Klippel Non-Linear Test Results

LSI (Large Signal Identification)

Driver Name: ND90-4

Introduction

Large Signal Modeling

At higher amplitudes, loudspeakers produce substantial distortion in the output signal, generated by nonlinear ties inherent in the transducer. The dominant nonlinear distortions are predictable and are closely related with the general principle, particular design, material properties and assembling techniques of the loudspeaker. The Klippel Distortion Analyzer combines nonlinear measurement techniques with computer simulation to explain the generation of the nonlinear distortions, to identify their physical causes and to give suggestion for constructional improvements. Better insight into the nonlinear mechanisms makes it possible to further optimize the transducer in respect with sound quality, weight, size and cost.

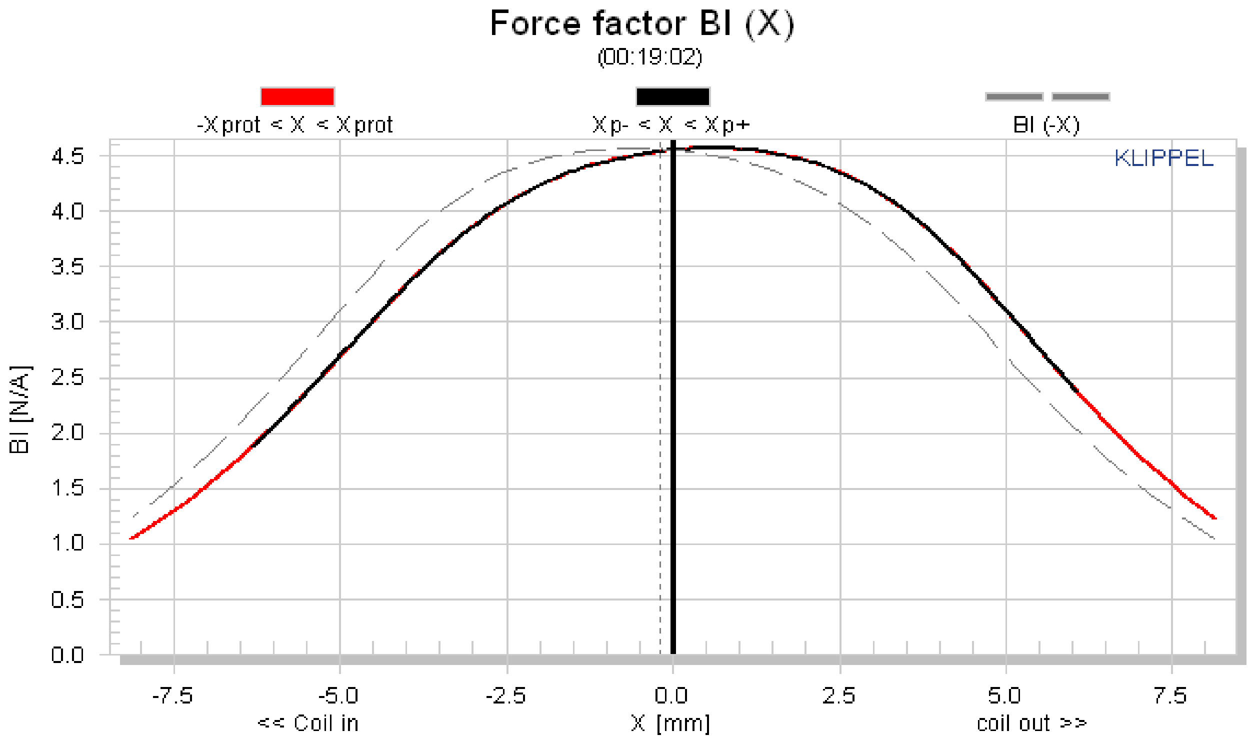
Nonlinear Characteristics

The dominant nonlinearities are modelled by variable parameters such as

Bl(x)	instantaneous electro-dynamic coupling factor (force factor of the motor) defined by the integral of the magnetic flux density B over voice coil length l as a function of displacement
KMS(x)	mechanical stiffness of driver suspension a function of displacement
LE(i)	voice coil inductance as a function of input current (describes nonlinear permeability of the iron path)
LE(x)	voice coil inductance as a function of displacement

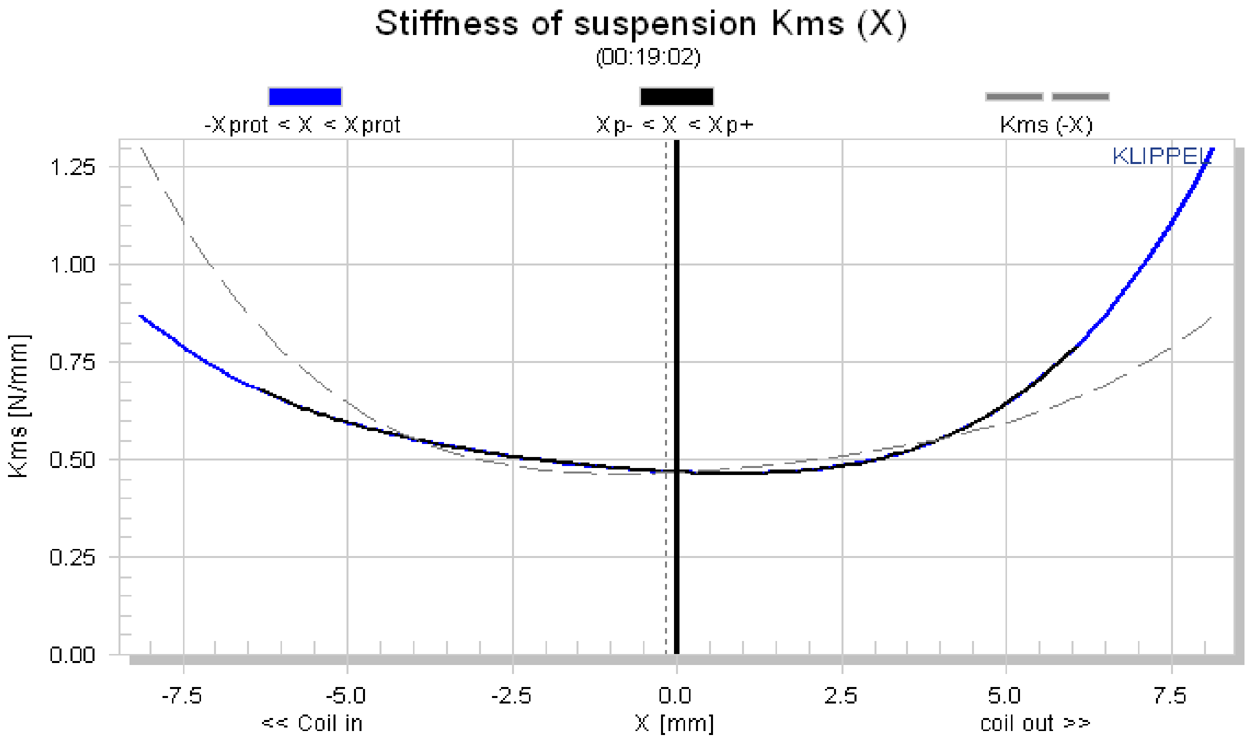
More information about these parameters can be found in the article “Displacement limits”

Nonlinear Parameters



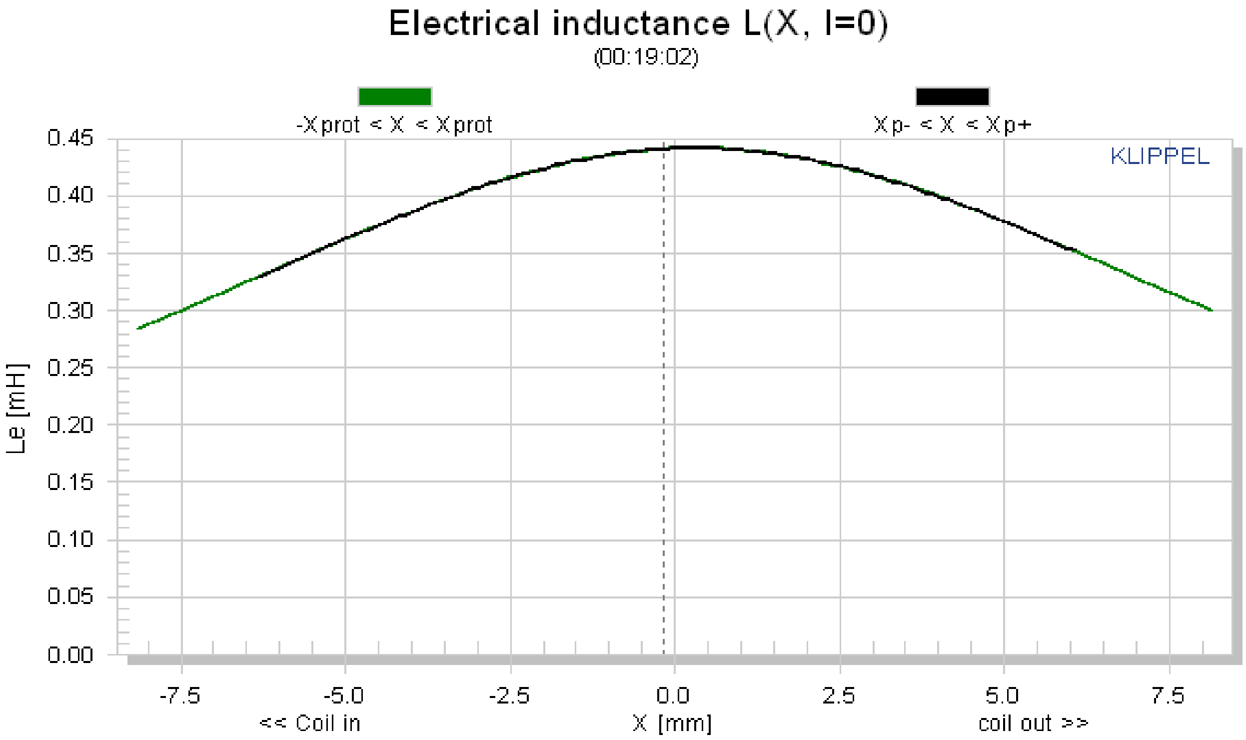
The electrodynamic coupling factor, also called Bl-product or force factor Bl(x), is defined by the integral of the magnetic flux density B over voice coil length l, and translates current into force. In traditional modeling this parameter is assumed to be constant. The force factor Bl(0) at the rest position corresponds with the Bl-product used in linear modeling. The red curve displays Bl over the entire displacement range covered during the measurement. You see the typical decay of Bl when the voice coil moves out of the gap.At the end of the measurement, the black curve shows the confidential range (interval where the voice coil displacement in this range occurred 99% of the measurement time). During the measurement, the black curve shows the current working range. The dashed curve displays Bl(x) mirrored at the rest position of the voice coil – this way, asymmetries can be quickly identified. Since a laser was connected during the measurement, a coil in / coil out marker is displayed on the bottom left / bottom right.

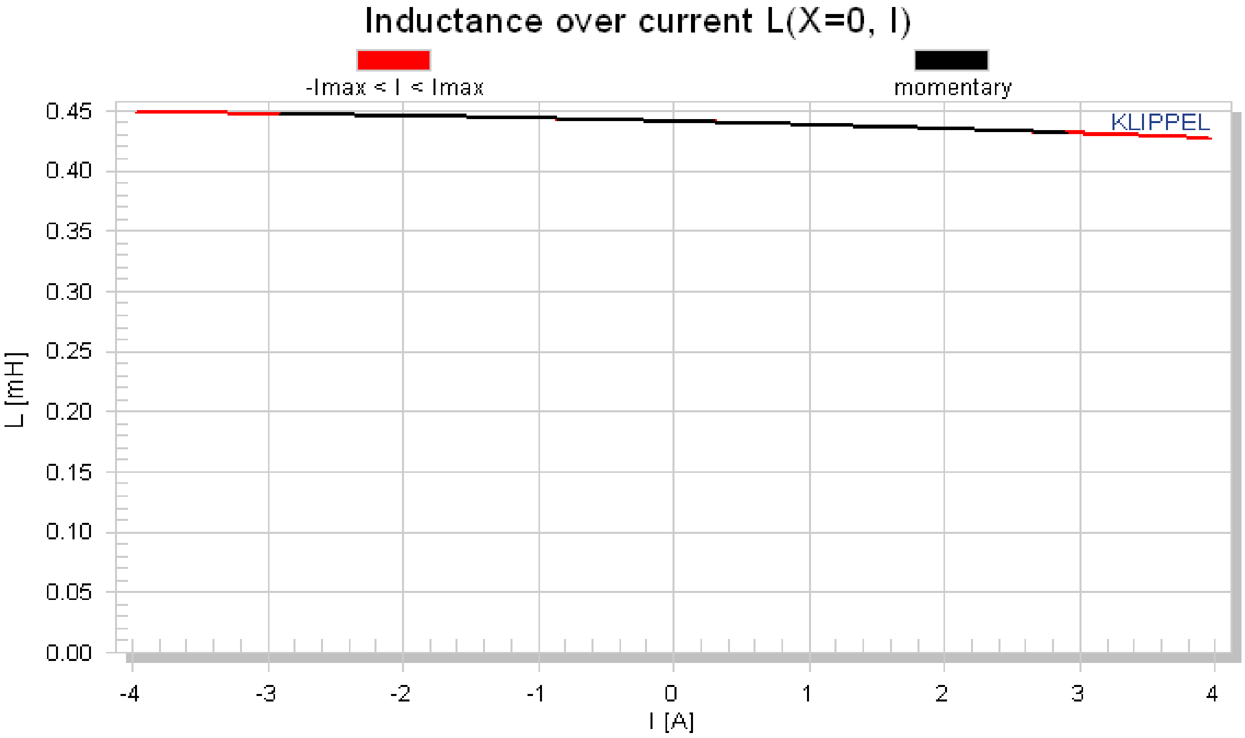
More information regarding Bl(x) and its optimization can be found in the article “Optimal Voice Coil Rest Position”



The stiffness KMS(*x)* describes the mechanical properties of the suspension. It's inverse is the compliance *CMS(x)*

More information regarding Kms(x) and its optimization can be found in the article “Adjusting Mechanical Suspension”





The inductance components Le (x) and Bl(i) of most drivers have a strong asymmetric characteristic. If the voice coil moves towards the back plate the inductance usually increases since the magnetic field generated by the current in the voice coil has a lower magnetic resistance due to the shorter air path.

The nonlinear inductance Le(x) has two nonlinear effects. First the variation of the electrical impedance with voice coil displacement x affects the input current of the driver. Here the nonlinear source of distortion is the multiplication of displacement and current. The second effect is the generation of a reluctance force which may be interpreted as an electromagnetic motor force proportional to the squared input current.

The flux modulation Bl(i) has two effects too. On the electrical side the back EMF Bl(i)*v produces nonlinear distortion due to the multiplication of current i and velocity v. On the mechanical side the driving force F = Bl(i)*i comprises a nonlinear term due to the squared current i. This force produces similar effects as the variable term Le(x).

Nonlinear Parameters

The displacement limits XBL, XC, XL and Xd describe the limiting effect for the force factor Bl(x), compliance Cms(x), inductance Le(x) and Doppler effect, respectively, according to the threshold values Blmin, Cmin, Zmax and d2 used. The thresholds Blmin= 82 %, Cmin=75 %, Zmax=10 % and d2=10% generate for a two-tone-signal (f1=fs, f2=8.5fs) 10 % total harmonic distortion and 10 % intermodulation distortion. The thresholds Blmin= 70 %, Cmin=50 %, Zmax=17 % create 20 % total harmonic distortion which is becoming the standard for acceptable subwoofer distortion thresholds.

Traditionally, Xmax has been defined as the physical overhang of the voice coil, 15% times the physical overhang, or the point where BL has dropped 70% from its X=0 value (same as X Bl). The additional nonlinear limits allow us to quantify the other factors that limit a loudspeaker’s performance.

These parameters are defined in more detail in the papers: “AN04 – Measurement of Peak Displacement Xmax”, “AN05 - Displacement Limits due to Driver Nonlinearities.”, “AN17 - Credibility of Nonlinear Parameters”, “Prediction of Speaker Performance at High Amplitudes”, “Assessment of Voice Coil Peak Displacement Xmax”, and “Assessing Large Signal Performance of Loudspeakers”

Symbol	**Number**	**Unit**	**Comment**
Displacement Limits			thresholds can be changed in Processing property page
X Bl @ Bl min=82%	3.3	mm	Displacement limit due to force factor variation
X C @ C min=75%	4.8	mm	Displacement limit due to compliance variation
X L @ Z max=10 %	>6.0	mm	Displacement limit due to inductance variation
X d @ d2=10%	19.7	mm	Displacement limit due to IM distortion (Doppler)
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 constamt 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
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
f1	-0.006115	1/A	coefficient (1) of Inductance over current (flux modulation)
f2	-0.000457	1/A^2	coefficient (2) of Inductance over current (flux modulation)
Bl0 = Bl (X=0)	4.6298	N/A	constant part in force factor
Bl1	0.065773	N/Amm	1st order coefficient in force factor expansion
Bl2	-0.077099	N/Amm^2	2nd order coefficient in force factor expansion
Bl3	-0.00098838	N/Amm^3	3rd order coefficient in force factor expansion
Bl4	0.00034136	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)	0.44012	mH	constant part in inductance
L1	0.0019246	mH/mm	1st order coefficient in inductance expansion
L2	-0.0031499	mH/mm^2	2nd order coefficient in inductance expansion
L3	-1.4492e-005	mH/mm^3	3rd order coefficient in inductance expansion
L4	1.4141e-005	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)	2.1454	mm/N	constant part in compliance
C1	0.010852	1/N	1st order coefficient in compliance expansion
C2	-0.021891	1/Nmm	2nd order coefficient in compliance expansion

C3	-0.00071187	1/Nmm^2	3rd order coefficient in compliance expansion
C4	4.2192e-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	-0.0083501	N/mm^2	1st order coefficient in stiffness expansion
K2	0.0042013	N/mm^3	2nd order coefficient in stiffness expansion
K3	0.00052573	N/mm^4	3rd order coefficient in stiffness expansion
K4	7.7367e-005	N/mm^5	4th order coefficient in stiffness expansion
Xpse	8.1	mm	-Xpse < X < Xpse, range where power series is fitted

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 modelling and may be referred as “linear parameters”. Please note that these parametersdepend 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| < xmax*), the variation of the parameters is not negligible, the voice coil temperature is increased (D *TV > 0*) due to heating.
LARGE+COLD	the transducer is operated in the large signal domain, the peak value of the displacement is high (|x| < xmax), the variation of the parameters is not negligible, the effect of heating is compensated while considering the cold voice coil resistance *Re(*D *TV =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| << xmax*), the variations of the nonlinear parameters are negligible, the increase of voice coil temperature is negligible (D *TV » 0*), the effects of the nonlinear, thermal and time-varying mechanisms are negligible, the transducer behaves almost linear.

Linear Parameters

Symbol	**Large + Warm**	**Large + Cold**	**Small Signal**	**Unit**	**Comment**
Note:					for accurate small signal parameters, use LPM module
Delta Tv =	29	0	0	K	increase of voice coil temperature during the

Tv-Ta					measurement
Xprot	8.1	8.1	4.1	mm	maximal voice coil excursion (limited by protection system)
Re (Tv)	4.52	4.07	4.07	Ohm	(imported) voice coil resistance considering increase of voice coil temperature Tv
Le (X=0)	0.44	0.44	0.38	mH	voice coil inductance at the rest position of the voice coil
L2 (X=0)	1.21	1.21	0.46	mH	para-inductance at the rest position due to the effect of eddy current
R2 (X=0)	1.62	1.62	1.77	Ohm	resistance at the rest position due to eddy currents
Cmes (X=0)	305	305	303	µF	electrical capacitance representing moving mass
Lces (X=0)	39.37	39.37	20.80	mH	electrical inductance at the rest position representing driver compliance
Res (X=0)	52.47	52.47	25.33	Ohm	resistance at the rest position due to mechanical losses
Qms (X=0, Tv)	4.62	4.62	3.06		mechanical Q-factor considering Rms only
Qes (Tv)	0.35	0.32	0.44		electrical Q-factor considering Re (Tv) only
Qts (X=0, Tv)	0.33	0.30	0.38		total Q-factor considering Re (Tv) and Rms only
fs	46.0	46.0	63.4	Hz	driver resonance frequency
Mms	5.600	5.600	5.600	g	(imported) mechanical mass of driver diaphragm assembly including voice-coil and air load
Rms (X=0)	0.350	0.350	0.729	kg/s	mechanical resistance of total-driver losses
Cms (X=0)	2.14	2.14	1.13	mm/N	mechanical compliance of driver suspension at the rest position
Bl (X=0)	4.55	4.55	4.55	N/A	(imported) force factor at the rest position (Bl product)
Vas	2.7958	2.7958	1.4702	l	equivalent air volume of suspension
N0	0.074	0.082	0.082	%	reference efficiency (2Pi-sr radiation using Re)
Lm	80.8	81.3	81.3	dB	characteristic sound pressure level
Sd	30.43	30.43	30.43	cm²	diaphragm area

For accurate system modelling “Large + Cold” parameters are preferable to “Small Signal” parameters because they more closely reflect the parameters in their typical operating range.

Asymmetrical Nonlinearities

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<fS) 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>fS) 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. An 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 behaviour.

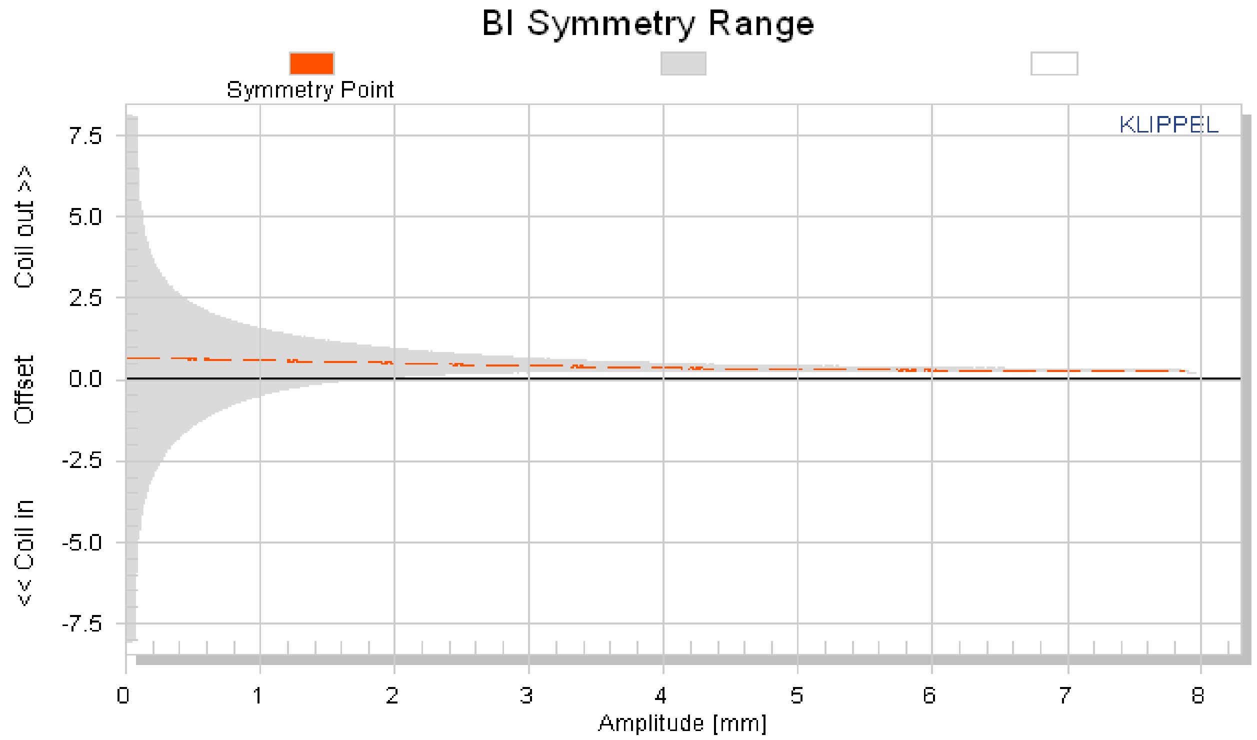
Bl Symmetry *xb(x)*

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

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

If the shift xb(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.

If the optimal shift xb(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.

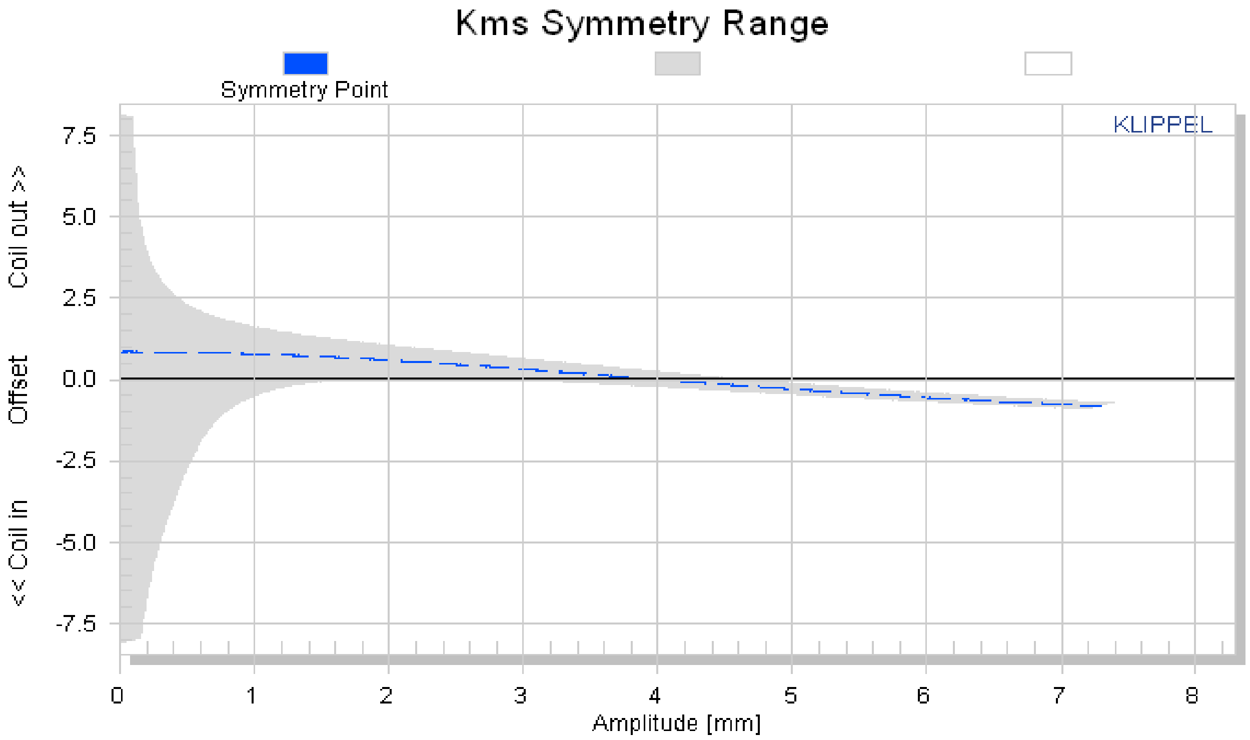


Kms Symmetry *xc(x)*

This curve shows *the* symmetry point in the nonlinear compliance curve where a negative and positive displacement x=xpeak will produce the same compliance value

kms(xc(x) + x) = kms(xc(x) – x).

A high value of the symmetry point *xc(x)* at small displacement amplitudes x » 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 *xc(x)* at maximal displacement *x» xmax* may be caused by asymmetric limiting of the surround.



You can find a detailed description of these non-linearities and their remedies in the papers "[Loudspeaker Nonlinearities - Causes and Symptoms](), [Assessing Large Signal Performance of Loudspeakers](), and [“Diagnosis and Remedy of Nonlinearities]()

Testing performed by Redrock Acoustics – www.redrockacoustics.com