KLIPPEL ANALYZER SYSTEM

Introductory Report

Large Signal Identification (LSI)

Driver Name: w2017 midrange

Driver Comment:
Measurement: LSI Woofer Nonl. P. Sp1

Measurement Comment: Finish after Nonlinear Mode
Connect woofer to SPEAKER 1

Overview

The Introductory Report illustrates the powerful features of the Klippel Analyzer module dedicated to the measurement speaker parameters and state variables in the large signal domain. Additional comments are added to the results of a practical measurement applied to the speaker specified above.
After presenting short information to the measurement technique the report comprises the following results

< nonlinear speaker parameters versus displacement
< coefficients of the power series expansion of the nonlinear parameters
< derived speaker parameters such as resonance frequency and loss factors
< parameters at the rest position (parameters for linear modeling)
< parameter variation versus time
< state variables of the speaker (temperature, displacement, …)
< contribution of each nonlinearity to the total distortion (distortion analysis)
< suggestions for loudspeaker improvements (remedy parameters)

Nonlinear Parameters

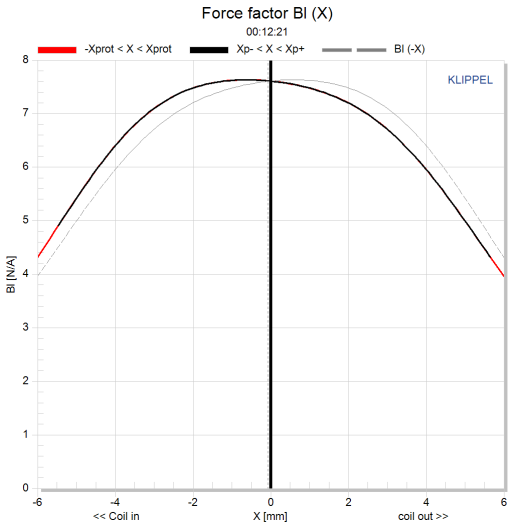
The dominant nonlinearities are modeled by variable parameters such as

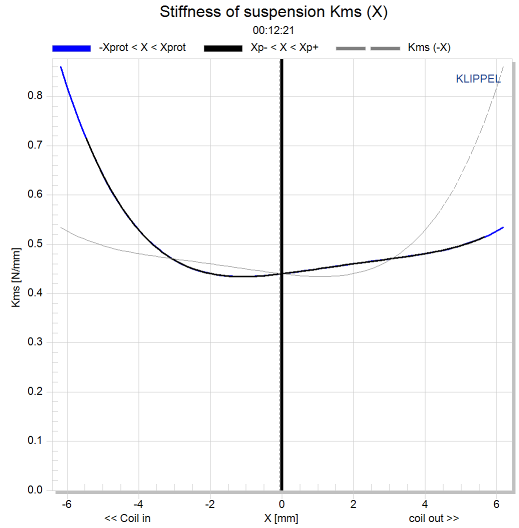
b(x)	instantaneous electrodynamic coupling factor (force factor of the motor) defined by the integral of the magnetic lux density B over voice coil length l,
$K_{MS}(x)$	mechanical stiffness of driver suspension
$L_E(x)$	part of voice coil inductance which depends on displacement
$L_E(i)$	part of voice coil inductance which depends on current
$C_{MES}(x)$	electrical capacity representing moving mass,
$R_{ES}(x)$	electrical resistance due to driver suspension losses
$L_{CES}(x)$	electrical inductance representing driver compliance

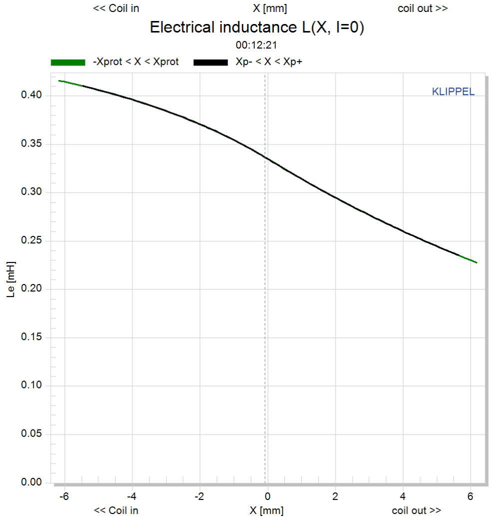
depending on the instantaneous voice coil displacement *x*.

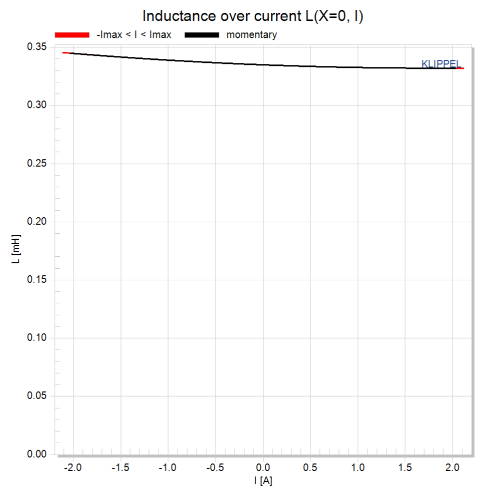
Force factor Bl (X)
00:12:21

Stiffness of suspension Kms (X)
00:12:21









A solid line represents the used working range x-peak < x < x+peak between the minimal and maximal peak displacement occurred in last update interval of the measurement. The dotted line shows the allowed working range xmax < x < xmax identified by the automatic gain adjustment by using predefined limit values.

Power Series Expansion

The nonlinear parameters force factor, compliance, stiffness and inductance are expanded in a power series expansion. This representation uses a minimal set of parameters and simplifies the export of the nonlinear parameters to the numerical simulation of the driver in the final enclosure.

Symbol	**Number**	**Unit**	**Comment**
Displacement Limits			thresholds can be changed in Processing property page
X Bl @ Bl min=82%	3.7	mm	Displacement limit due to force factor variation

X C @ C min=75%	4.6	mm	Displacement limit due to compliance variation
X L @ Z max=10 %	>5.5	mm	Displacement limit due to inductance variation
X d @ d2=10%	32.6	mm	Displacement limit due to IM distortion (Doppler)
Asymmetry (IEC 62458)			
Ak	46.77	%	Stiffness asymmetry Ak(Xpeak)
Xsym	-0.19	mm	Symmetry point of Bl(x) at maximal excursion
Thermal Parameters			
alpha			Heating of voice coil by eddy currents
alphaOrg			Heating of voice coil by eddy currents (without limits)
Rtv		K/W	thermal resistance coil ==> pole tips
rv		Ws/Km	air convection cooling depending on velocity
Rtm		K/W	thermal resistance magnet ==> environment
tau m		min	thermal time constant of magnet
Ctm		Ws/K	thermal capacity of the magnet
tau v		s	thermal time constant of voice coil
Ctv		Ws/K	thermal capacity of the voice coil
Thermal State			
delta Tw		K	Temperature increase in Warm Resistance Mode
delta Tc		K	Temperature increase in Convection Mode
delta Te		K	Temperature increase in Eddy Mode
Pcoil(warm)		W	Pcoil in warm mode
Pcoil(conv)		W	Pcoil in convection mode
Ptv(mag.beg)		W	power heating the coil at beginning of magnet mode
Ptv(mag.mid)		W	power heating the coil sampled in the middle of magnet mode
Ptv(mag.end)		W	power heating the coil at end of magnet mode
Ptm(mag.beg)		W	power heating the magnet at beginning of magnet mode
Ptm(mag.mid)		W	power heating the magnet sampled in the middle of magnet mode
Ptm(mag.end)		W	power heating the magnet at end of magnet mode
Power Series			
Bl0 = Bl (X=0)	7.6622	N/A	constant part in force factor
Bl1	-0.068407	N/Amm	1st order coefficient in force factor expansion

Bl2	-0.087100	N/Amm^2	2nd order coefficient in force factor expansion
Bl3	0.00084999	N/Amm^3	3rd order coefficient in force factor expansion
Bl4	-0.00035418	N/Amm^4	4th order coefficient in force factor expansion
Bl5		N/Amm^5	5th order coefficient in force factor expansion
Bl6		N/Amm^6	6th order coefficient in force factor expansion
Bl7		N/Amm^7	7th order coefficient in force factor expansion
Bl8		N/Amm^8	8th order coefficient in force factor expansion
L0 = Le (X=0)	0.33503	mH	constant part in inductance
L1	-0.018956	mH/mm	1st order coefficient in inductance expansion
L2	-0.00054233	mH/mm^2	2nd order coefficient in inductance expansion
L3	0.00010869	mH/mm^3	3rd order coefficient in inductance expansion
L4	6.4822e-006	mH/mm^4	4th order coefficient in inductance expansion
L5		mH/mm^5	5th order coefficient in inductance expansion
L6		mH/mm^6	6th order coefficient in inductance expansion
L7		mH/mm^7	7th order coefficient in inductance expansion
L8		mH/mm^8	8th order coefficient in inductance expansion
C0 = Cms (X=0)	2.2916	mm/N	constant part in compliance
C1	-0.020230	1/N	1st order coefficient in compliance expansion
C2	-0.019884	1/Nmm	2nd order coefficient in compliance expansion
C3	0.0023901	1/Nmm^2	3rd order coefficient in compliance expansion
C4	1.5369e-005	1/Nmm^3	4th order coefficient in compliance expansion
C5		1/Nmm^4	5th order coefficient in compliance expansion
C6		1/Nmm^5	6th order coefficient in compliance expansion
C7		1/Nmm^6	7th order coefficient in compliance expansion
C8		1/Nmm^7	8th order coefficient in compliance expansion
K0 = Kms (X=0)		N/mm	constant part in stiffness
K1	0.0086772	N/mm^2	1st order coefficient in stiffness expansion
K2	0.0021407	N/mm^3	2nd order coefficient in stiffness expansion
K3	-0.00092064	N/mm^4	3rd order coefficient in stiffness expansion
K4	0.00012091	N/mm^5	4th order coefficient in stiffness expansion
f1	-0.009415	1/A	coefficient (1) of L(I) Inductance over current (flux modulation)

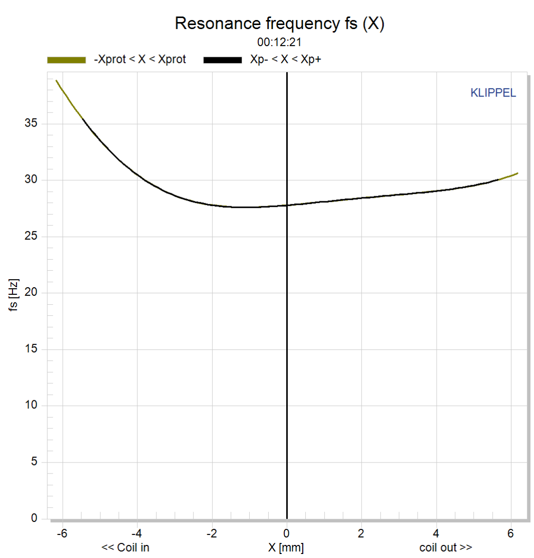
f2	0.002584	1/A^2	coefficient (2) of L(I) Inductance over current (flux modulation)
Xpse	6.2	mm	-Xpse < X < Xpse, range where power series is fitted
			Parameters for Auralization available.

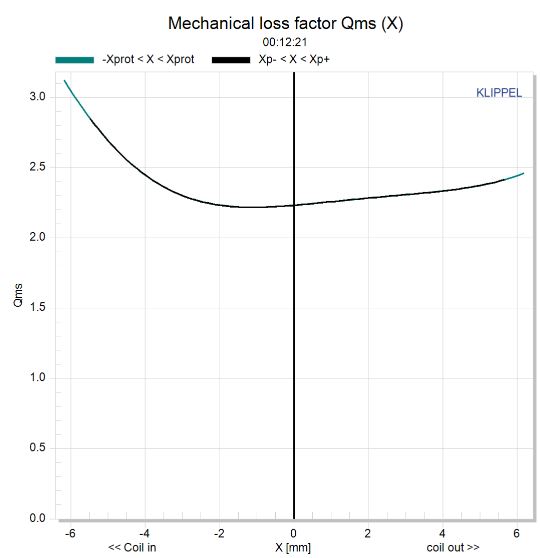
Derived Loudspeaker Parameters

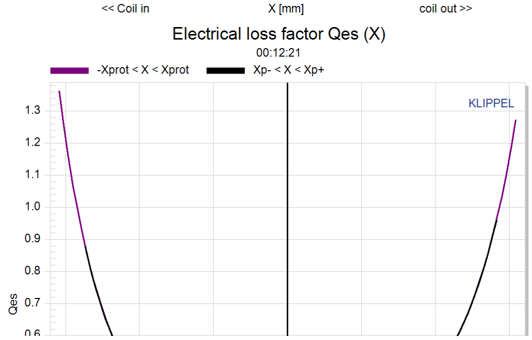
For the analysis and synthesis of loudspeaker system it is convenient to use special transducer parameters:

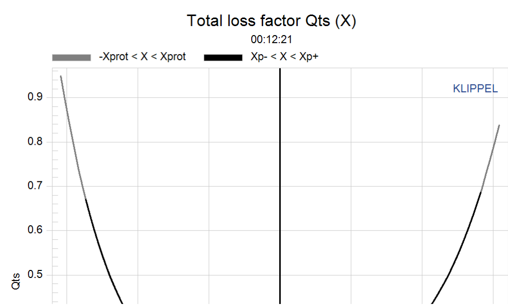
f_s	resonance frequency of the transducer
$Q_{MS}(x)$	mechanical loss factor of the transducer at fs considering driver non-electrical resistances only,
$Q_{ES}(T_V, x)$	electrical loss factor by considering the electrical resistance $R_E(T_V)$ only,
$Q_T(T_V, x)$	total loss factor at f_s and voice coil temperature T_V considering mechanical and electrical resistances R_{MS} and $R_E(T_V)$ only.

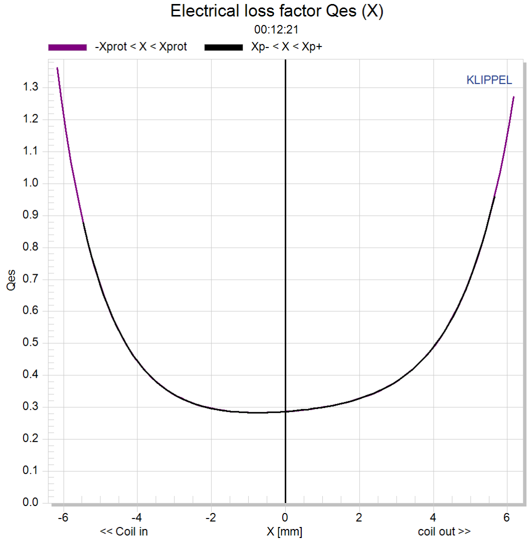
In contrast to linear modeling most of these parameters are not constant but depend on the instantaneous state of the transducer (displacement x, the voice coil temperature T_V).

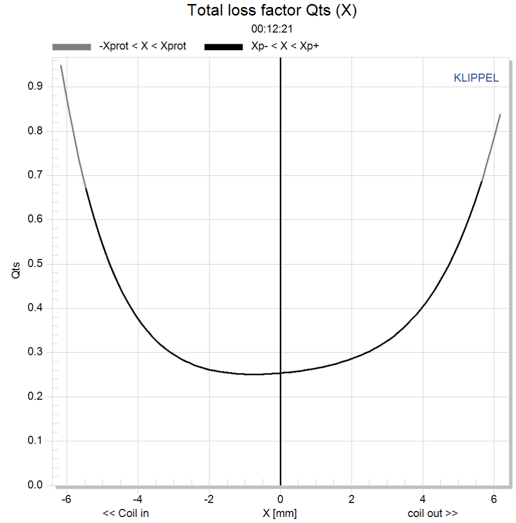












Parameters at the Rest Position

The value of the nonlinear parameters at the rest position ($x=0$) may be used as input for the traditional linear modeling and may be referred as “linear parameters”. Please note that these parameters depend on the instantaneous state of the driver (voice coil temperature, peak value of displacement) and are presented for three different modes of operation:

Mode	Properties
LARGE+WARM	the transducer is operated in the large signal domain, the peak value of the displacement is high ($\|x\| < x_{max}$), the variation of the parameters is not negligible, the voice coil temperature is increased ($\Delta T_V > 0$) due to heating.
LARGE+COLD	the transducer is operated in the large signal domain, the peak value of the displacement is high ($\|x\| < x_{max}$), the variation of the parameters is not negligible, the effect of heating is compensated while considering the cold voice coil resistance $R_e(\Delta T_V = 0)$.
SMALL SIGNAL	the transducer is operated in the small signal domain, the amplitude of the excitation signal is sufficiently small, the displacement is small in comparison to the allowed maximal displacement ($\|x\| << x_{max}$), the variations of the nonlinear parameters are negligible, the increase of voice coil temperature is negligible ($\Delta T_V \approx 0$), the effects of the nonlinear, thermal and time-varying mechanisms are negligible, the transducer behaves almost linear.

Symbol	Large + Warm	Large + Cold	Small Signal	Unit	Comment
Note:					for accurate small signal parameters, use LPM module

Delta Tv = Tv-Ta	11	0	0	K	increase of voice coil temperature during the measurement
Xprot	6.2	6.2	0.7	mm	maximal voice coil excursion (limited by protection system)
Re (Tv)	6.58	6.31	6.31	Ohm	(imported) voice coil resistance considering increase of voice coil temperature Tv
Le (X=0)	0.34	0.34	0.36	mH	voice coil inductance at the rest position of the voice coil
L2 (X=0)	0.60	0.60	0.42	mH	para-inductance at the rest position due to the effect of eddy current
R2 (X=0)	1.45	1.45	1.67	Ohm	resistance at the rest position due to eddy currents
Cmes (X=0)	276	276	290	µF	electrical capacitance representing moving mass
Lces (X=0)	118.93	118.93	83.01	mH	electrical inductance at the rest position representing driver compliance
Res (X=0)	46.34	46.34	27.21	Ohm	resistance at the rest position due to mechanical losses
Qms (X=0, Tv)	2.23	2.23	1.61		mechanical Q-factor considering Rms only
Qes (Tv)	0.29	0.27	0.32		electrical Q-factor considering Re (Tv) only
Qts (X=0, Tv)	0.25	0.24	0.27		total Q-factor considering Re (Tv) and Rms only
fs	27.8	27.8	32.5	Hz	driver resonance frequency
Mms	14.424	14.424	14.424	g	(imported) mechanical mass of driver diaphragm assembly including voice-coil and air load
Rms (X=0)	1.129	1.129	1.831	kg/s	mechanical resistance of total-driver losses
Cms (X=0)	2.27	2.27	1.67	mm/N	mechanical compliance of driver suspension at the rest position
Kms (X=0)	0.44	0.44	0.60	N/mm	mechanical stiffness of driver suspension at the rest position
Bl (X=0)	7.61	7.61	7.61	N/A	(imported) force factor at the rest position (Bl product)
Vas	39.0914	39.0914	28.6574	l	equivalent air volume of suspension
N0	0.281	0.293	0.293	%	reference efficiency (2Pi-sr radiation using Re)
Lm	86.6	86.8	86.8	dB	characteristic sound pressure level

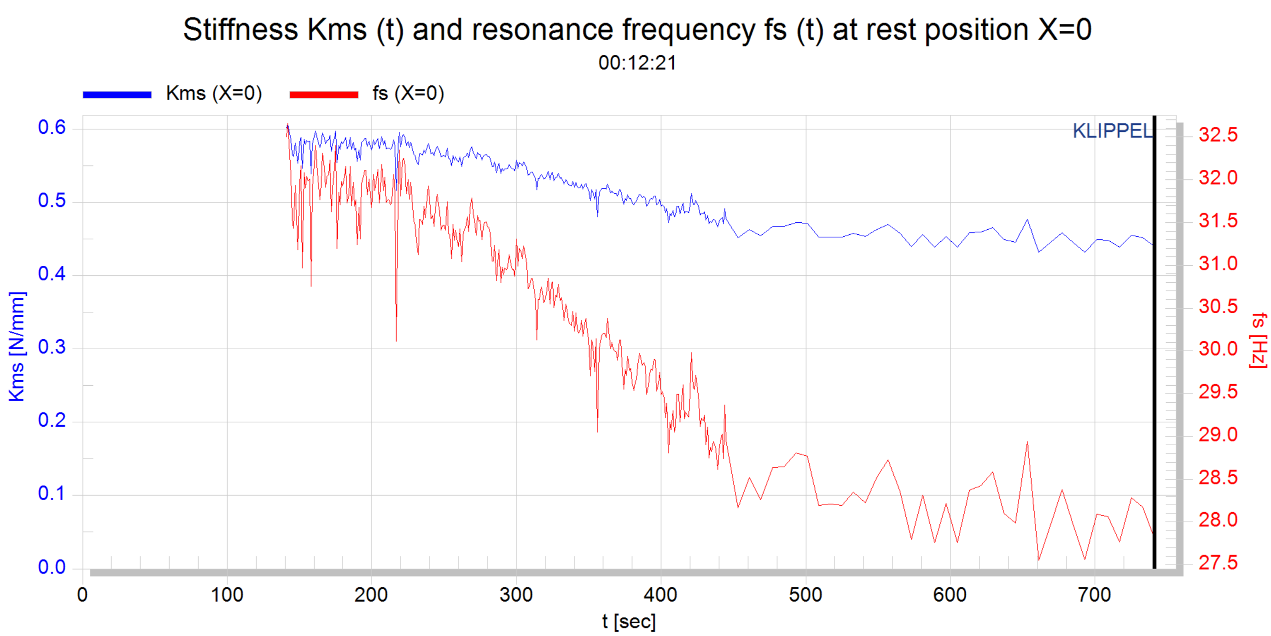
Sd	110.44	110.44	110.44	cm²	diaphragm area

Parameter Variation versus Time

The instantaneous estimates of the speaker parameters are sampled during the measurement and stored in a database. Note the difference between the initial identification which starts in the small signal domain and determines the maximal amplitude limits (xmax, Pmax, …) of the safe range of operation and the final long term measurement where the amplitude of the signal is almost constant.

Temporal Variations of the Stiffness $K_{MS}(t, x=0)$

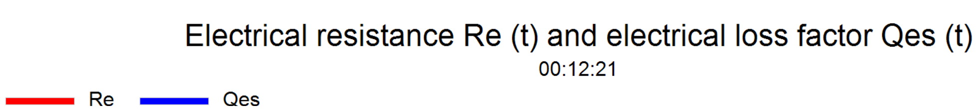
The properties of the mechanical suspension depend not only on the instantaneous displacement x but also on the maximal peak value of displacement in the last few seconds and vary with time. There are reversible and non-reversible processes due to creep, aging and relaxation.

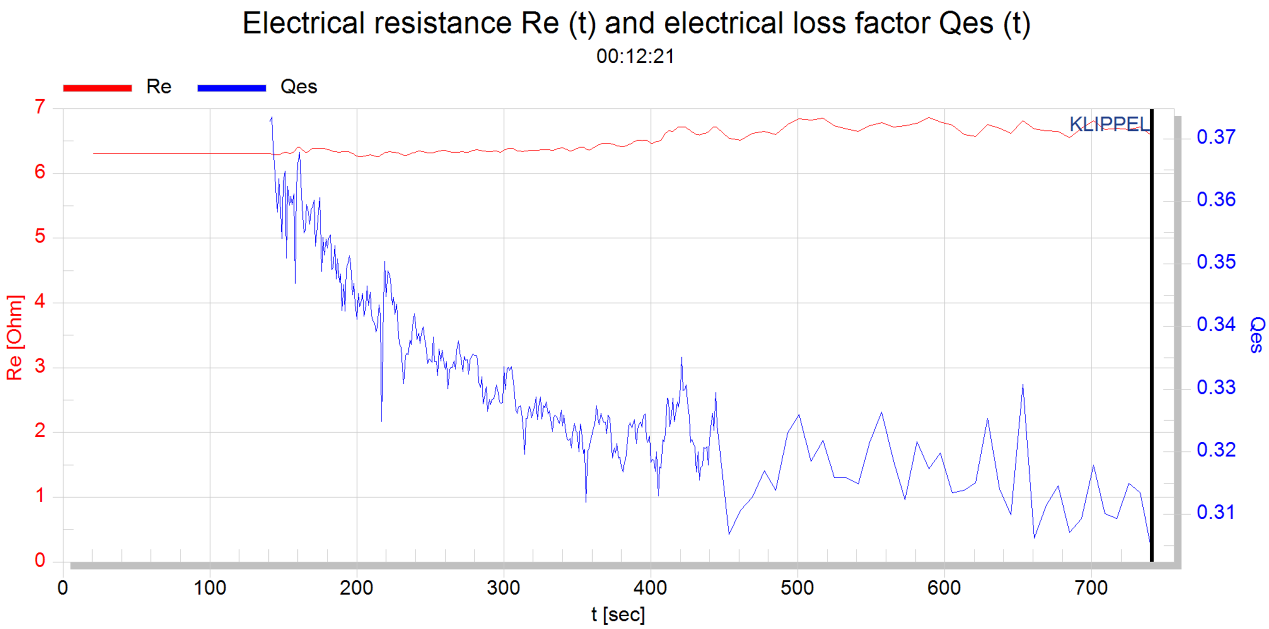


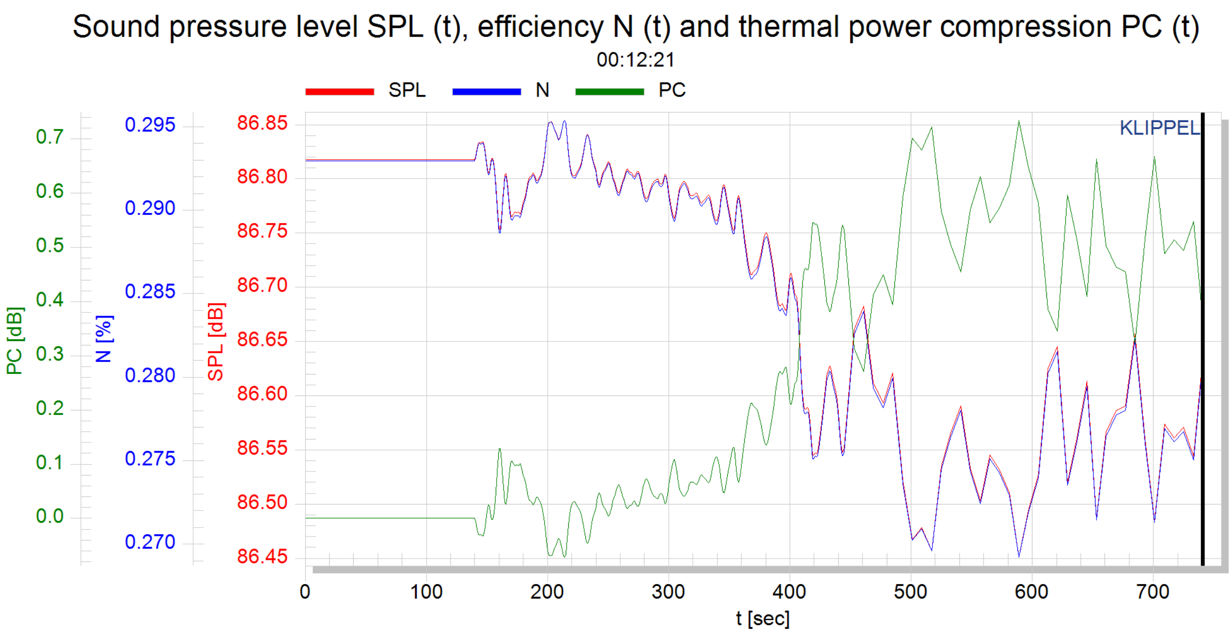
Temporal Variations of the Voice Coil Resistance $R_E(t)$

The voice coil resistance $R_E(t)$ varies during the measurement due to heating of the voice coil. This variations affect

$Q_{ES}(t, x=0)$	electrical loss factor
$h_0(t)$	efficiency
PC	power compression factor is expressed in dB and describes the loss of efficiency in the pass-band of the transducer where the electric resistance R_E dominates the electric input impedance.
SPL(t)	reference sound pressure level







Transducer State

The state information describes the progress of system identification and important transducer variables in the last update interval of the measurement.

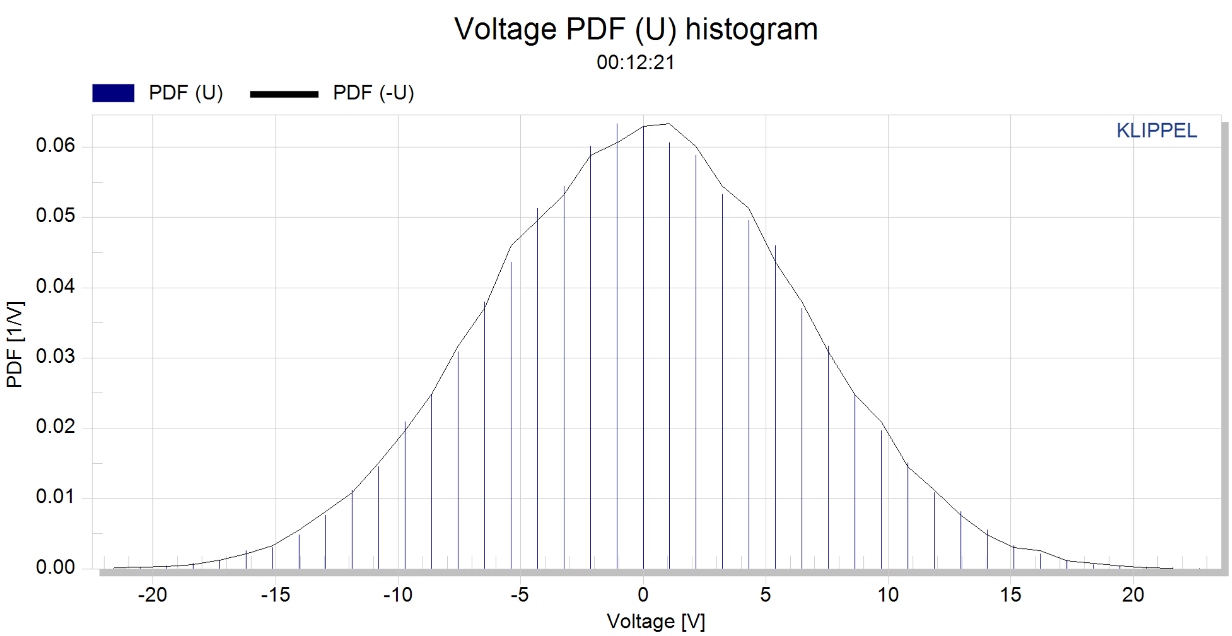
Symbol	Value	Unit	Comment
Date	2013-05-13		
Time	15:52:22		
Serial number	750		
Mode	Nonlinear Mode 5(7)		

Record	443/443		
Laser	signal reliable		
t	00:12:21	h:min:s	measurement time
Time remaining	00:00:04	h:min:s	recalculated at thermal mode(a)
Ei (t)	4.3	%	error current measurement
Ex (t)	3.1	%	error laser measurement
Eu (t)	7.0	%	error amplifier check
Delta Tv (Delta Tlim)	11.1 (60.0)	K	increase of voice coil temperature (limit)
Blmin (Bllim)	49.8 (50.0)	%	minimal force factor ratio (limit)
Cmin (Clim)	51.1 (50.0)	%	minimal compliance ratio (limit)
P (Plim)	3.4710 (50.000)	W	real electrical input power (limit)
Lmin	68.0	%	minimal inductance ratio
Pn	4.741947	W	nominal electrical input power
P Re	2.851925	W	Power heating voice coil
P Mech	0.322700	W	....
Irms	0.659	A	rms value of the electrical input current
Urms	6.159	V	rms value of the electrical voltage at the transducer terminals
Ipeak	2.033	A	peak value of the electrical input current
Upeak	19.987	V	peak value of the electrical voltage at the transducer terminals
PC	0.36	dB	thermal power compression factor
Glarge (Gmax)	19.9 (26.0)	dB	gain of the excitation amplitude increased in the large signal domain (maximum)
Mech. system		abs.	import used to identify mechanical system in absolute quantities
Xdc	0.09	mm	dc component of voice coil excursion measured in the last update intervall
Xpeak	6.59	mm	positive peak value of voice coil excursion measured in the last update intervall
Xbottom	-6.54	mm	negative peak value (bottom) of voice coil excursion measured in the last update intervall
Xp+	5.7	mm	upper limit of displacement range (99% probability)
Xp-	-5.5	mm	lower limit of displacement range (99% probability)
Xprot	6.2	mm	maximal voice coil excursion allowed by protection system
v rms	0.4	m/s	voice coil velocity

Distortion			
Db	38.5	%	distortion factors representing contribution of nonlinear force factor
Dl	7.0	%	distortion factor representing contribution of nonlinear inductance
Dc	5.1	%	distortion factor representing contribution of nonlinear compliance
D l(i)	1.4	%	distortion factor representing contribution of L(I) nonlinearity
Thermal			
R th total	3.90	K/W	Delta Tv / P Re

Voltage Probability Density Function pdf(u)

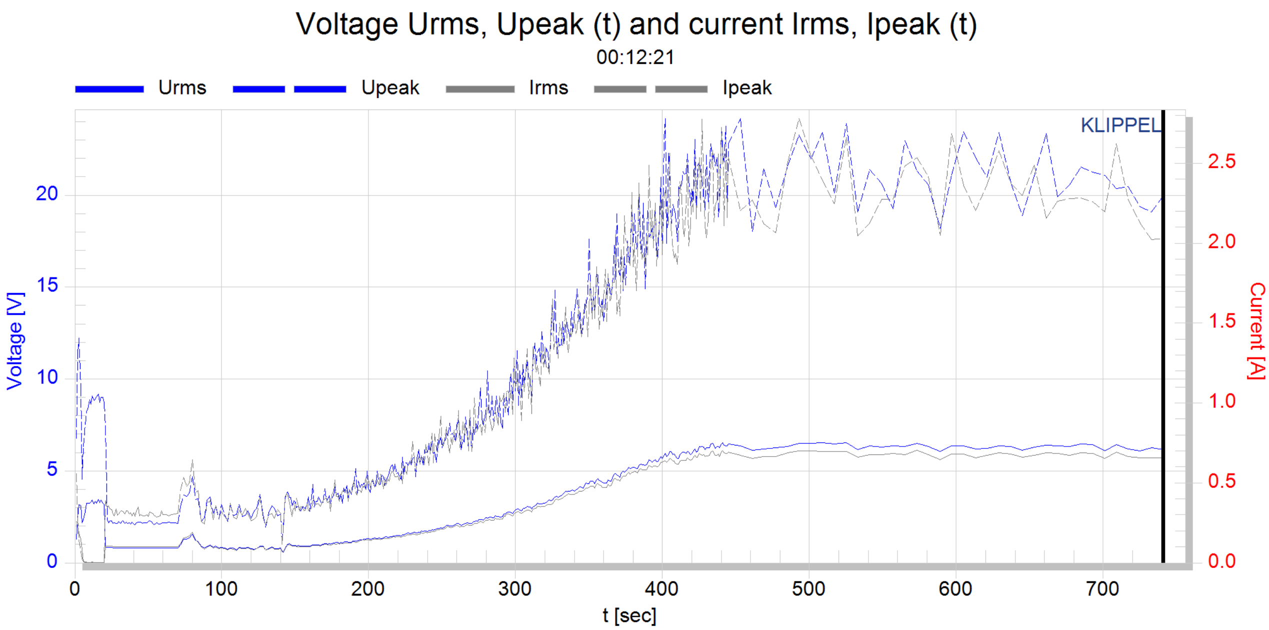
The probability density function of the voltage pdf(u) reflects the properties of the excitation signal (noise) and of the power amplifier used. If the power amplifier is not limiting and does not generate a DC-component in the output signal the pdf(u) is almost perfectly symmetrical. The positive and negative peak values, the rms-value and the crest-factor of the signal can be derived from the properties of the pdf (u).



Voltage $u_{peak}(t)$ and Current $i_{peak}(t)$

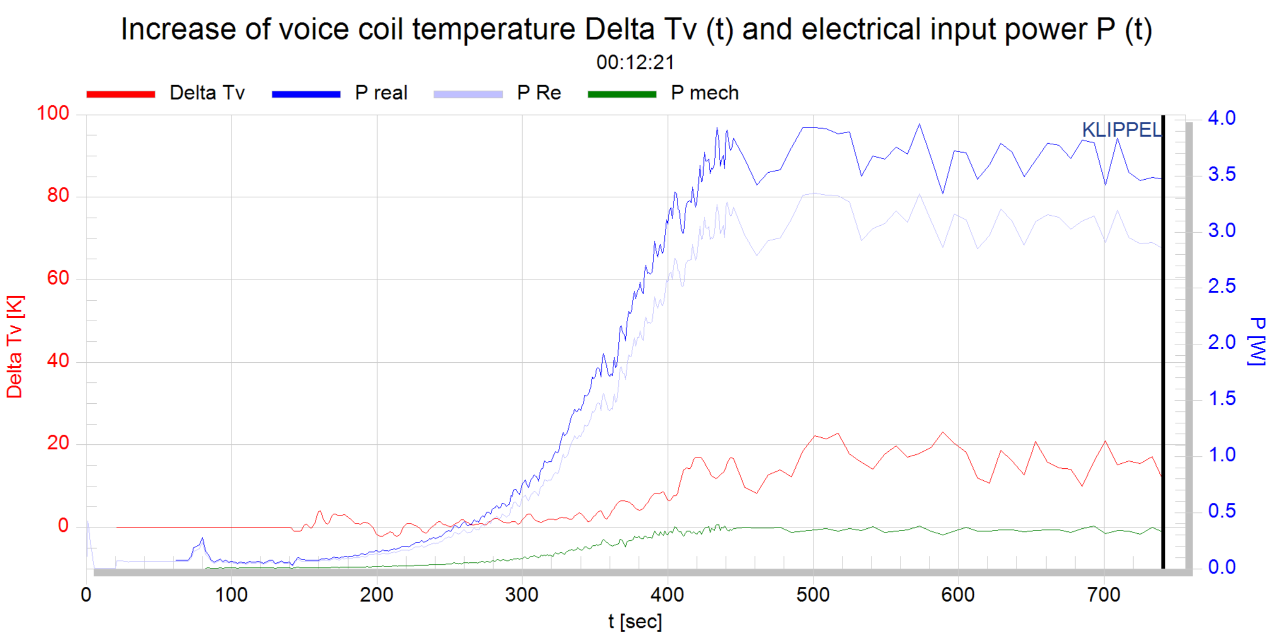
The electric signals at the transducer terminals are represented by

i_{peak}	peak value of the electric input current,
u_{peak}	peak value of the electric voltage at the transducer terminals.



Voice Coil Temperature $\Delta T_V(t)$ and Power $P(t)$

The increase of the voice coil temperature $\Delta T_V(t)$ in comparison to the electric input power P(t) versus measurement time t shows the thermal characteristic of the transducer.



The different modes of operation can easily be identified in the time plot.

In the Amplifier Mode 1(7) the loudspeaker is disconnected and the gain, polarity and distortion of the power amplifier is checked. Here the amplitude of the current is zero.

In the Resistance Mode 2(7) the dc-resistance of the voice coil is measured by a pulsed noise signal.

In the Linear Mode 3(7) the loudspeaker is connected and noise at low amplitude is used as stimulus. The transducer is operated in the small-signal domain. The temperature of the voice coil at the end of this phase is used as reference temperature T_A which equals the ambient temperature.

In the Fast Mode 4(7) the amplitude of the stimulus is increased and the limits of the allowed working range are detected automatically. The voice coil temperature T_V increases with the input power. Both state signals are used as protection variables and are compared with the limit values P_{lim} and T_{lim} defined by the user.

In the Nonlinear Mode 5(7) the learning speed is reduced and the nonlinear curves are measured at highest precision.

The Thermal Mode 6(7) consist of special heating and cooling phases to identify the thermal parameters

a) heating up to delta T_{lim} by using a band-pass filtered signal 400 Hz – 1 kHz

b) cooling down phase to measure coil capacity

c) heating up to delta T_{lim} by using a band-pass filtered signal 10 Hz – 1kHz to measure convection cooling

d) cooling down phase

e) heating up to delta T_{lim} by using a band-pass filtered signal 400Hz – 2.5 kHz to measure heating by eddy currents.

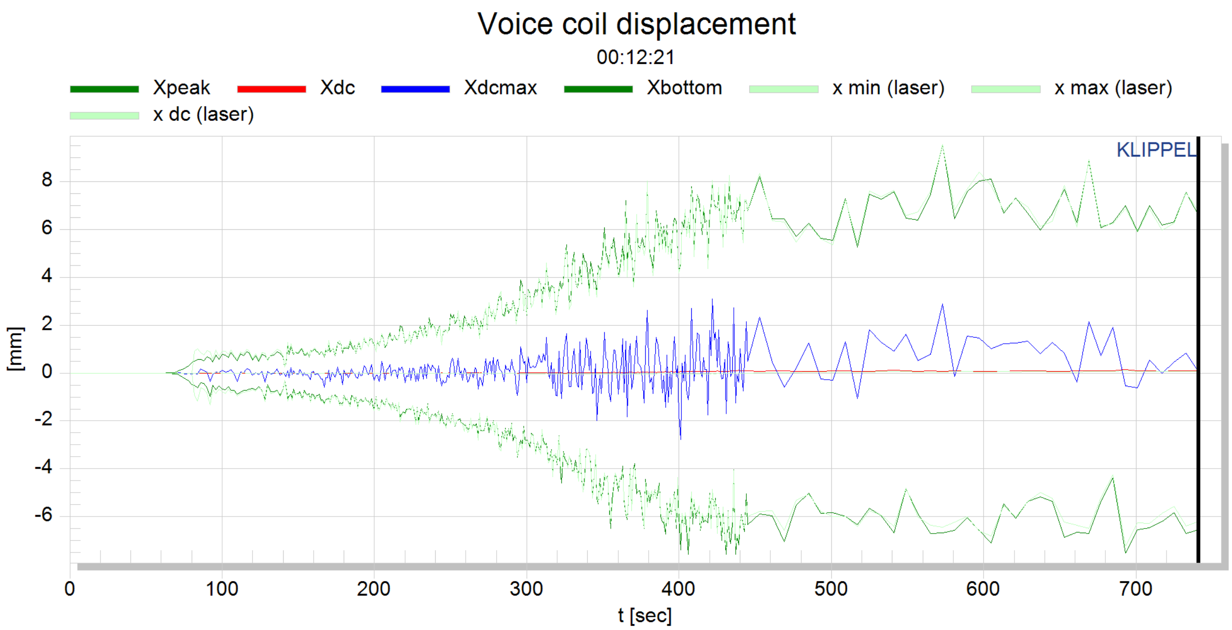
f) heating up to delta T_{lim} by using a band-pass filtered signal 400Hz – 2.5 kHz to measure resistance and capacity of the magnet (duration 50 min)

The Final Mode 7(7) uses the same signal as in the Nonlinear Mode but the learning speed is significantly reduced. It may run for ever to measure long term variations of the loudspeaker parameters.

Displacement *x(t)*

The displacement signal versus measurement time is represented as

$x_{peak}(t)$	positive peak of the voice coil displacement in the update interval,
$x_{dc}(t)$	averaged dc-value *in* voice coil excursion,
$x_{bottom}(t)$	negative peak value (bottom value) of the voice coil displacement in the updated interval,
$x_{dcmax}(t)$	maximal dc-value in voice coil excursion $x_{dcmax}(t)=(x_{peak}(t)+x_{bottom}(t))/2$



Asymmetrical nonlinearities produce not only second- and higher-order distortions but also a dc-part in the displacement by rectifying low frequency components.

For an asymmetric stiffness characteristic the dc-components moves the voice coil for any excitation signal in the direction of the stiffness minimum.

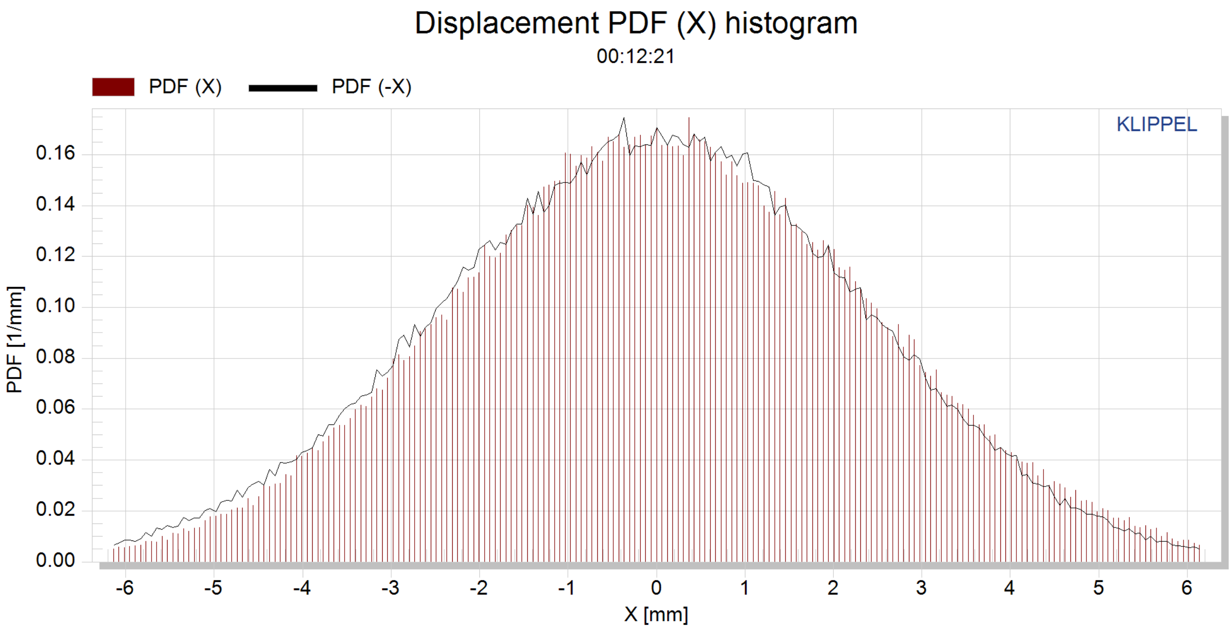
For an asymmetric force factor characteristic the dc-component depends on the frequency of the excitation signal. A sinusoidal tone below resonance ($f<f_S$) would generate or force moving the voice coil always in the force factor maximum. This effect is most welcome for stabilizing voice coil position. However, above the resonance frequency ($f>f_S$) would generate a dc-component moving the voice coil in the force factor minimum and may cause severe stability problems.

For an asymmetric inductance characteristic the dc-component moves the voice coil for any excitation signal in the direction of the inductance maximum.

Please note that the dynamically generated DC-components cause interactions between the driver nonlinearities. A optimal rest position of the coil in the gap may be destroyed by an asymmetric compliance or inductance characteristic at higher amplitudes. The module "Large Signal Simulation (SIM)" allows systematic investigation of the complicated behavior.

Displacement Probability Density Function *pdf(x)*

The probability density function of the displacement signal *pdf(x)* depends on the properties of the excitation signal (noise) and on the behavior of the transducer as well: An asymmetrical *pdf(x)* indicates a dynamic generation of a dc-component in the displacement caused by asymmetric transducer nonlinearities. The *pdf(x)* plays an important role as a weighting function in the nonlinear system identification and shows in which region of the displacement the nonlinear parameters are measured with highest precision.

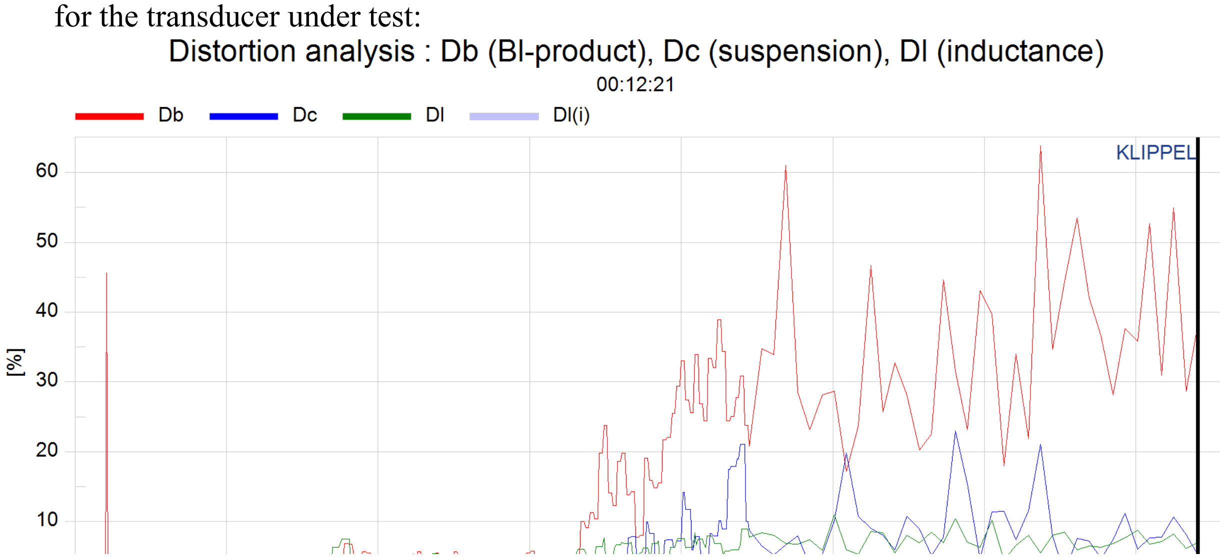


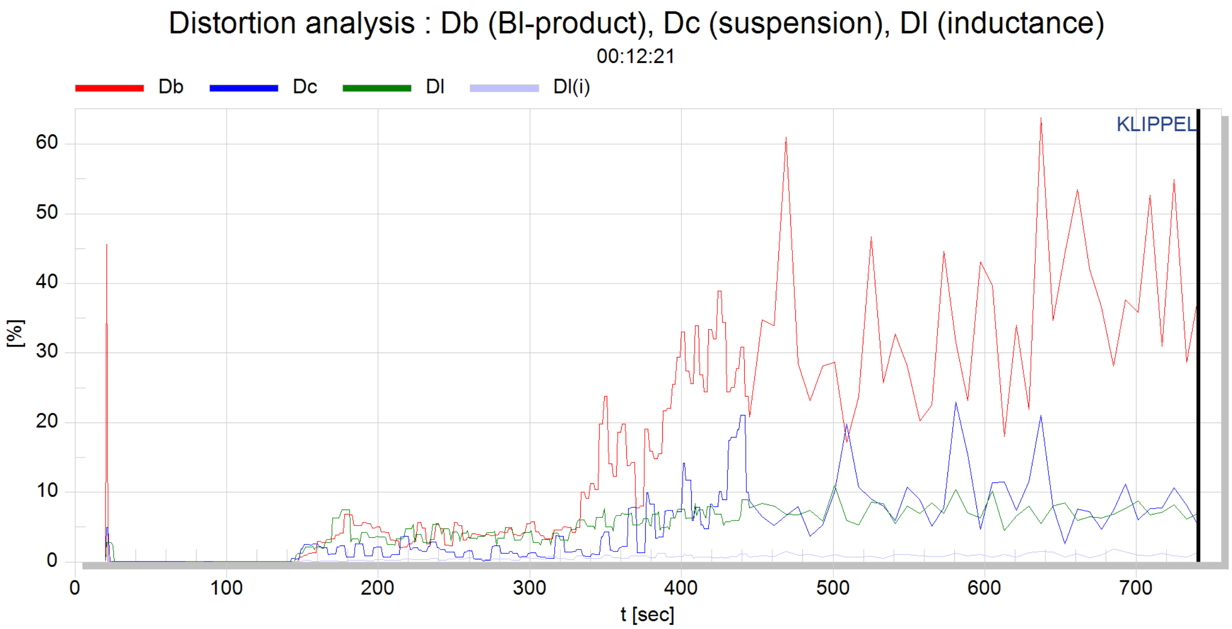
Distortion Analysis

The Distortion Analysis shows the contribution of each nonlinearity to the total distortion in the reproduced output signal for the audio-like excitation signal used during parameter measurement. The identified digital model of the transducer makes it possible to measure the peak value of the distortion components generated by force factor, compliance and inductance and to relate each value to the peak value of the total output signal (sound pressure):

d_b	relative degree of distortion generated by nonlinear Bl-product (force factor)
d_C	relative degree of distortion generated by nonlinear compliance
d_L	relative degree of distortion generated by nonlinear inductance (versus displacement)
$d_{L(i)}$	relative degree of distortion generated by nonlinear inductance (versus current)

The distortion analysis is performed simultaneously with the parameter identification. The relative degrees of distortion are expressed in percent and presented versus measurement time (in seconds) for the transducer under test:





Each degree is a one-number representation of the distortion summarizing all of the harmonic and intermodulation components. Please note that the amount of distortion depend on the spectral properties of the excitation signal.

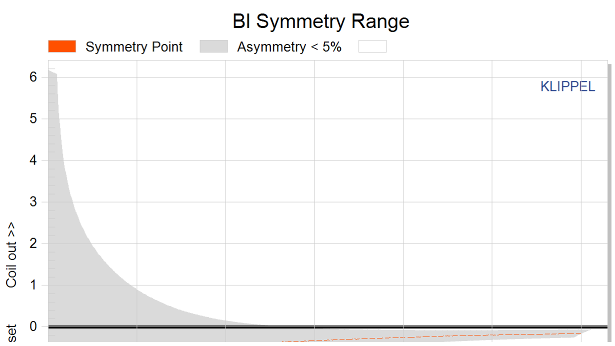
Remedies for Transducer Nonlinearities

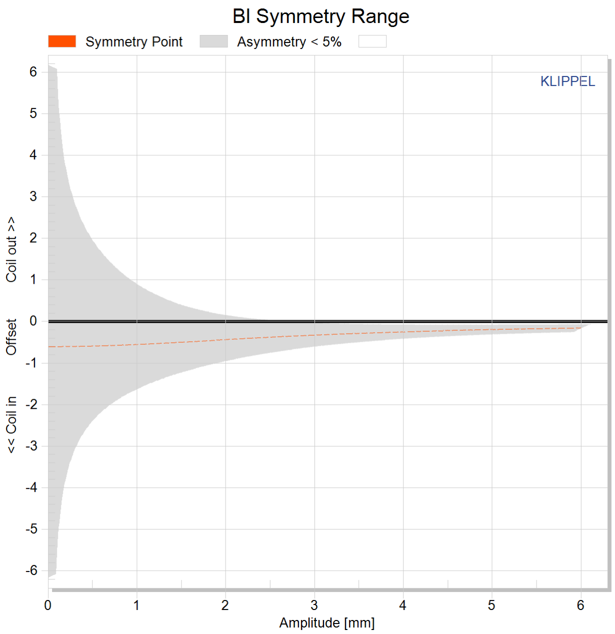
Bl Symmetry $x_b(x)$

This curve shows *the* symmetry point in the nonlinear Bl-curve where a negative and positive displacement $x=x_{peak}$ will produce the same force factor

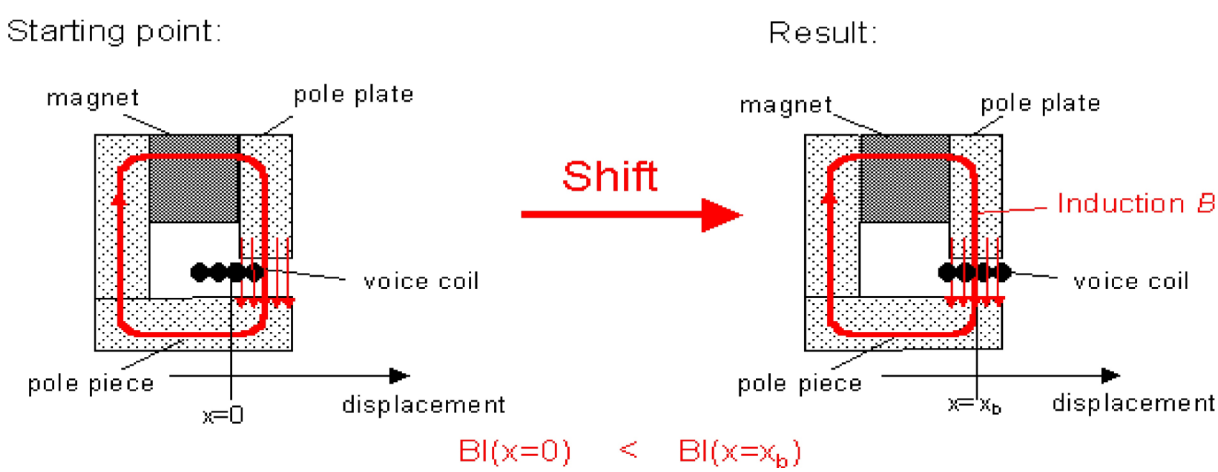
$$Bl(x_b(x) + x) = Bl(x_b(x) - x).$$

The plot also shows the symmetry region (less than 5 % asymmetrical variation of Bl) as a grey area around the symmetry point.
If the x-axis is within the symmetry region the asymmetries are negligible.
If the symmetry point $x_b(x)$ is independent on the displacement amplitude x then the force factor asymmetry is caused by an offset of the voice coil position and can be simply compensated by shifting.
If the optimal shift $x_b(x)$ varies with the displacement amplitude x then the force factor asymmetry is caused by an asymmetrical geometry of the magnetic field and can not completely be compensated by coil shifting.





Improving the rest position of the Coil



K_{ms} Symmetry $x_c(x)$

This curve shows *the* symmetry point in the nonlinear stiffness curve where a negative and positive displacement $x=x_{peak}$ will produce the same stiffness value

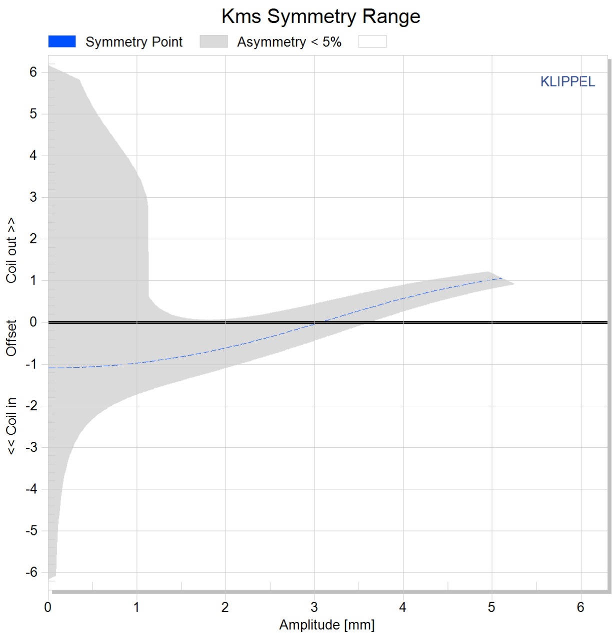
$$K_{ms}(x_c(x) + x) = K_{ms}(x_c(x) - x).$$

The plot also shows the symmetry region (less than 5 % asymmetrical variation of K_{ms}) as a grey area around the symmetry point.

If the x-axis is within the symmetry region the asymmetries are negligible.

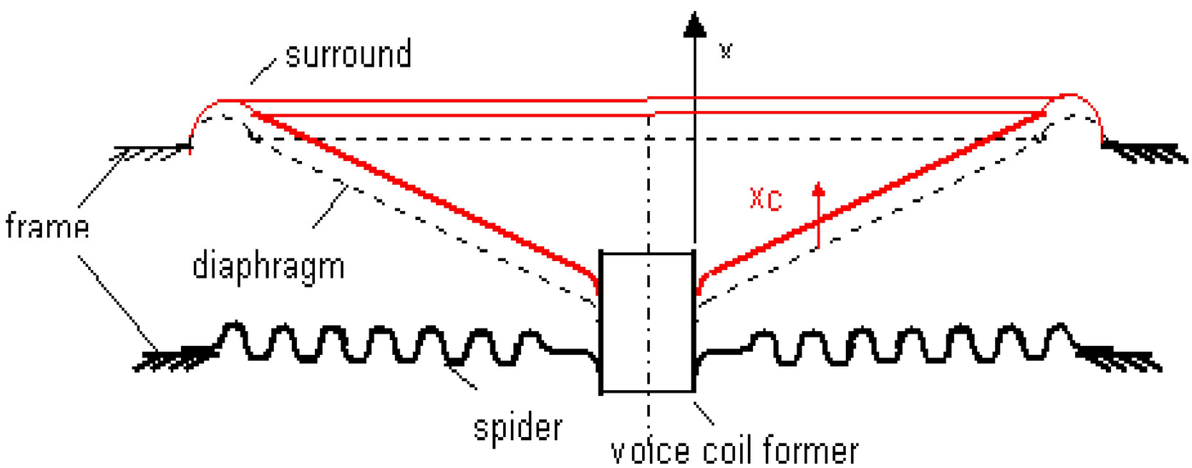
A high value of the symmetry point $x_c(x)$ at small displacement amplitudes $x \approx 0$ indicates that the rest position does not agree with the minimum of the stiffness characteristic. This may be caused by an asymmetry in the geometry of the spider (cup form) or surround (half wave).

A high value of the symmetry point $x_c(x)$ at maximal displacement $x \approx x_{max}$ may be caused by asymmetric limiting of the surround.



Adjustment of spider and surround

The asymmetry of the suspension may be reduced by reducing the distance x_R between spider and outer rim of the surround.



Please find more information in Application Note 1,2,3 (10/2001)

This report is generated by the report generator in the frame software *dB-Lab* in the KLIPPEL ANALYZER SYSTEM. Using an existing report as template, the old data are replaced by the results of the current measurement automatically.	
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