Diaphragm shape	Dropdown list	Select only points measured on the rigid part of the diaphragm removing the surround central units in coaxial drivers: <ul style="list-style-type: none"> <li>- Circular</li> <li>- Rectangular</li> <li>- Ring (coaxial units)</li> </ul>
	Rigidly oscillating diaphragm dimension	Input Value	Part of the diaphragm that oscillates rigidly, without major deformation [e. g. measured in cross-section view of with Klippel SCN software] <ul style="list-style-type: none"> <li>- Rigidly oscillating radius (&gt;Circular)</li> <li>- Rigidly oscillating half-length and half-width (&gt;Rectangular)</li> <li>- Rigidly oscillating internal and external Radius: <math>r_i</math> and <math>r_e</math> (&gt;Ring)</li> </ul>
	Analysis frequency range	Input Value	Minimum and maximum frequency for analysis and option to exclude eventually corrupted frequency range.

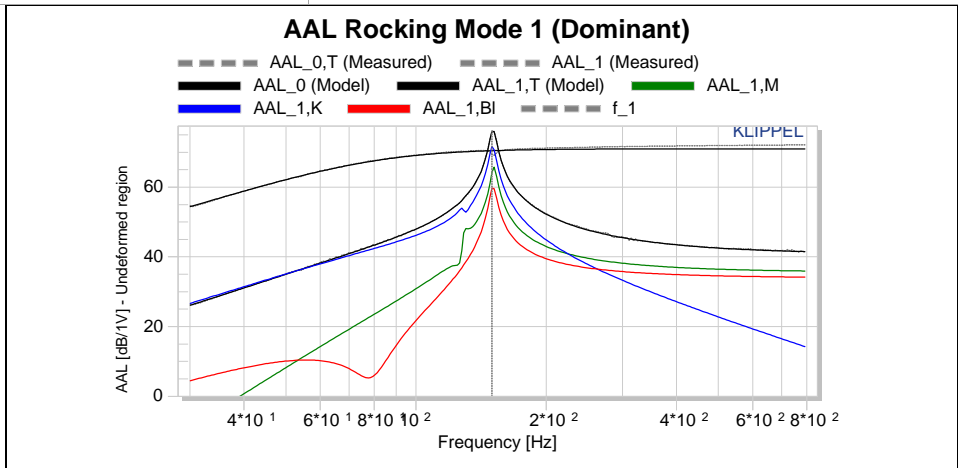
## 5 Measurement results (output)

### 5.1 Results

**Output Curves**

**Accumulated acceleration levels** of each rocking modes.  $AAL_{1,E}$  and  $AAL_{2,E}$ .

Frequency curves corresponding to the “mechanical energy” of the two modes. *To be displayed in dB-Lab window.*



Accumulated acceleration level of the rocking mode and each of the root cause contributions. A similar figure is generated for each mode separately and also as  $AAL_{Rocking,Total}$  for both modes combined.

How to interpret the AAL curves

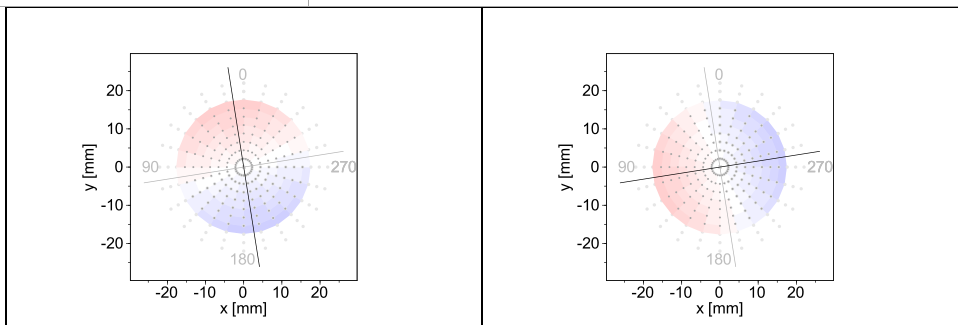
The Klippel magnitude AAL (see Klippel Application Notes AN-31 and AN-32) is used to describe the mechanical energy of the cone. The RMA module performs a modal decomposition, which allows separating the total vibration as the superposition of three normal modes; the piston and the two rocking modes.

A stable driver should have a very small value of the dominant rocking energy  $AAL_{1,T}$  compared to the energy of the piston mode  $AAL_0$  at the resonance frequency  $f_1$  of the resonator. Note that the total rocking energy  $AAL_{1,T}$  is composed by the superposition of the contribution associated to the mass, stiffness and *BI* root causes on that mode each of the causes present a distinct curve shape. In this context, the total rocking energy will present similar curve characteristics as the dominant root cause, in the example above the stiffness imbalance produces a  $AAL_{1,K}$  (blue) that coincides with the total rocking energy at low frequencies. This figure is complemented with the Relative Rocking Level RRL presented in a table. It determines the proportion between the rocking energy of each root cause and the piston mode energy.

**Output Diagrams**

**Mode-Shape Diagrams** for both rocking modes

Indicating the displacement pattern of each rocking mode, its main axis of vibration relative to coordinates of the Klippel Vibrometric Scanning System SCN and measurement points of the SCN grid.



Output Windows

**Summary**

Window summarizing the most important global analytic parameters of RMA. Sequentially, the following questions are treated:

- How severe is the problem? This is measured by comparing the rocking vibration to the desired piston mode > RRL
- Which root cause deserves most focus in order to improve the transducer? The combined excitation forces from both modes are compared to the piston mode. The ranking shows which root cause is dominant > CFR magnitude
- Where are the imbalances located? > Imbalance diagram

**RMA Result**

**Severity: Relative Rocking Levels RRL**

Description	Frequency [Hz]	Direction [°]	RRL [dB]
<b>Rocking mode 1 (Dominant) (Details)</b>	<b>293</b>	<b>1</b>	<b>-4.9</b>
Rocking mode 2 (Details)	323	91	-12.7
Piston mode 0	127	-	0 (= ref.)

**Rocking excitation: Combined Force Ratio CFR<sub>ε</sub>**

For  $f_m = 308$  Hz,  $d_{ref} = 15$  mm

Description	Parameter	Value [%]	Dominant Excitation
Mass	CFR <sub>M</sub>	.31	
Stiffness	CFR <sub>K</sub>	.18	
<b>BI</b>	<b>CFR<sub>BI</sub></b>	<b>.58</b>	<b>B-field Inhomogeneity</b>

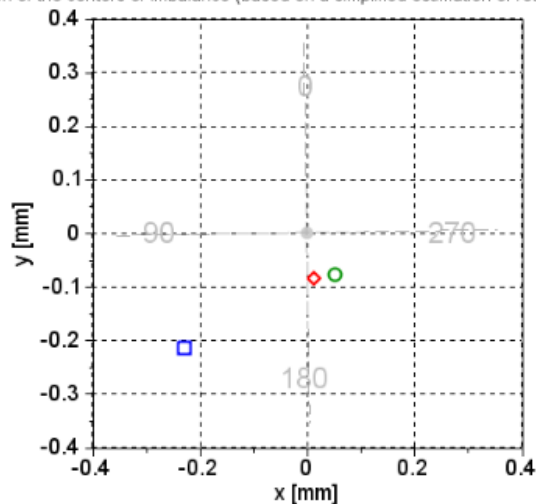
The contribution that induces the largest excitation force for rocking motion at  $f_m$  is most beneficial to improve ("dominant excitation").

**Root causes: Imbalances**

Offsets in the distributions of mass, stiffness and force factor from the geometrical center of the diaphragm.

Description	Parameter	Mark	Offset [mm]	Direction [°]
Center of Mass	$d_M$	○	.09	214
Center of Stiffness	$d_K$	□	.31	133
<b>Center of BI</b>	<b><math>d_{BI}</math></b>	◇	<b>.09</b>	<b>189</b>

Location of the centers of imbalance (based on a simplified estimation of rotational stiffness)



RMA result window for a headphone with dominant BI problem: Note that the dominant root-cause (the one responsible for the largest excitation) might be different from the one showing the largest imbalance. The result window clearly indicates this. Note that root causes without major contribution will be excluded from identification, so this window might show less than three.

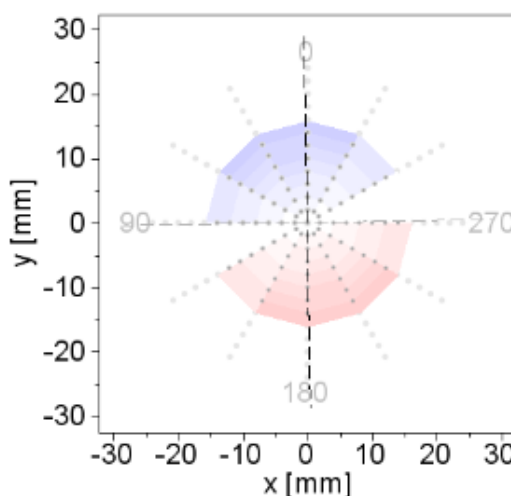
**Rocking Mode n**

(one window for each mode with analogous content)

Details about each rocking mode separately, similar to the window “RMA result” (see above). On top of the window the respective modeshape is shown along with the modal resonance frequency and the main direction of tilting. The vibration response from each root-cause is given below in the Relative Rocking Level table. Afterwards, the excitation of the mode is analysed (Modal Force Ratio) and the dominant excitation parameter marked in color. Finally, the parameters describing the modal resonator H are stated. They describe the amplification and damping of the mode (compare section 3.2).

**Rocking Mode 1 (Dominant)**

Resonance frequency  $f_1 = 293$  Hz, Orientation  $\alpha_1 = 1^\circ$



**Severity: Relative Rocking Level  $RRL_{1,E}$  > [Details](#)**

Description	Parameter	Value (dB)
<b>Total (measurement)</b>	<b><math>RRL_{1,T,meas}</math></b>	<b>-4.9</b>
Total (model)	$RRL_{1,T}$	-5.3
Mass	$RRL_{1,M}$	-9.1
Stiffness	$RRL_{1,K}$	-16.7
Bl	$RRL_{1,Bl}$	-3.4

**Rocking excitation: Modal Force Ratio  $MFR_1$**

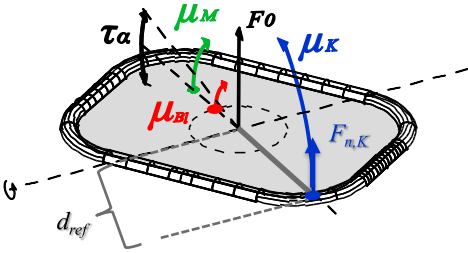
For  $d_{ref} = 15$  mm

Description	Parameter	Value [%]
Mass	$MFR_{1,M}$	.3
Stiffness	$MFR_{1,K}$	.12
<b>Bl</b>	<b><math>MFR_{1,Bl}</math></b>	<b>.57</b>

**Rocking Mode Parameters  $H_1$**

Description	Parameter	Value
Resonance Frequency [Hz]	$f_1$	293
Relative Modal Gain [dB]	$RG_1$	41.5
Modal Damping	$\eta_1$	.04
Modal Q-Factor	$Q_1$	13.4

Note that the MFR measure above only shows the parameter that contributes with the largest excitation for this mode alone. The overall strongest root cause for both modes combined (shown in the CFR table, see above) might be a different one.

<p><b>Output Parameters</b></p>	<p>Assessing rocking severity:</p> <ul style="list-style-type: none"> <li>• <math>AAL_{n,E}</math></li> <li>• <math>RRL_{n,E}</math></li> </ul>	<p>Vibration level AAL (Accumulated Acceleration Level as defined in IEC 60268-22) and Relative Rocking Level RRL of each rocking mode and root cause contribution</p> <p>n: Mode Number (1,2)</p> <p>E: Excitation caused by mass (M), stiffness (K) or (BL) imbalance.</p> <p><i>In dB-Lab, vibration level AAL is given as diagram over frequency and RRL in provided in table format</i></p>
	<p>Assessing excitation:</p> <ul style="list-style-type: none"> <li>• <math>MFR_E</math></li> <li>• <math>CFR_E</math></li> </ul>	<p>Ratio of tilting-excitation forces relative to the symmetric force of the voice coil. The forces are gathered by converting the tilting momentum <math>\mu_E</math> into a pair of forces at the reference distance <math>d_{ref}</math>. By convention this distance is identical to the rigidly oscillating part of the diaphragm as specified by the user in the input property page.</p>  <p><math>MFR_{n,E}</math>: Modal Force Ratio describes the magnitude of the asymmetric forces exciting a particular mode at respective modal resonance frequency, compared to the piston mode.</p> <p><math>CFR_E</math>: Combined Force Ratio describes the magnitude of the excitation produced by the three root causes, relative to the piston mode. This output is computed based on the superposition of the forces from both modes at the mean frequency between the rocking resonators.</p> <p><i>Results are given as tables in dB-Lab</i></p>
	<p>Assessing the root causes (imbalances):</p> <ul style="list-style-type: none"> <li>• <math>d_E</math></li> <li>• <math>\gamma_E</math></li> </ul>	<p>Offset in mm and direction in degrees of the center of mass, stiffness and <i>Bl</i> distributions, relative to the center of the vibration scan which shall coincide with the center of the diaphragm.</p> <hr/> <p><b>Please note:</b> The calculation of the offset distance <math>d_E</math> provided by RMA is based on a simplified estimation of rotational stiffness, which the values of <math>d_E</math> are directly proportional to. Since the geometry and parameters of the suspension design of the DUT are not known to RMA, this parameter can only be estimated roughly. Absolute values can be assessed when combining RMA with FEA tools capable of calculating exact rotational stiffnesses. The imbalance diagram can only show this simplified estimate of <math>d_E</math>.</p> <p>This restriction affects only <math>d_E</math> which might be scaled with a factor. The angles (direction) of the center of imbalance will still be correct.</p> <hr/> <p><i>Results are given in dB-Lab as imbalance diagram and table (see above in result window "RMA Result")</i></p>
	<p>Modal resonator parameters:</p> <ul style="list-style-type: none"> <li>• <math>f_n</math></li> <li>• <math>RG_n</math></li> <li>• <math>\eta_n</math></li> <li>• <math>Q_n</math></li> </ul>	<p>Describe the characteristics of the modal resonator, transfer path between the moments and the mechanical energy.</p> <p><math>f_n</math>: Modal resonance frequency</p> <p><math>RG_n</math>: Relative gain of the modal resonator at <math>f_n</math></p> <p><math>\eta_n</math>: Modal loss factor</p> <p><math>Q_n</math>: Quality factor of the modal resonator</p> <p><i>Provided in table format in dB-Lab</i></p>

**5.2 Result quality assessment**

**Output windows**

**Error/Warnings**

Output window summarizing the quality of the identification in three sections, checking the following:

- Is the specified section of the diaphragm oscillating without major deformation? This is required for the modal analysis to work flawlessly. (Rocking modes are rigid-body modes)
- Is the behavior of the piston mode in the linear parameter measurement congruent to the distributed laser vibration scan? This is important to assess whether the lumped parameters passed by LPM are useful for further processing by RMA.
- Did the rocking mode fitting algorithm of RMA come to a meaningful result? If this is not the case, then results shall not be trusted.

Along with these quality assessment measures, which are summarized by a color-coded grading, guidance is given how to improve the fitting quality in case of problems.

**Errors/Warnings/Info**

Warnings & Information	
<b>Warning</b>	<p><b>LPM/SCN Piston Mode Fitting Error is large</b> To improve this, try or check the following:</p> <ul style="list-style-type: none"> <li>• Make sure that the selected LPM operation belongs to the scanned driver</li> <li>• Make sure that LPM is measured in the centerpoint of the diaphragm and that this is exactly the same point as the center of your SCN measurement (preferably measure LPM directly on the SCN turntable, without moving DUT)</li> <li>• Check TRF settings in SCN setup to ensure that measurement displacement at transducer resonance frequency is roughly identical to displacement of LPM measurement.</li> <li>• Check dimensions of diaphragm geometry that shall be included in the analysis in RMA setup.</li> <li>• Check fitting quality of the linked LPM operation</li> </ul>
<b>Information</b>	LPM data source: Measured LPM
<b>Information</b>	<p><b>Full set of parameters (mass, stiffness and BI) has been identified.</b> BI unique symptom found on rocking mode: H1 [Yes] and H2 [Yes]</p>

**Result Quality Assessment**

RMA performs the following self-tests to assess how reliable the results are. The overall reliability is determined by the lowest ranking.

Description	Parameter	Value (%)	Grading
<b>Spatial SCN Plate-Fitting Error</b>	$E_{SCN}$	7	<b>Good</b>
<b>LPM/SCN Piston Mode Fitting Error</b>	$E_{LPM}$	31	<b>Poor</b>
<b>Rocking-Mode Modeling Error</b>	$E_{RMA,Model}$	0	<b>Good</b>

## 6 Limitations of the RMA module

RMA is designed to analyze a single passive transducer in free air. Its main focus is modelling of headphone and microspeaker transducers. Accuracy for woofers will be reduced.

Modelled physical effects include asymmetries of mass, stiffness and electrodynamic force factor (Bl-product). The algorithm can only work correctly if its internal model of physics corresponds to physical reality. This excludes the following cases

- Asymmetry of viscoelastic damping. Such is often found on transducers using ferrofluids, which causes the RMA to fail. Anyhow, ferrofluids themselves do suppress rocking-modes.
- Transducers in which rocking-modes strongly interfere with other flexural modes of the diaphragm. This is often the case in large woofers - on the other hand the rocking mode problem is usually small in such devices.
- Assembled loudspeaker systems. We strongly recommend to measure the transducer alone. Especially resonance effects of connected acoustical elements that are active inside the analysis frequency range (e. g. acoustical ports, passive radiators (“drones”), back-cavity-resonances, other transducers breathing in the same rear volume) change the frequency response of the transducer under test and will cause faulty results in the modelling.

Exceptions are situations in which external resonant elements are not active inside the analysis frequency range of RMA. Consequently, they can be modelled as lumped together with the mechanical properties of the transducer, which conserves validity of the RMA models:

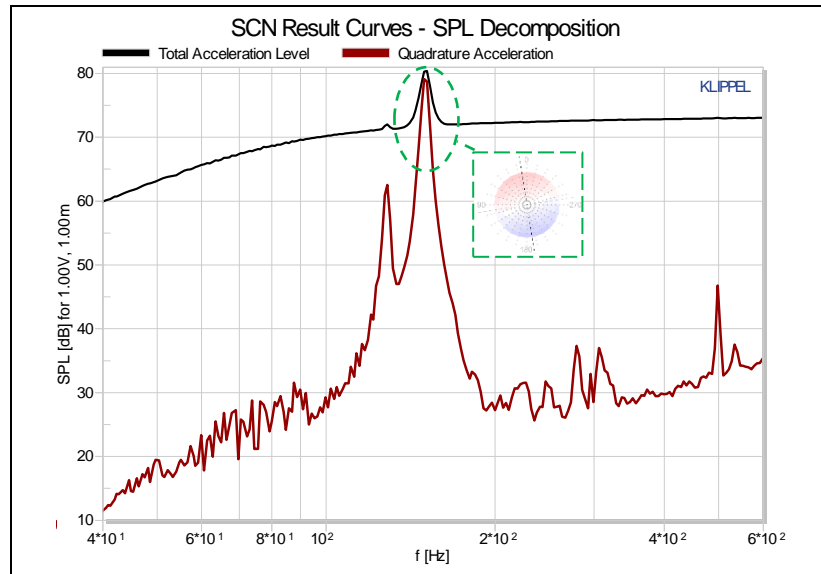
- Closed box systems without modal cavity-resonances interfering with the RMA analysis frequency range
- Microspeaker ports resonating at much higher frequencies than the RMA analysis frequency range.



## 7 Application examples / Use cases

### 7.1 Headphone transducer with severe stiffness inhomogeneity problem

A measured headphone presents a critical rocking mode at 151 Hz. Its main symptom can be detected as a sharp peak in the quadrature component of the SPL related decomposition of the AAL in the Klippel scanner analysis software:



Symptom of the rocking: Large peak in the AAL quadrature component

As the quadrature component provides valuable information about the direction and the energy of the rocking mode, it does not inform about the causes of this undesired behaviour. The problem can be only be solved by means of a root cause analysis (diagnostics) based on RMA measurement.

The RMA module gathers the most important information in the window “RMA Result”. The user is guided through the process step by step. In the first step, the information that we already have read out by hand from the SCN view above is summarized. The table in the section “Severity: Relative Rocking Levels” informs us, that the dominant mode is vibrating 9 dB stronger than the piston mode (which is just what we see in the AAL plot above), which confirms that we indeed have a major problem. We are also informed about direction and resonance frequency of the modes. The piston mode is given as a reference.

**Severity: Relative Rocking Levels RRL**

Description	Frequency [Hz]	Direction [°]	RRL [dB]
<b>Rocking mode 1 (Dominant) (Details)</b>	<b>151</b>	<b>9</b>	<b>8.9</b>
Rocking mode 2 (Details)	129	99	-9.5
Piston mode 0	79	-	0 (= ref.)

Step 1: Overview of the symptoms of the rocking

Yet RMA has not given us a lot of new knowledge, but this changes drastically with step 2: Here the root causes and the modal resonator characteristics required to describe the rocking of the headphone are analyzed. In the current example RMA indicates that the problem is caused by a major stiffness imbalance. This result is shown in the respective section “excitation” of the result window “Summary”.

**Rocking excitation: Combined Force Ratio CFR<sub>c</sub>**

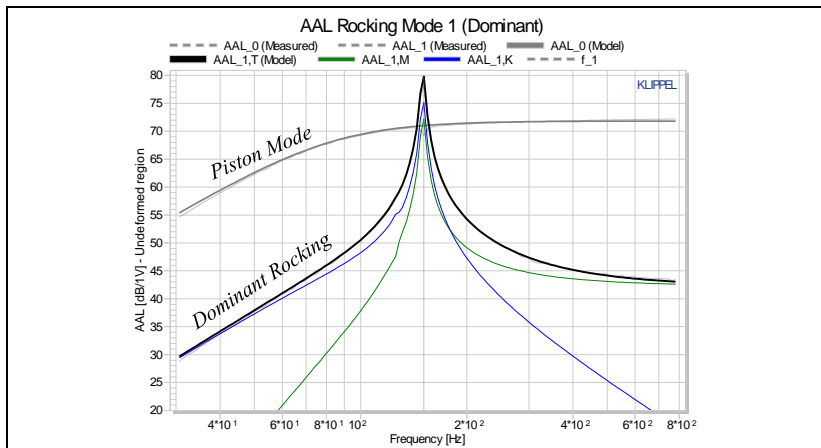
For  $f_m = 139 \text{ Hz}$ ,  $d_{ref} = 16 \text{ mm}$

Description	Parameter	Value [%]	Dominant Excitation
Mass	CFR <sub>M</sub>	1.96	
Stiffness	CFR <sub>K</sub>	2.8	Stiffness asymmetry
Bl	CFR <sub>Bl</sub>	- no indication -	

The contribution that induces the largest excitation force for rocking motion at  $f_m$  is most beneficial to improve ("dominant excitation").

Step 2: The excitation table for the combined force ratio CFR shows clearly that the suspension of the headphone is the dominant effect. The magnitude of the forces driving the rocking are almost 3% of the piston-mode force.

We can see the contribution of the stiffness effect on the response of the driver by looking into the Accumulated Acceleration Level diagram of the dominant rocking mode 1. The curve associated with the stiffness asymmetry (blue line) provides the largest contribution to the amplitude of the rocking mode at its resonance frequency ( $f_1=151 \text{ Hz}$ ). We can also see the influence of the mass just below (green line). Since the effects of mass and stiffness add up, generating the black curve, we can conclude that mass and stiffness imbalances work in phase, which makes the problem even worse.



AAL of the contribution of each excitation term, shows dominance of the stiffness asymmetry (blue line) over the mass effect (green), which also contributes to the problem

To understand the exceptionally high level of this rocking mode, we have a look into the diagnostics table in result window "Rocking Mode 1". It indicates that the Q-factor of the rocking resonator is 37 (very undamped), which is boosting the effects of small imbalances to the observed large amplitudes.

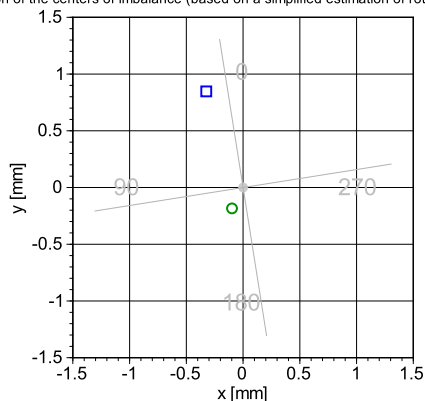
Since we already know that the majority of the problem is associated with the stiffness asymmetry, we would like to know the direction of the center of imbalance on the diaphragm. The approximate location of the stiffness center is shown the window "Summary" in the section "Root causes". It indicates clearly, in which direction the harder side of the suspension is oriented. For convenience, the RMA imbalance diagram visualizes this result.

**Root causes: Imbalances**

Offsets in the distributions of mass and stiffness from the geometrical center of the diaphragm.

Description	Parameter	Mark	Offset [mm]	Direction [°]
Center of Mass	$d_M$	○	.21	152
Center of Stiffness	$d_K$	□	.91	21

Location of the centers of imbalance (based on a simplified estimation of rotational stiffness)



Step 3: RMA imbalance table and plot indicating an offset in the center of stiffness of 0.9 mm (rigidly oscillating diaphragm radius = 16mm) at 21 degrees angle relative to the position of the transducer on the SCN turntable.

Starting from the symptoms and based on a fast scanner measurement, the RMA module unveils the relationship between the symptoms produced by the rocking mode (peak in quadrature component) and the root cause of the problem (stiffness asymmetry located at 21°). The excess of tilting of the voice coil in the gap will produce *Rub&Buzz* producing non-acceptable impulsive distortion already at relatively low amplitudes.

With the diagnostic information available now, the mechanical reasons for the stiffness-imbalance can be assessed by the engineer who shall analyse the design and production process for inhomogeneities in the indicated direction.

Find explanations for symbols at:

<http://www.klippel.de/know-how/literature.html>

Last updated: May 12, 2021

