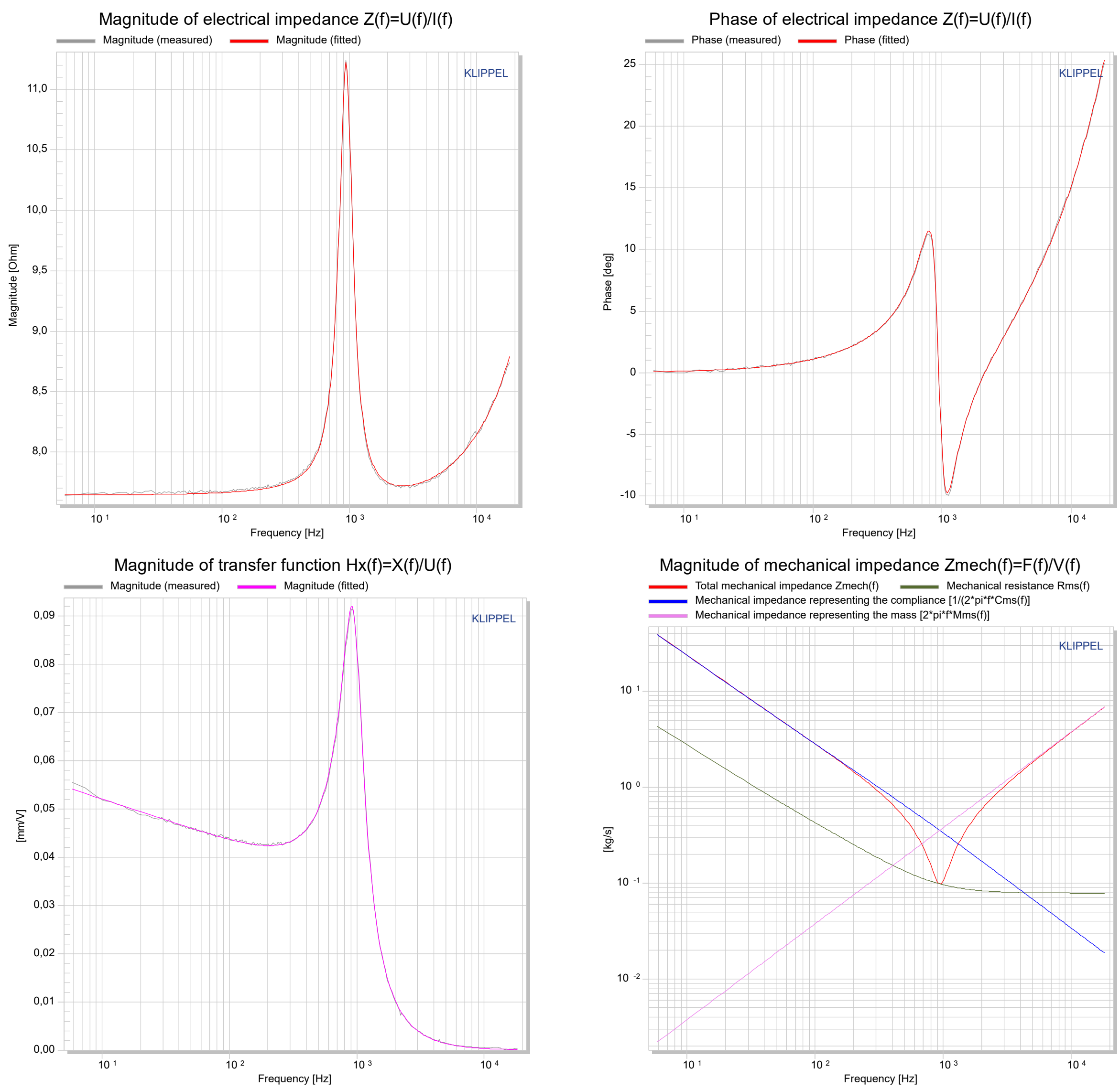
Extended Creep Modeling AN49

Application Note to the KLIPPEL ANALYZER SYSTEM (Document Revision 1.1)

This application note gives an outline how to deploy the Extended Creep Modeling (ECM) tool to estimate linear transducer parameters with a more sophisticated model for the creep of the suspension. The tool offers an improved fitting algorithm and two additional models for the creep of the suspension. This application note shows how to perform a parameter-identification and explains the new models as well as the associated result windows.



CONTENT

1 Background

Introduction

The traditional Thiele Small Loudspeaker Model considers the compliance of the suspension (C_{ms}) and the mechanical losses (R_{ms}) constant parameters. Taking the creep effect of the suspension into account, these parameters become frequency dependent.

The current Klippel LPM module (version 210) offers a creep model with a frequency dependent compliance increasing towards lower frequencies, but still constant losses:

$$C_{\text{ms}} = C_{\text{ms}}(f_s)\left[1 - \lambda \log_{10}\left(\frac{f}{f_s}\right)\right] \quad (1)$$

This simple model delivers good results for speakers with low creep effect, but yields fitting results of limited accuracy for speakers with a high creep effect. The main improvement of this script is the introduction of two extended creep models, for modeling high creep effect.

Complex Compliance

Both new models consider the compliance $C(f)$ to be complex. Thus interpreting the compliance as a spring is not appropriate anymore.

Splitting the complex impedance of the compliance Z_C into its real and imaginary part makes it possible to consider it to be a series connection of a spring and a dashpot:

$$Z_{\text{C}} = \frac{1}{j2\pi f C(f)} = \frac{1}{j2\pi f C_{\text{ms}}(f)} + R_{C_{\text{ms}}}(f) \quad (2)$$

with

$$C_{\text{ms}}(f) = \frac{\text{abs}^2\{C(f)\}}{\Re\{C(f)\}} \quad (3)$$

and

$$R_{\text{Cms}}(f) = \frac{-\Im\{C(f)\}}{2\pi f * \text{abs}^2\{C(f)\}} \quad (4)$$

The dashpot modeling the frequency dependent losses of the suspension $R_{C_{ms}}(f)$ can be added to the constant losses R_{ms0}, which results into the total mechanical losses $R_{ms}(f)$. Thus the equivalent circuit of the transducer will remain the same, just considering the losses and the compliance to be frequency dependent.

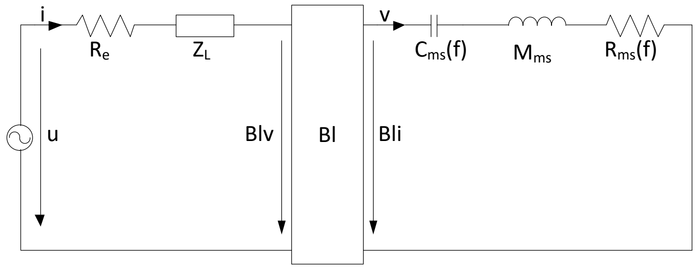


Figure 1 Equivalent electrical circuit used as linear transducer model

Knudsen Creep Model

Knudsen proposed a model for the suspension creep [2] using a logarithm weighted with the creep factor λ:

$$C(f) = C_0\left(1 - \lambda \log_{10}\left(\frac{jf}{f_s}\right)\right)$$

This model is purely mathematical, based on the experience that the creep increases nearly linear towards lower frequencies, when viewed on a semi-logarithmic scale.

The parameter C_0 contains the value of the real part at the resonance frequency f_s but is not equal to the value of the compliance $C_{ms}(f_s)$ when using the notation of formula (2).

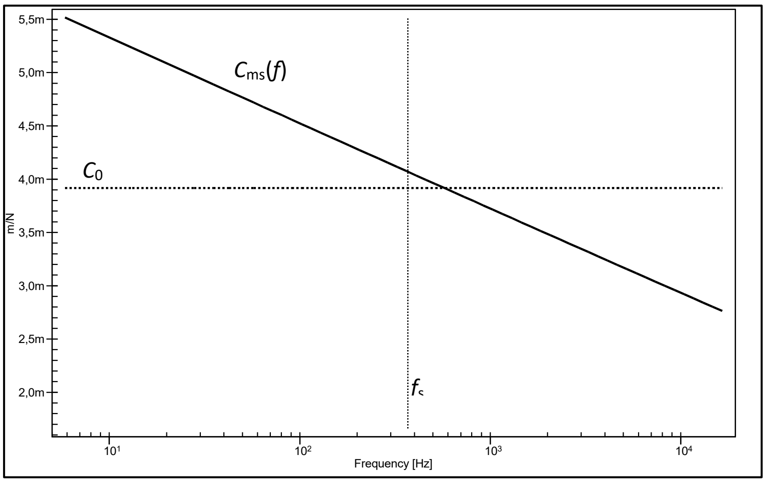


Figure 2 Compliance of suspension Knudsen Model

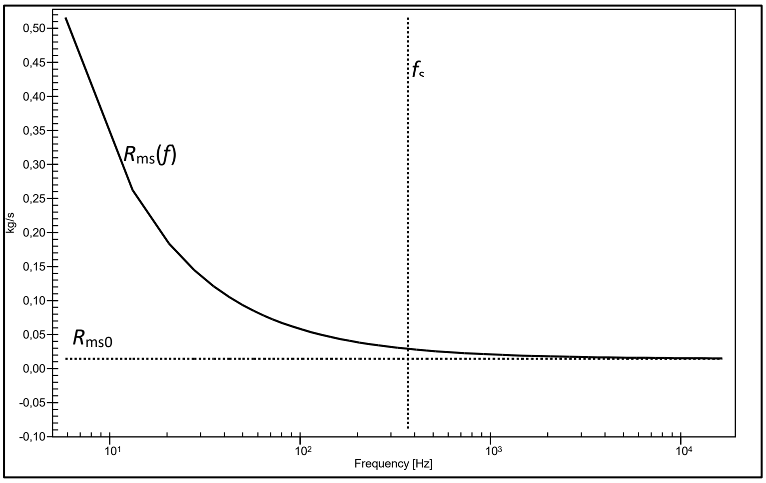


Figure 3 Mechanical losses Knudsen Model

The model integrated in the LPM Module bases upon this model, but neglects the complex argument of the logarithm and thus the frequency dependence of the mechanical losses.

Ritter Creep Model

A three-parameter model based on retardation spectra was introduced by Ritter [3].

$$C(f) = C_0\left(1 - \kappa \log_{10}\left(\frac{j\frac{f}{f_{\min}}e^{-j\tan^{-1}\left(\frac{f}{f_{\min}}\right)}}{\sqrt[2]{1+\left(\frac{f}{f_{\min}}\right)^2}}\right)\right)$$

Instead of becoming negative towards high frequencies the creep reaches a minimum compliance, which is described by C_0.

The frequency $f_{\min}$ corresponds to the minimum retardation time of the retardation spectra and can be interpreted as the frequency where the creep of the suspension starts to rise.

This model is rather complex, but delivers best fitting results, with just one additional parameter.

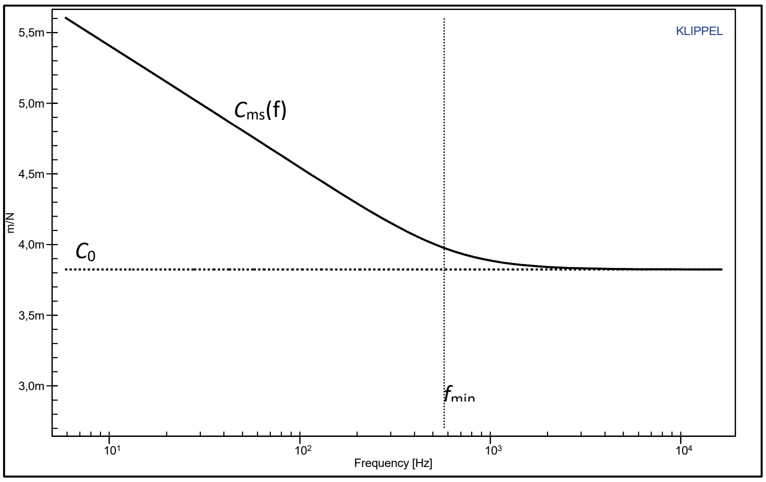


Figure 4 Compliance of suspension Ritter Model

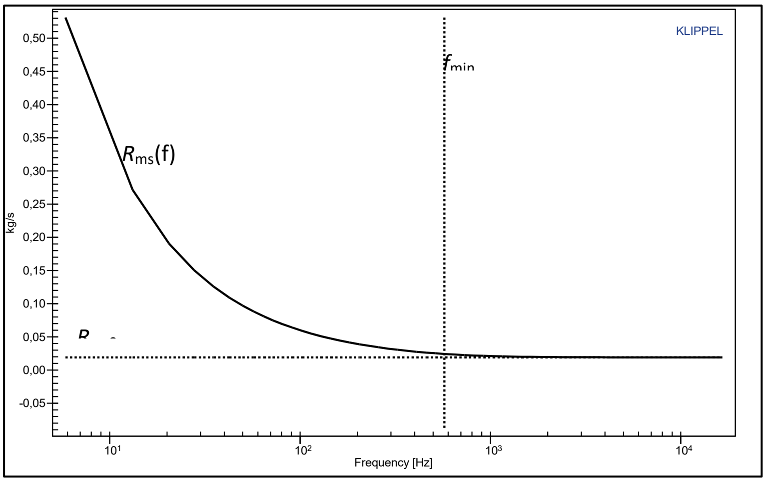
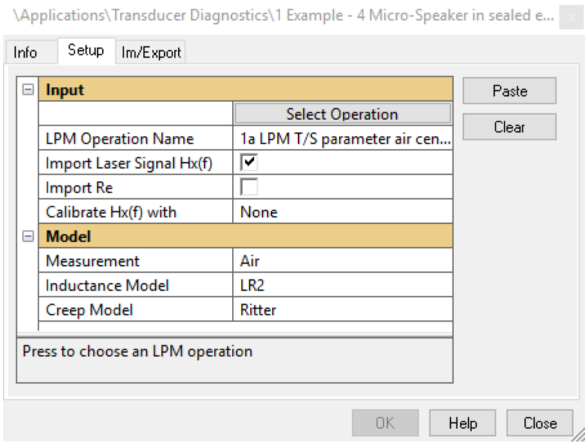
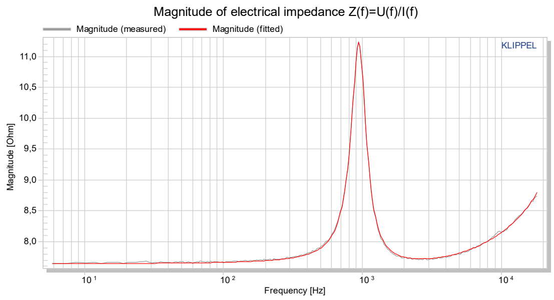
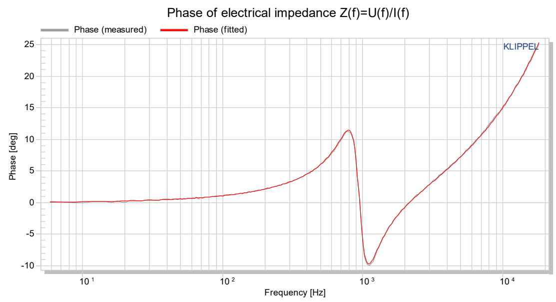


Figure 5 Mechanical losses Ritter Model

2 Application

Requirements	Running the tool requires dB-Lab 210.6xx, as well as the LPM Module. The tool performs post-processing on measured LPM data to estimate the linear parameters, including the electrical impedance ($Z(f) = U(f)/I(f)$) and the transfer function ($H_x(f) = X(f)/U(f)$) of the transducer.	
Setup	To use the *Extended Creep Modeling*, create a new object and select the *LPM Extended Creep Modeling AN49* template. Conduct the *LPM T/S parameter* as usual to gain the source data for. Please see [8] for further information. Before running the *Extended Creep Modeling*, open the properties page and set the input parameters. See the next section for further information. 	
Input Parameters	**Note:** It is recommended to use vacuum measurements, hence a joined air volume would distort the estimation of the parameters of the creep model.	
	Select Operation *LPM Operation Name*	Operation used for post-processing, set via dialogue or directly by name.
	Import Re	Electrical voice coil resistance at DC, importing this value will influence the fitting of all parameters
	Calibrate $H_x(f)$ with ***Force Factor (Bl)***[1]	Calibrates the absolute value of the measured transfer function
	Calibrate $H_x(f)$ with ***Mass (Mms)***[1]	Mass of the suspension, calibrates the absolute value of the measured transfer function
	Measurement	Affect the names and exported parameters. See application note 50 for further information about this issue.

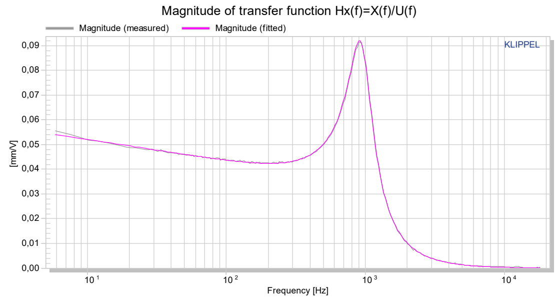
[1] Importing one of this calibration factors will lead into shifting the measured H_x curve in the result window

Input Parameters	*Inductance Model*	Inductance model used for the post processing. Available values: • *none*: considers the inductance to be a constant parameter Le: • *LR2*: shunted inductor model • *Leach*: two parameter model by Leach • *Wright*: four parameter model by Wright • *Thorborg*: five parameter model by Thorborg see [4]
	Creep Model	Models the creep effect of the transducer at low frequencies. Available models: • *none*: compliance is real and constant • *Log*: simple, real logarithmic creep model • *Knudsen*: complex logarithmic creep model by Knudsen • *Ritter*: complex creep model by Ritter
Result Windows	**Electrical Impedance Magnitude** Displays the magnitude of electrical impedance |*Z*(*f*)| over the frequency *f*. There are no differences compared to the illustration in the LPM module.  	
	Electrical Impedance Phase Displays the phase of the electrical impedance arg(*Z*(*f*)) over the frequency *f*. There are no differences compared to the illustration In the LPM module.  	

Result Windows

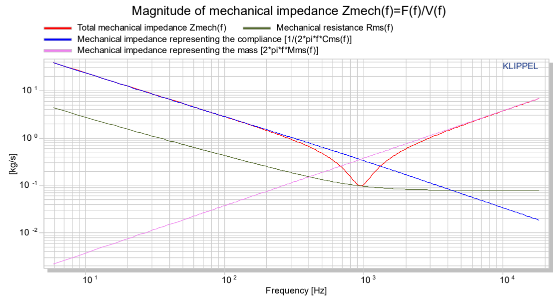
Hx(f) Magnitude

Displays the magnitude of the transfer function |Hx(*f*)| over frequency *f*. Importing a calibration factor (M_{ms} or *Bl*) will shift the measured curve and mark it as imported.



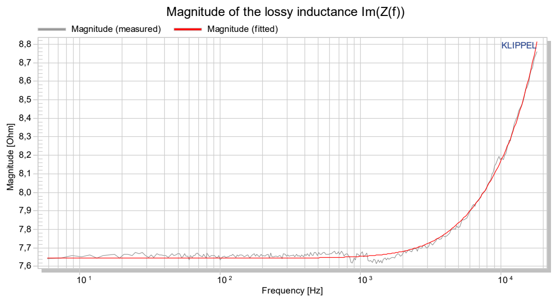
Mechanical Impedance Magnitude

Displays the impedance magnitude of the mechanical components $|R_{ms}(f)|$, $|C_{ms}(f)|$ and $|M_{ms}(f)|$, as well as the magnitude of the total mechanical impedance $|Z_{mech}(f)|$ over frequency *f*.



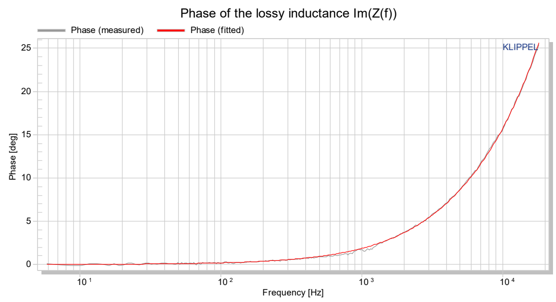
Lossy Inductance Magnitude

Displays the magnitude of the lossy inductance $|\Im\{Z(f)\}|$ over frequency *f*.



Lossy Inductance Phase

Displays the phase of the lossy inductance $\arg(\Im\{Z(f)\})$ over frequency *f*.



Result Windows

Mechanical Compliance

Displays the magnitude of the mechanical compliance $|C_{ms}(f)|$ over the frequency f. Linear value C_{ms0} and cutoff frequency f_{min} are marked, depending on the used model.

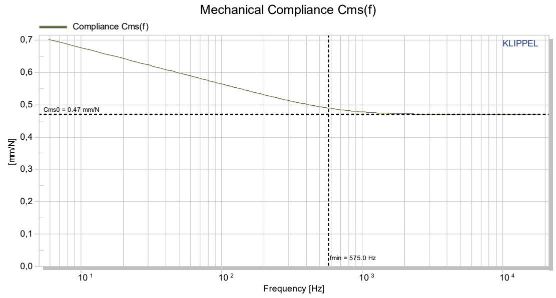


Table Linear Parameters

Shows the fitted parameters, as well as warnings, errors and other status messages.

Parameter	Value	Unit	Description
Setup			
Measurement Type	Air		Type of the LPM measurement
Operation	1a LPM T/S parameter air center		Results from this LPM Operation will be loaded
Inductance Model	LR2		Model of the lossy inductance
Creep Model	Ritter		Model of the suspension creep
Electrical Parameters			
R_e	7.64	Ω	DC resistance of voice coil
L_e	0.032	mH	Frequency independent part of the voice coil inductance
L_2	0.0072	mH	Para-inductance of the voice coil
R_2	0.36	Ω	Electrical resistance due to eddy current losses in the voice coil
C_{mes}	0.17	mF	Electrical capacitance representing moving mass measured in free air
$L_{ces}(f_s)$	0.17	mH	Electrical inductance representing the compliance of the suspension in free air @ f_s
$R_{es}(f_s)$	3.572	Ω	Electrical resistance representing mechanical losses measured in free air @ f_s
Mechanical Parameters			
M_{ms}	0.060	g	Mechanical moving mass of driver diaphragm assembly including voice coil and air load
$C_{ms}(f_s)$	0.479	mm/N	Mechanical compliance of driver suspension measured in free air @ f_s
$K_{ms}(f_s)$	2.087	N/mm	Mechanical stiffness of driver suspension measured in free air @ f_s
$R_{ms}(f_s)$	0.098	kg/s	Mechanical losses of driver in free air @ f_s
Bl	0.592	N/A	Force factor (Bl product)
κ	0.24	-	Creep factor of the Ritter creep model
f_{min}	575.04	Hz	Frequency representing the minimum retardation time of the Ritter creep model
$C_{ms,0}$	0.470	mm/N	Minimum compliance of the Ritter creep model measured in free air
$R_{ms,0}$	0.078	kg/s	Frequency independent part of mechanical losses (losses at high frequencies) in free air
Derived Parameters			
f_s	939	Hz	Driver resonance frequency in free air
Q_{tps}	2.46	-	Total quality-factor considering all losses in free air
Q_{ms}	3.60	-	Mechanical quality-factor measured in free air considering R_{ms} only
Q_{ms}	7.71	-	Electrical quality-factor measured in free air considering R_e only
Q_{ts}	2.46	-	Total quality-factor measured in free air considering R_{ms} and $R_{e\ only}$
Fitting Errors			
rmse Z_{air}	0.32	%	root-mean-square fitting error of driver impedance Z(f) measured in free air
rmse $H_{x,air}$	1.03	%	root-mean-square fitting error of transfer function $H_x(f)$ measured in free air

3 More Information

Papers	[1]. W. Klippel and U. Seidel, "Fast and Accurate Measurement of Linear Transducer Parameters," presented at the 110th Convention of the Audio Engineering Society, Amsterdam, May 12-15, 2001, preprint 5308 [2]. M.H. Knudsen and J.G. Jensen, "Low-Frequency Loudspeaker Models that Include Suspension Creep," J. Audio Eng. Soc., vol. 41, pp. 3-18, (Jan./Feb. 1993) [3]. F. Agerkvist and T. Ritter, "Modelling Viscoelasticity of Loudspeaker Suspensions using Retardation Spectra," presented at the 129th Convention of the Audio Engineering Society, San Francisco, November 4-7, 2010, preprint 8217 [4]. K. Thorborg, A. Unruh and C. Struck, "An Improved Electrical Equivalent Circuit Model for Dynamic Moving Coil Transducers", presented at the 122nd Convention of the Audio Engineering Society, Vienna – Austria, May 5-8, 2007 [5]. K. Thorborg, C. Tinggaard, F. Agerkvist and C. Futtrup, "Frequency Dependence of Damping and Compliance in Loudspeaker Suspensions", J. Audio Eng. Soc. Vol. 58 no. 6, June 2010. [6]. K. Thorborg and C. Futtrup, "Electro-Dynamic Transducer Model Incorporating Semi-Inductance and Means for Shorting AC-Magnetization", J. Audio Engineering Society, vol.59 September 2011.
Software	User Manual and online help system of the Klippel R&D System
Application Notes	[7]. AN 50 Multipoint Parameter Fitting and Load Separation [8]. AN 25 Maximizing LPM Accuracy

Last updated: December 19, 2022

Find explanations for symbols at:

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