

# PRACTICAL LOUDSPEAKER THD MODELING AND SIMULATION

# Introduction


When developing a loudspeaker, engineers now have a number of simulation tools :


- To develop magnet system, having at the end a good estimation of BL and  $BL(x)$ , Inductance  $Le(f)$  and  $Le(x)$
- To develop moving parts having at the end a good estimation of eigenfrequencies, frequency response, excursion,.... and  $Kms(x)$


**But having a good estimation of low frequency THD can be more difficult**



We are presenting in this workshop an efficient solution to estimate low frequency THD at early development stage based on a virtual prototype

**Goal**  Estimate low frequency THD at development stage

 Simulation of non-linear curves  $BL(x)$ ,  $Le(x)$ ,  $Kms(x)$   
(based on **Comsol** simulation in this presentation)

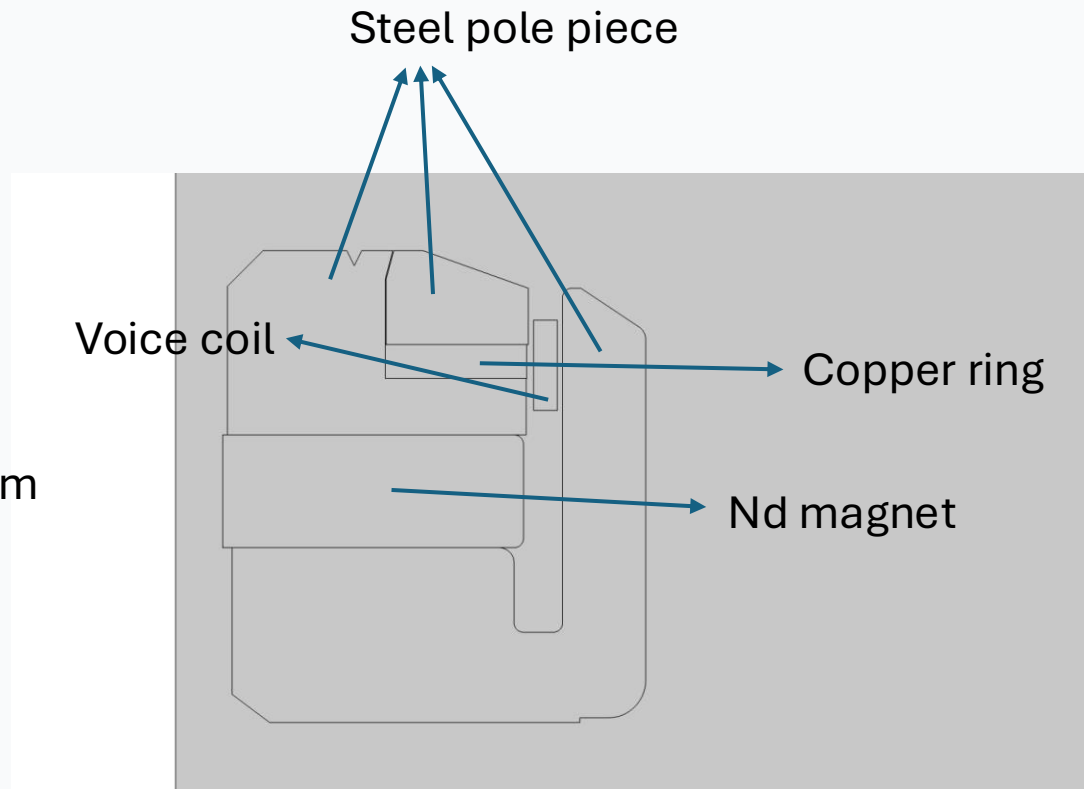
 Simulation of THD using **Klippel** simulation module  
based on simulated non-linear curves

- For this workshop we took as example a 6.5inch automotive loudspeaker
- We will show our methodology to estimate THD at development stage
- We will compare the results between virtual sample and real sample

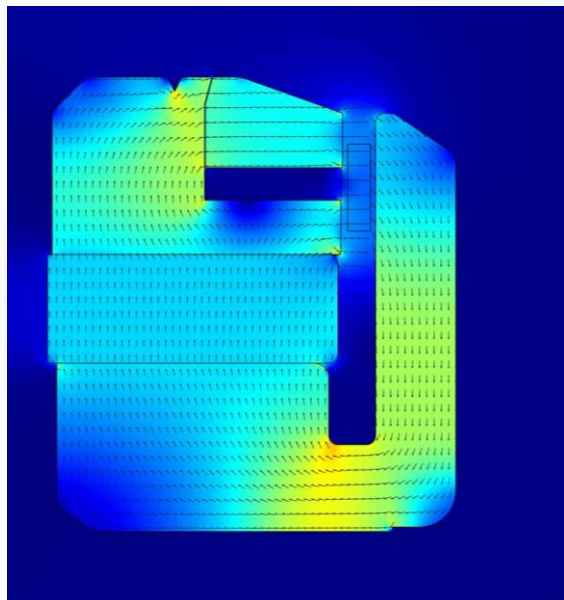


# Magnetic simulation – BL(x)

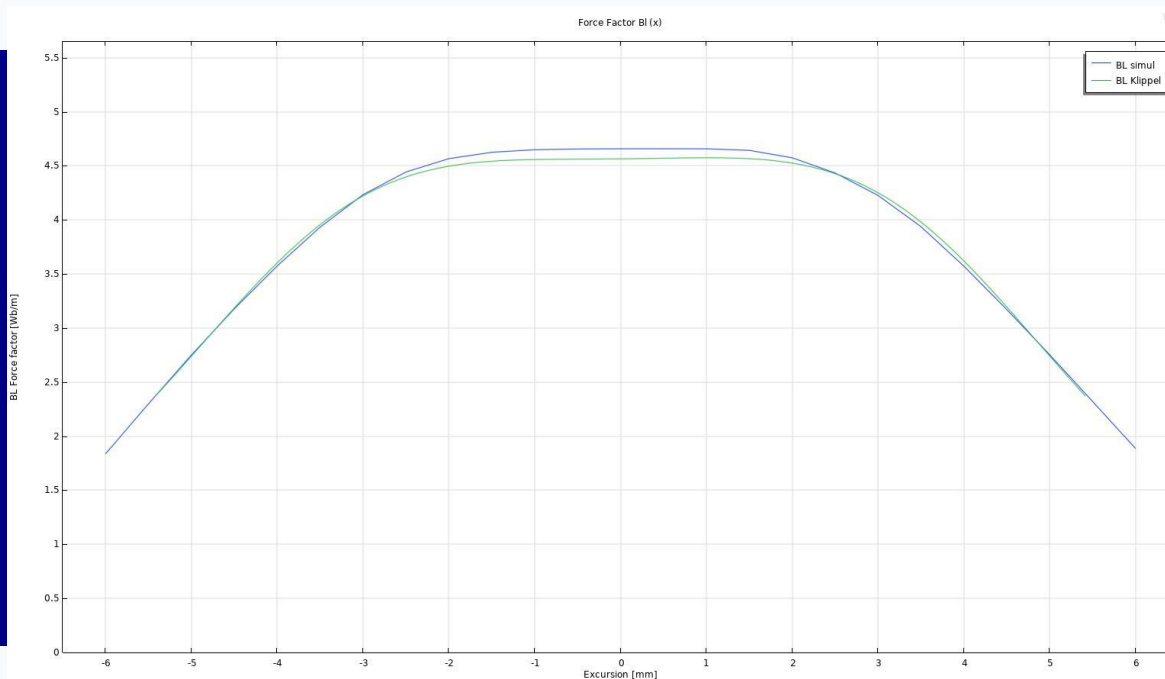
Model of magnet system



# Magnetic simulation – BL(x)

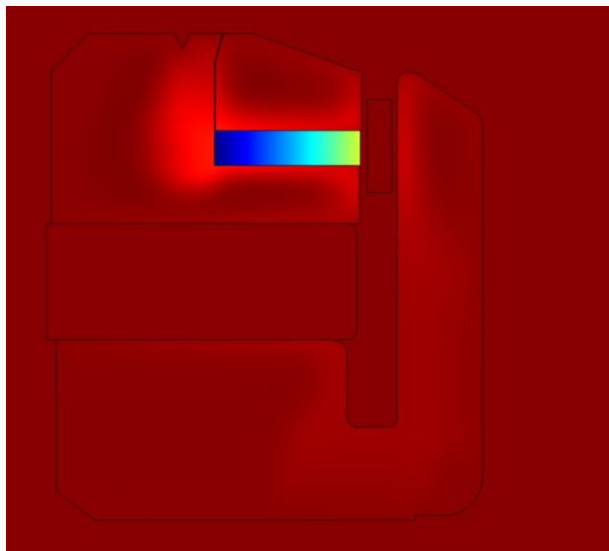


*Magnetic field*

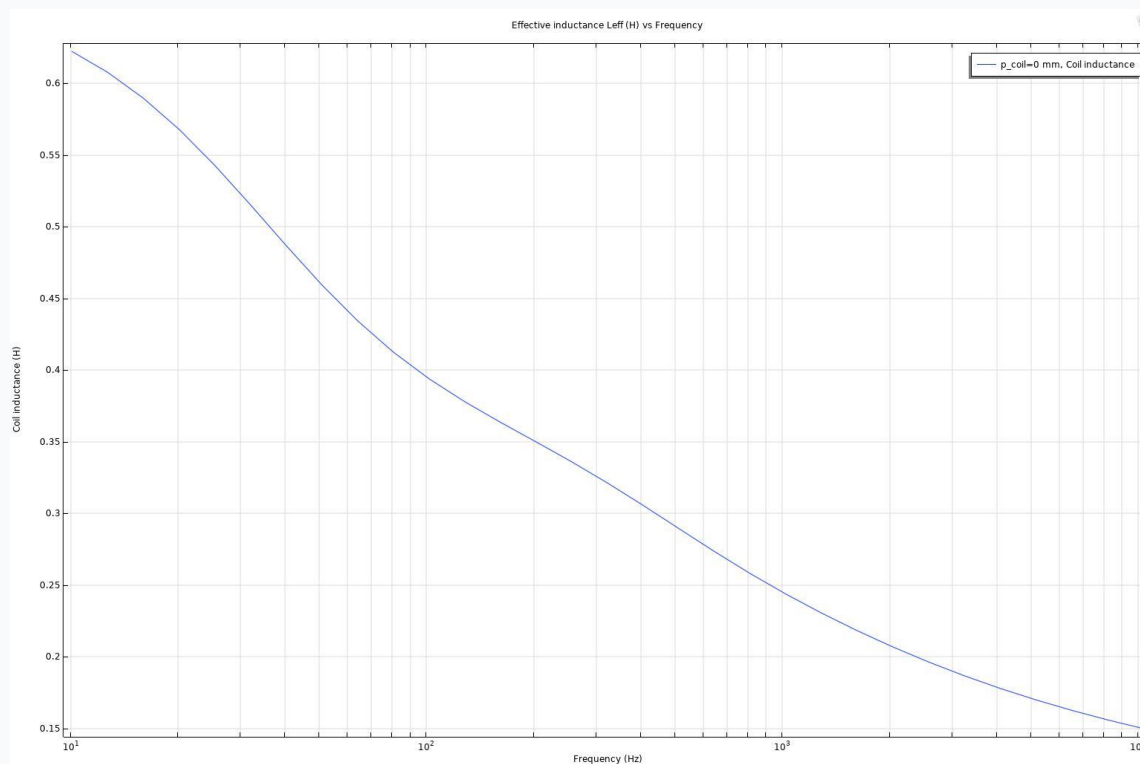


*BL(x)*

# Magnetic simulation – $Le(x)$

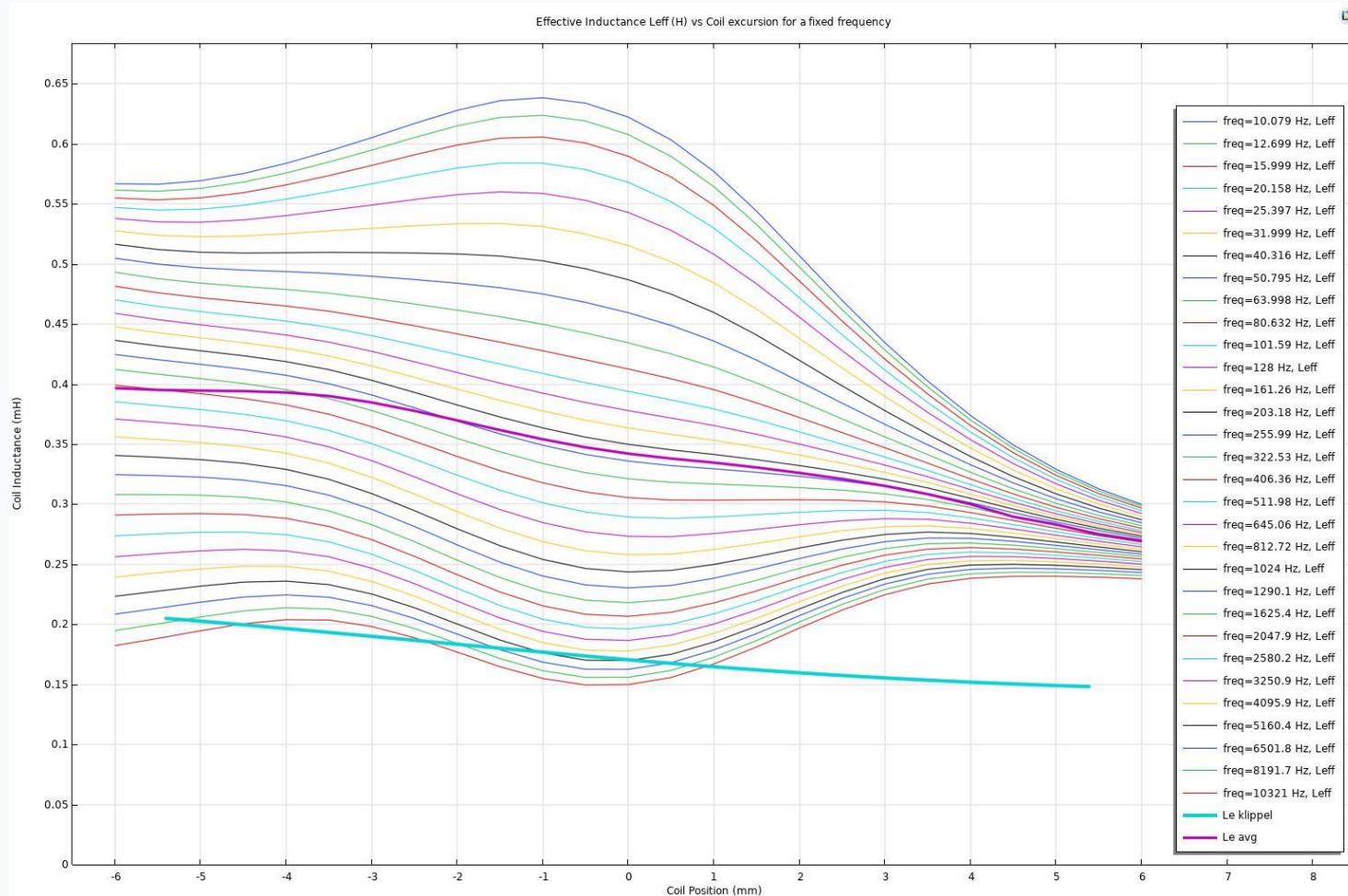


*Induced current @40Hz*



$Le(f)$

# Magnetic simulation – $L_e(x)$



## Magnetic simulation – $L_e(x)$

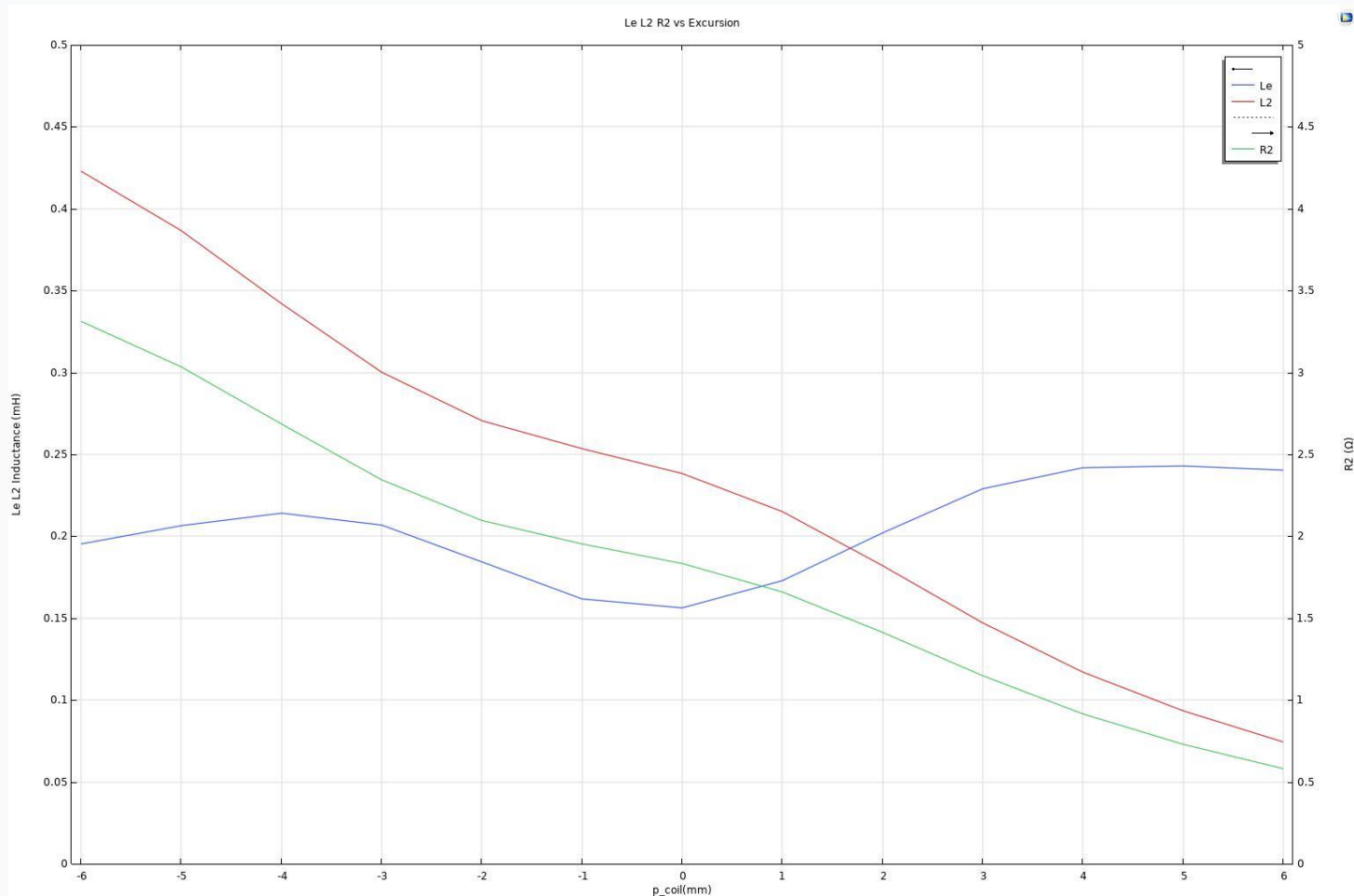
Regarding Inductance, Klippel LSI and Klippel simulation only show and use one single  $L_e(x)$  curve whereas in reality inductance is a function of both frequency and coil position ( $L_e(x,f)$ ).

Klippel LSI is calculating a « static » inductance. And Klippel simulation tool is using this « static » inductance.

So to get a single  $L_e(x)$  from Comsol we are using an average of all inductance curves calculated at all frequencies (from 10Hz to 10kHz) (purple curve in previous graph)

NB: Klippel has launch a new module (FLSI pro) showing dynamic inductance  $L_e(x,f)$   
But simulation tool still require 1 single  $L_e(x)$  curve

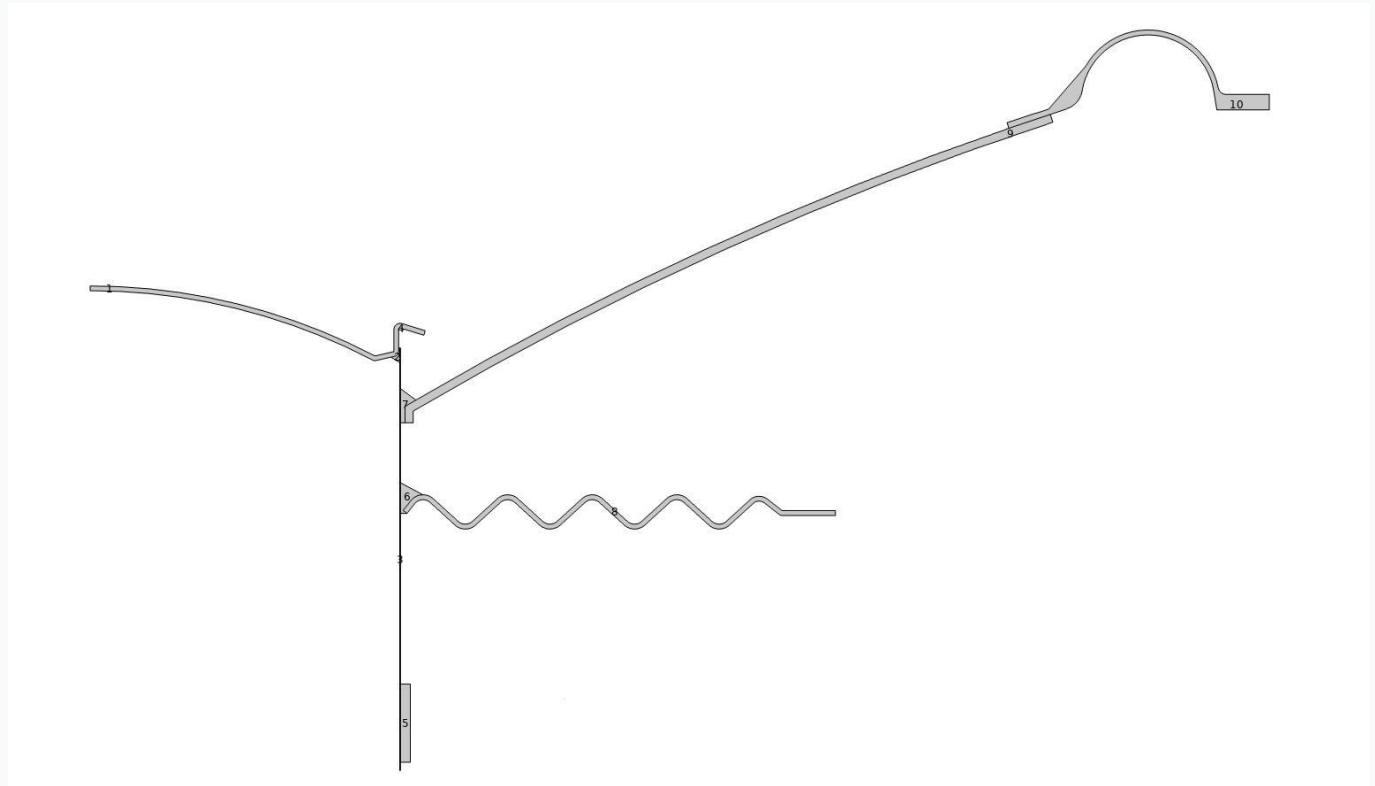
# Magnetic simulation – $L_e(x)$



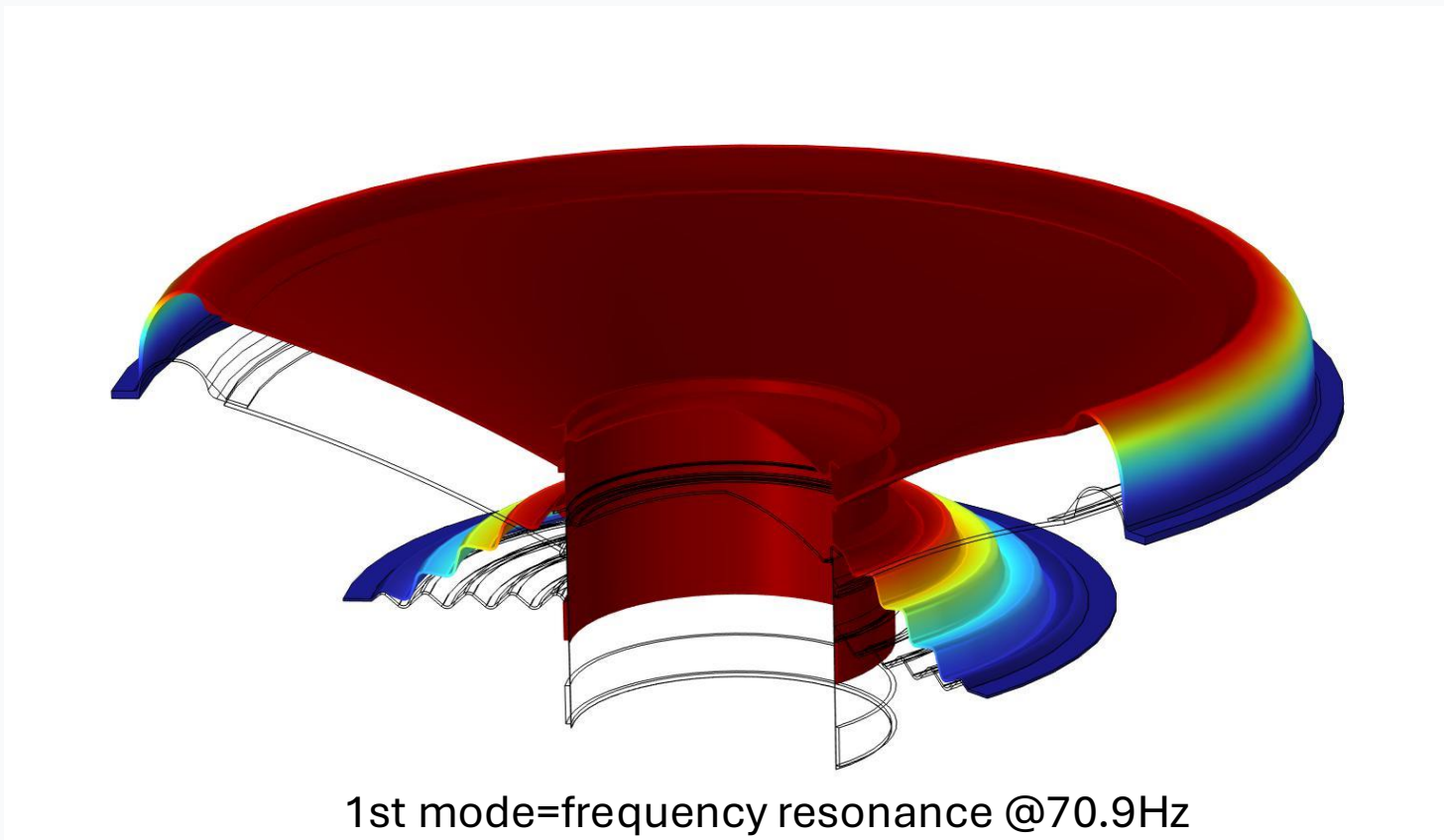
*Le, L2, R2*

# Mechanical simulation – Kms(x)

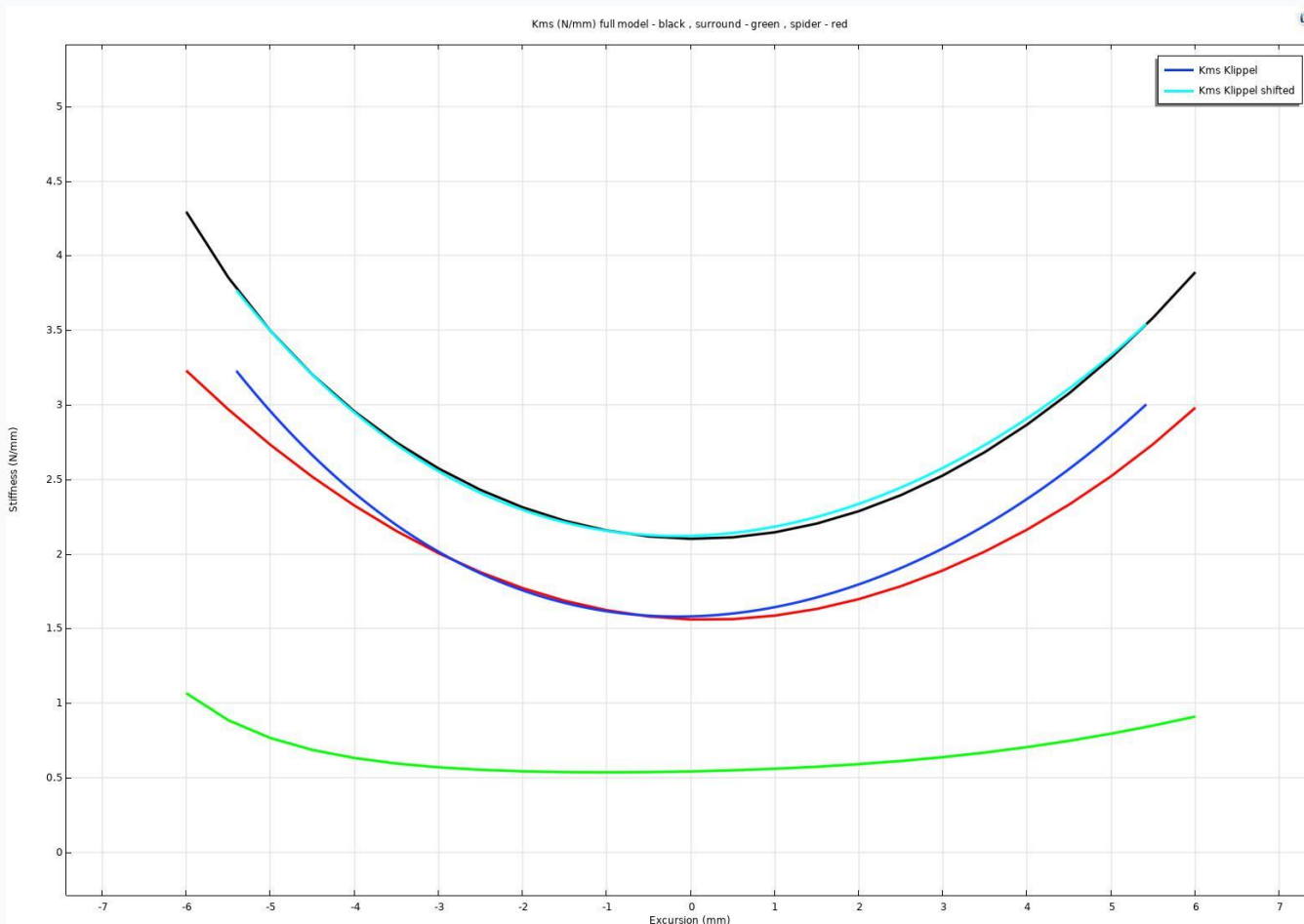
Mechanical model



## Mechanical simulation – Kms(x)



# Mechanical simulation – $K_{ms}(x)$



Simulated  $K_{ms}(x)$

# LPM simulation

## BOM moving parts (mass calculated from CAD)

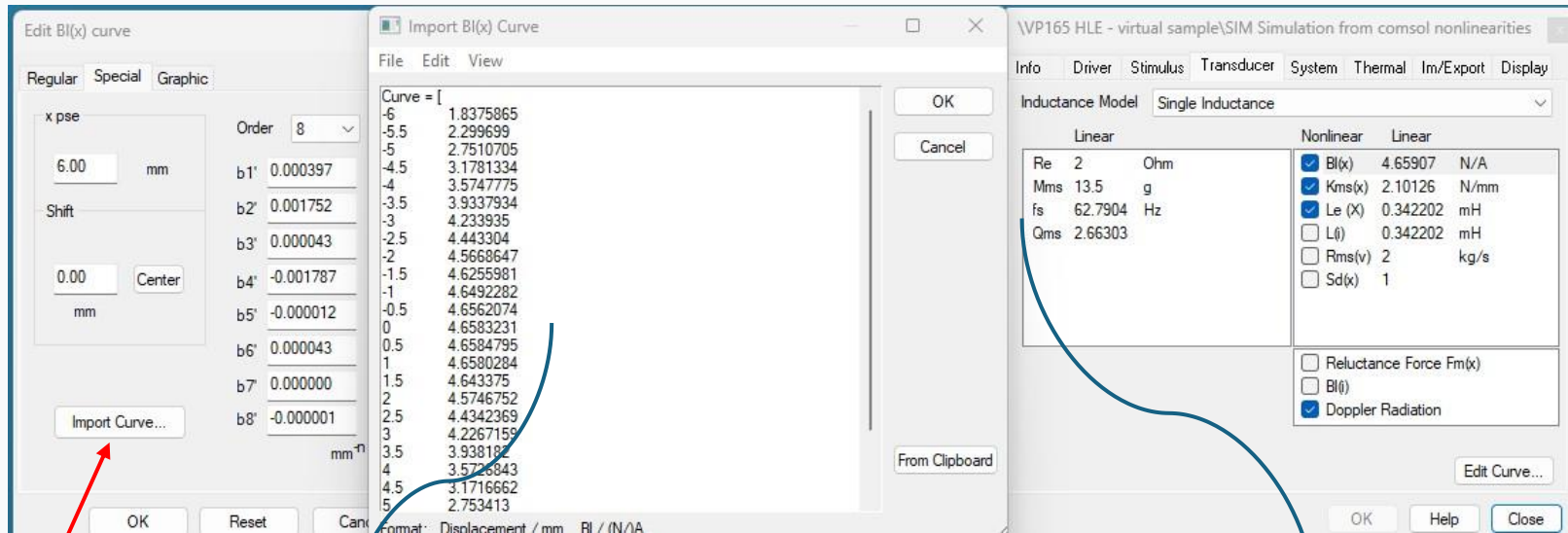
	mass (gr)
VC (4layer/Copper/0.28/56turns/2ohm)	3,9
surround (NBR)	2,85
VC former (Alu)	0,5
cone (paper)	3,5
dust cap (paper)	0,3
Glue	0,4
<b>Total</b>	<b>11,45</b>

## Calculated LPM

Re	2 ohm
Fs	70,9 Hz
Mmd	11,45 gr
Mms	13,5 gr
Kms	2,1 N/mm
Qms	2,7
Sd	132,7 cm <sup>2</sup>

# THD Simulation

➔ Use simulated non-linear curves and calculated LPM as Klippel simulation inputs

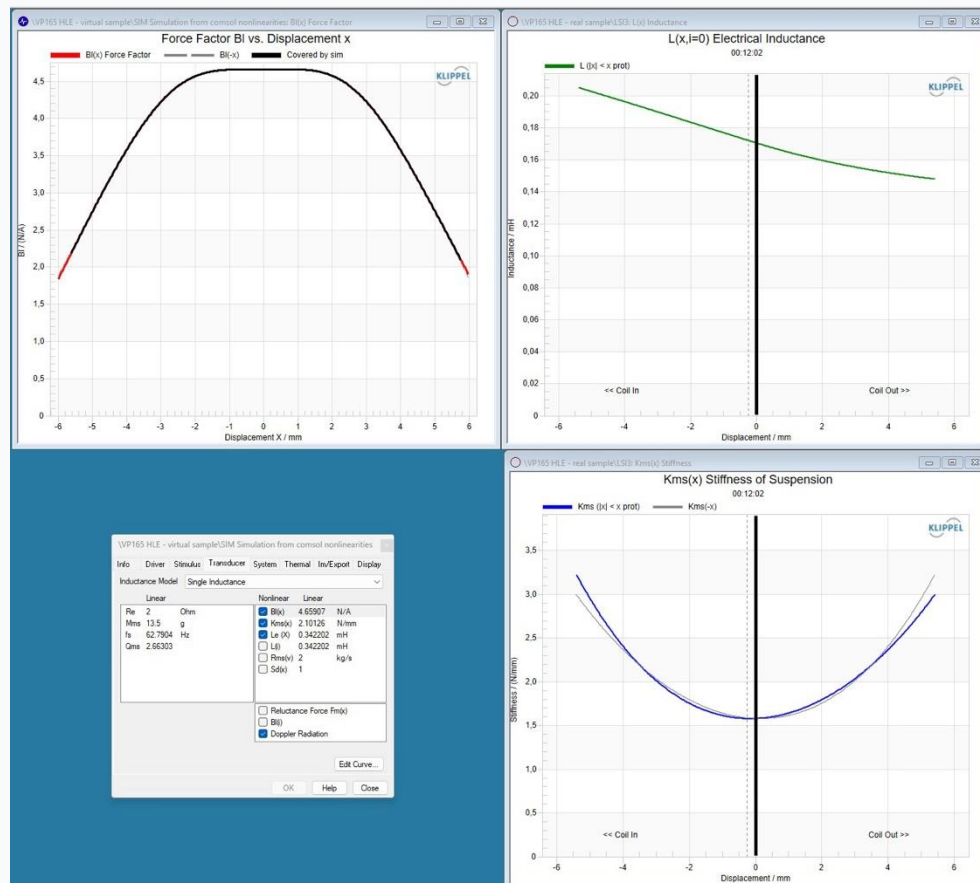


BL(x) curve from Comsol export

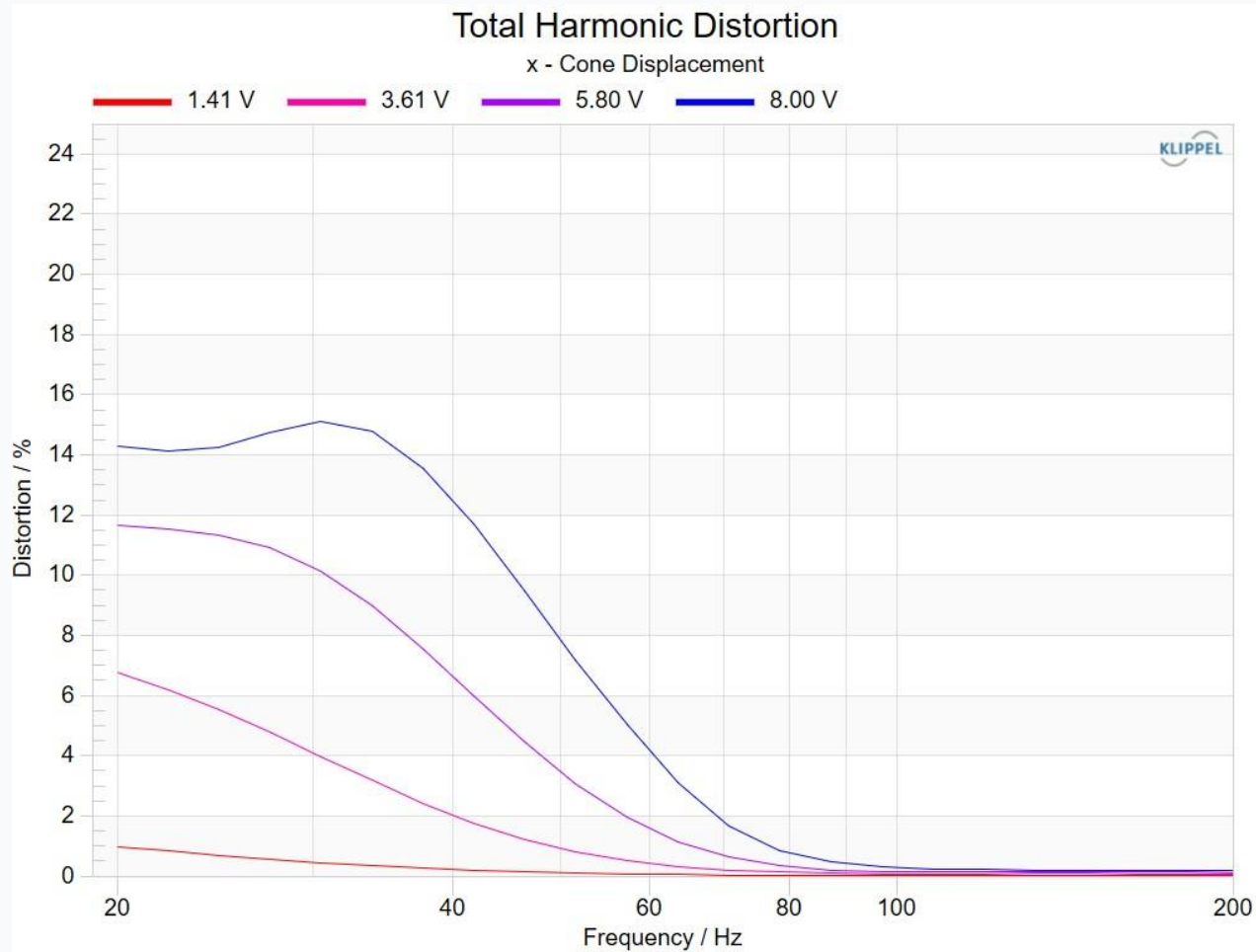
$F_s$  is calculated here based on  $K_{ms}(0)$  and  $m_{ms}$   
 $F_s$  in simulation is considering only  $m_{md}$ !

# THD Simulation

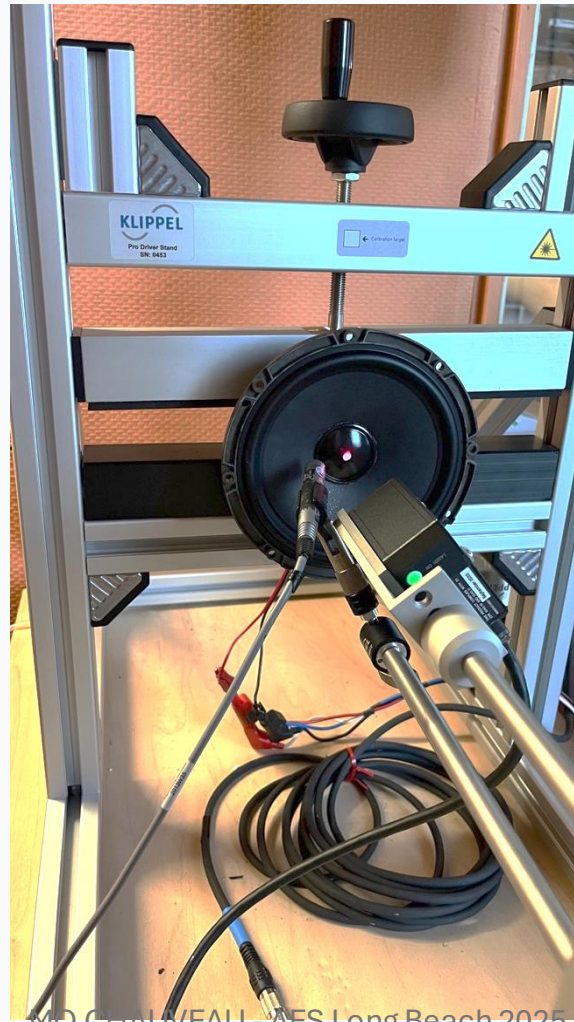
➔ Use simulated non-linear curves and calculated LPM as Klippel simulation inputs



# THD Simulation



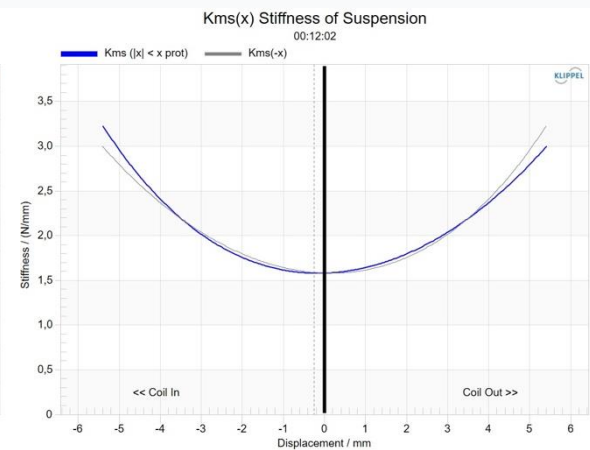
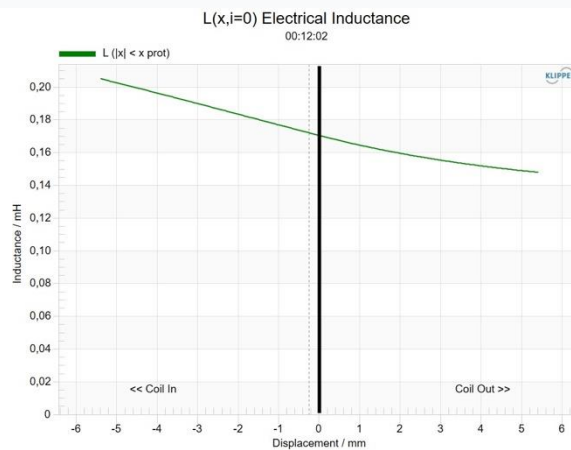
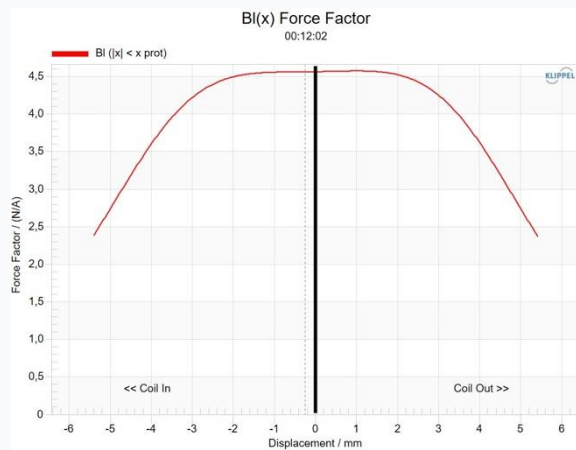
# Real sample measurement



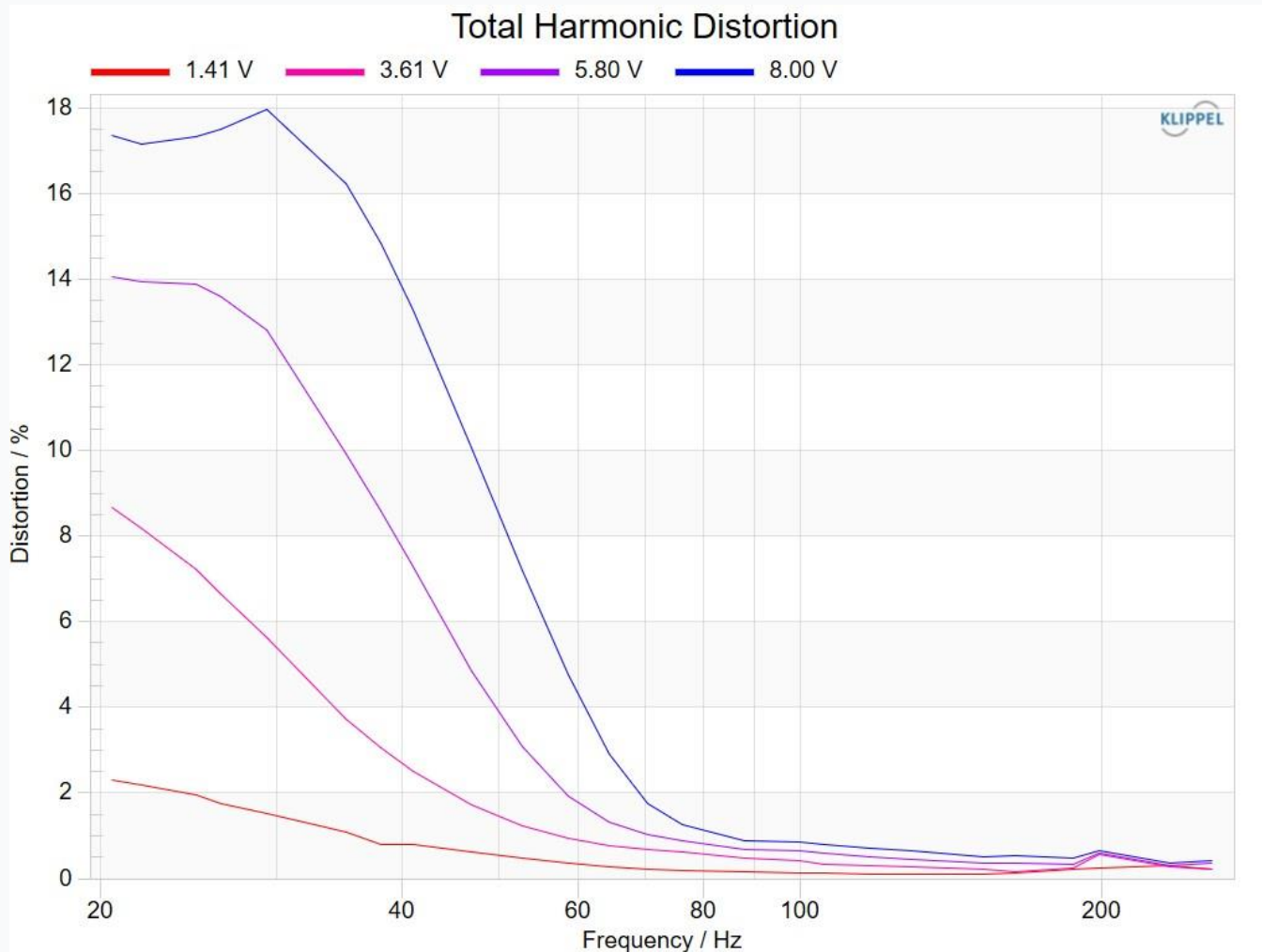
# LPM - Measured

Name	Value	Unit	Comment
<b>Electrical Parameters</b>			
Re	2.00	Ohm	electrical voice coil resistance at DC
Le	0.113	mH	frequency independent part of voice coil inductance
L2	0.162	mH	para-inductance of voice coil
R2	1.90	Ohm	electrical resistance due to eddy current losses
Cmes	656.69	µF	electrical capacitance representing moving mass
Lces	7.37	mH	electrical inductance representing driver compliance
Res	13.39	Ohm	resistance due to mechanical losses
fs	72.4	Hz	driver resonance frequency
<b>Mechanical Parameters</b>			
(using laser)			
Mms	13.684	g	mechanical mass of driver diaphragm assembly including air load and voice coil
Mmd (Sd)	11.956	g	mechanical mass of voice coil and diaphragm without air load
Rms	1.556	kg/s	mechanical resistance of total-driver losses
Cms	0.354	mm/N	mechanical compliance of driver suspension
Kms	2.83	N/mm	mechanical stiffness of driver suspension
Bl	4.565	N/A	force factor (Bl product)
Lambda s	0.069		suspension creep factor
<b>Loss factors</b>			
Qtp	0.521		total Q-factor considering all losses
Qms	3.998		mechanical Q-factor of driver in free air considering Rms only
Qes	0.598		electrical Q-factor of driver in free air considering Re only
Qts	0.520		total Q-factor considering Re and Rms only
<b>Other Parameters</b>			
Vas	8.8150	l	equivalent air volume of suspension
n0	0.537	%	reference efficiency (2 pi-radiation using Re)
Lm	89.32	dB	characteristic sound pressure level (at 1 m for 1 W @ Re)
Lnom	89.31	dB	nominal sensitivity (SPL at 1 m for 1 W @ Zn)
rmse Z	2.97	%	root-mean-square fitting error of driver impedance Z(f)
rmse Hx	2.01	%	root-mean-square fitting error of transfer function Hx(f)
Series resistor	0.00	Ohm	resistance of series resistor
Sd	132.73	cm <sup>2</sup>	diaphragm area

# Non-linearities - Measured

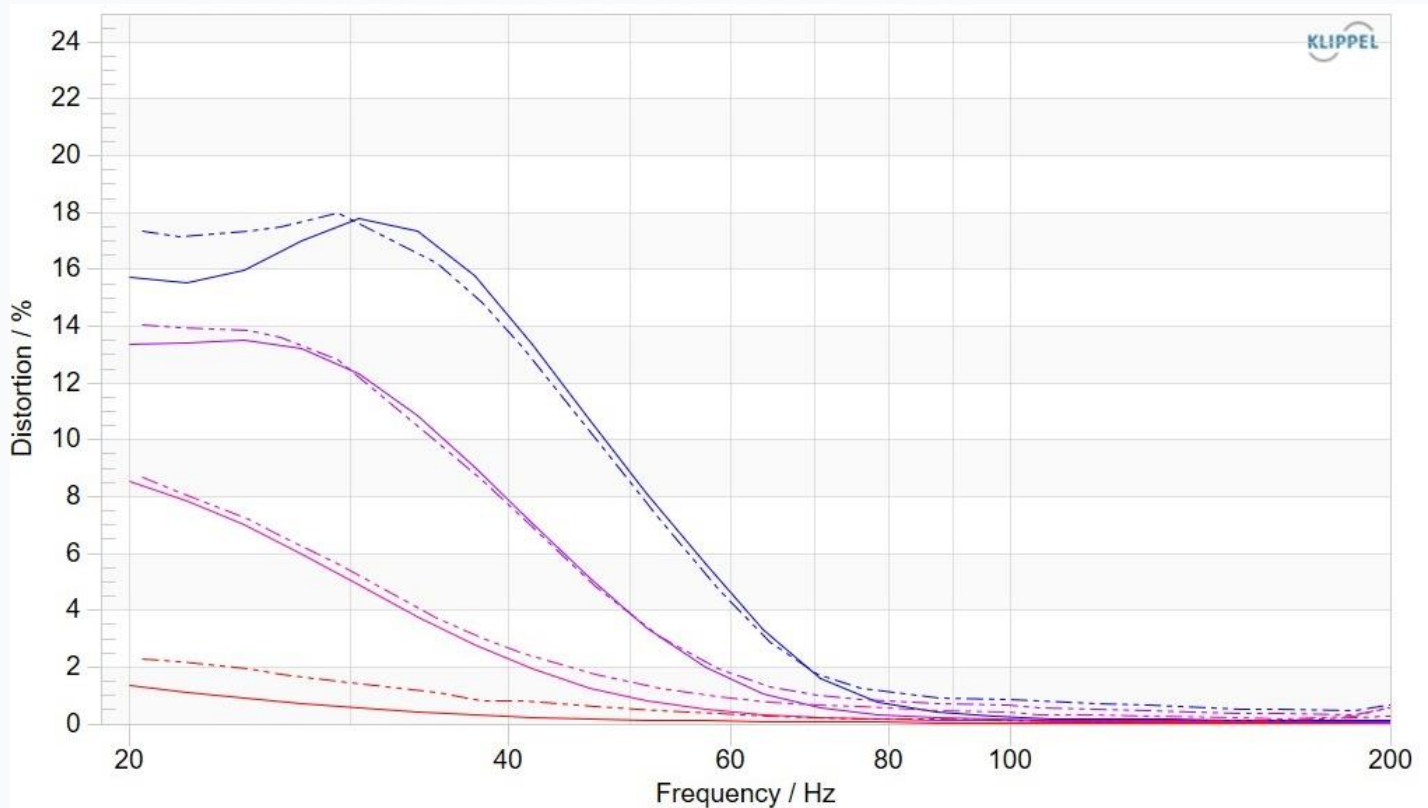


# Distortion - Measured



# Distortion – Simulation based on measured non-linearities

➔ Measured non-linear curves and LPM as Klippel simulation inputs (single inductance model)



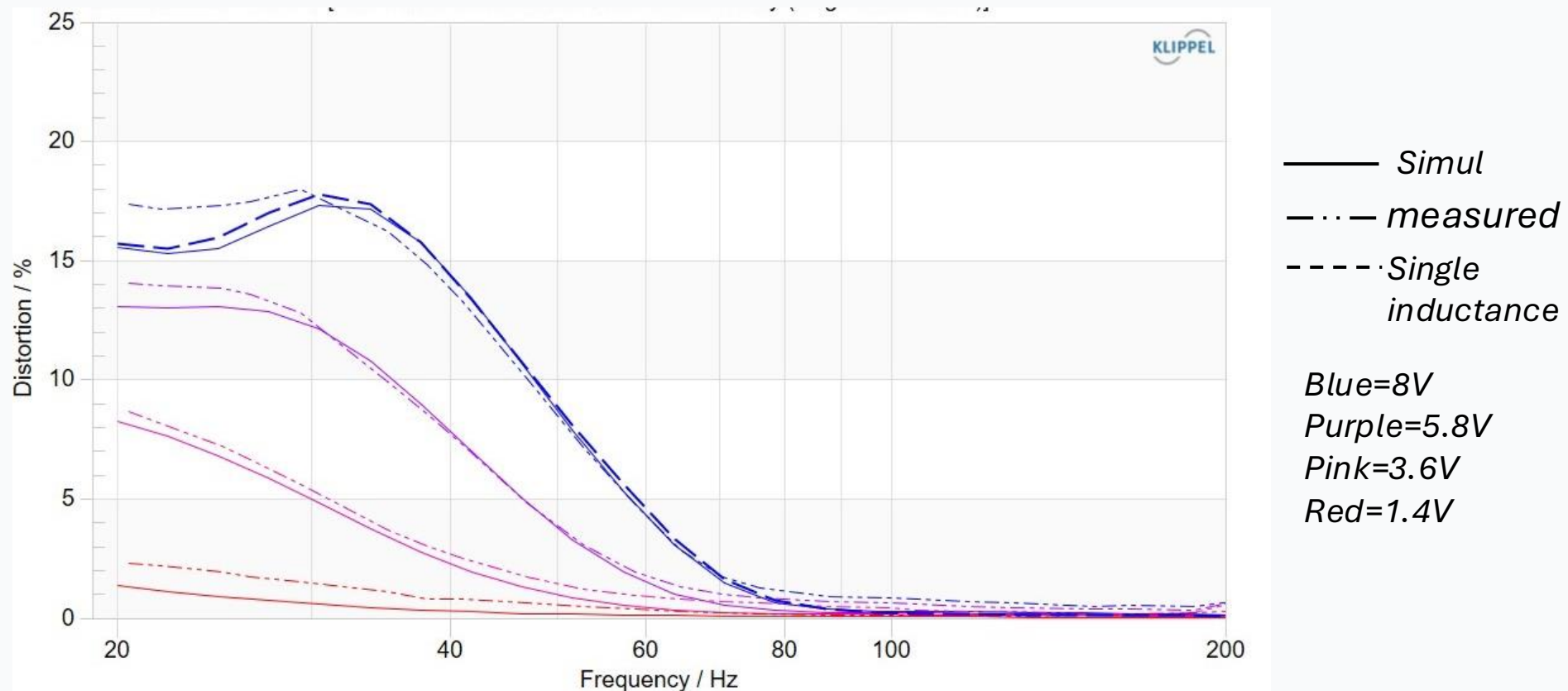
— Simul  
 - - - measured

Blue=8V  
 Purple=5.8V  
 Pink=3.6V  
 Red=1.4V

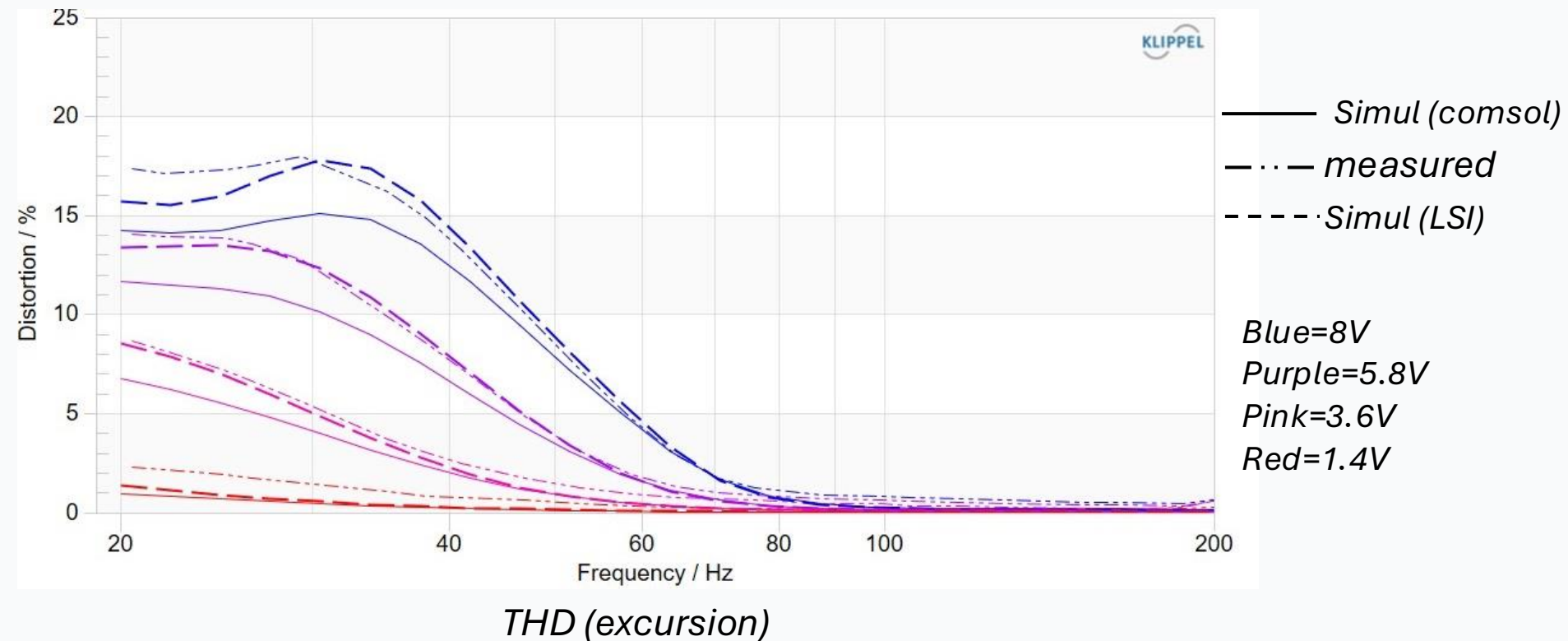
THD (excursion)

# Distortion – Simulation based on measured non-linearities

➔ Using LR-2 model



# Comparison between THD simulated based on simulation and real measured non-linearities



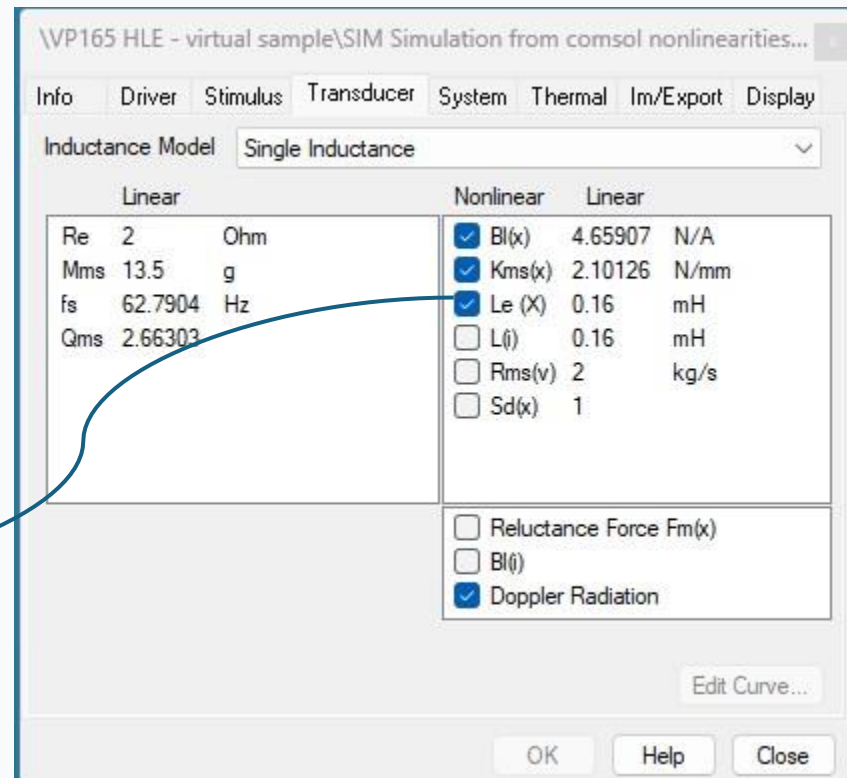
# Distortion – Comparison between THD simulated based on simulation and real measured non-linearities

We have seen  $L_e(x)$  from LSI is a « static »  $L_e$ .

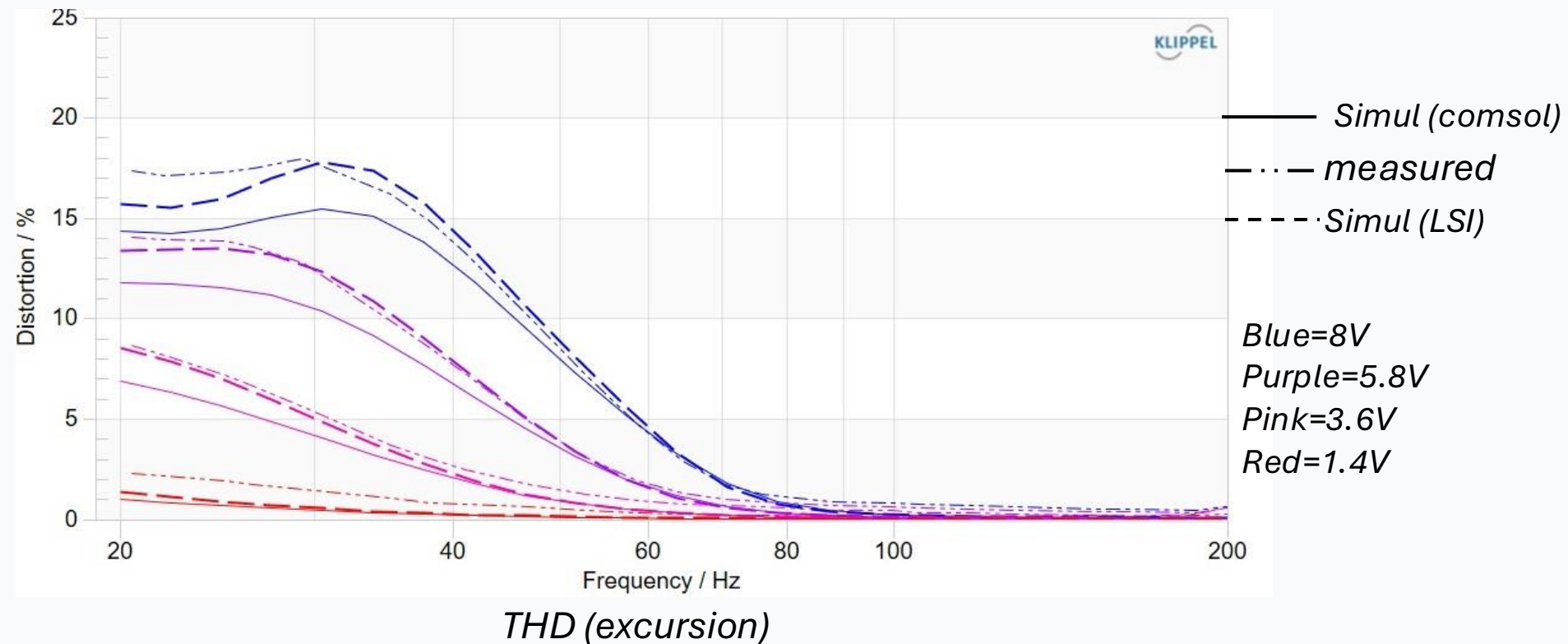
$L_e(0)$  is very different from the  $L_e(0)$  we get from averaging comsol inductance  $L_e(x,f)$

Let's adjust  $L_e(0)$  using the  $L_e$  value we get from  $L_e/L^2/R^2$  simulation (which corresponds to  $L_e@10kHz$ )

It will keep the curve unchanged, just shift it to get  $L_e(0)=0.16mH$

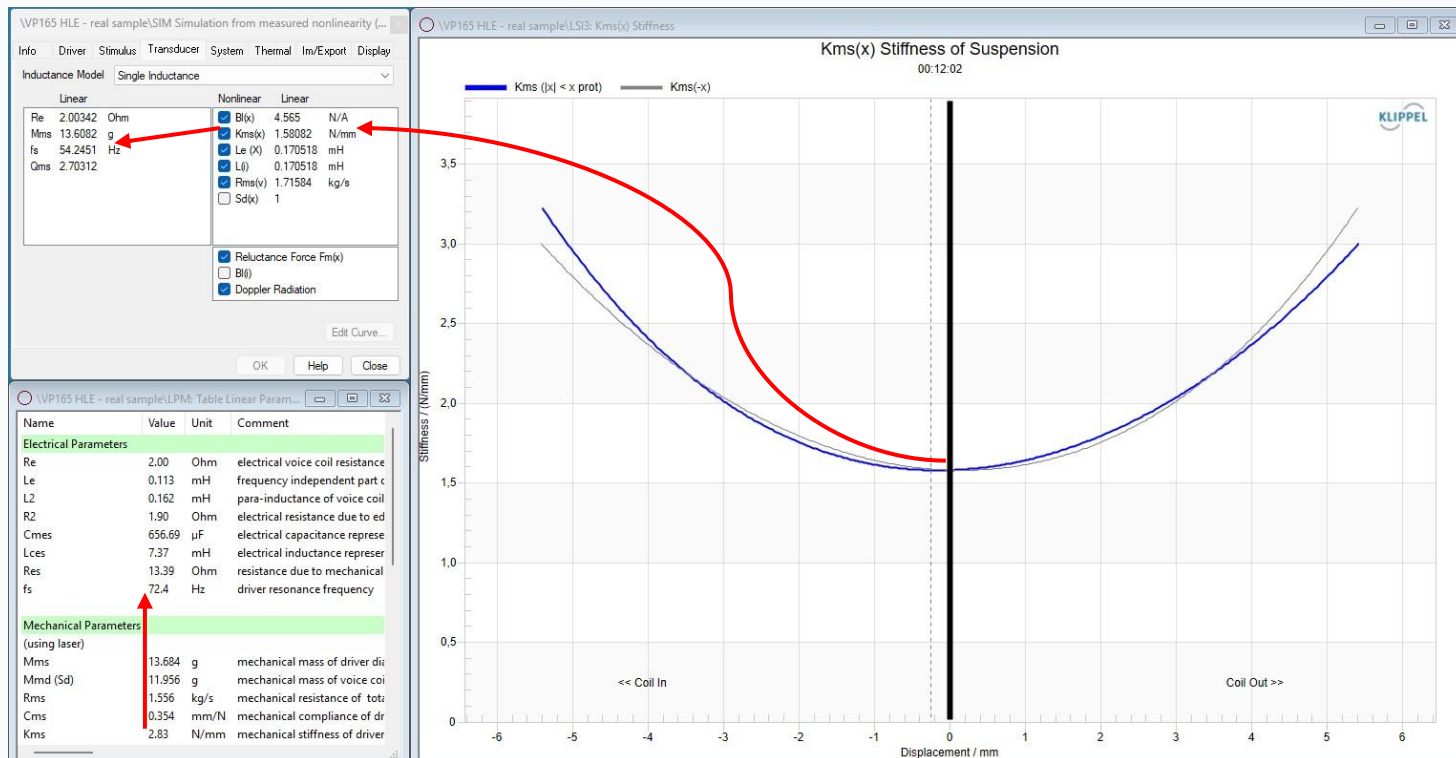


# Comparison between THD simulated based on simulation and real measured non-linearities with $L_e$ adjusted



# Distortion – Comparison between THD simulated based on simulation and real measured non-linearities

We can also observe that in LSI the  $K_{ms}(0)$  is pretty different to LPM one which causes a different calculated excursion and thus THD

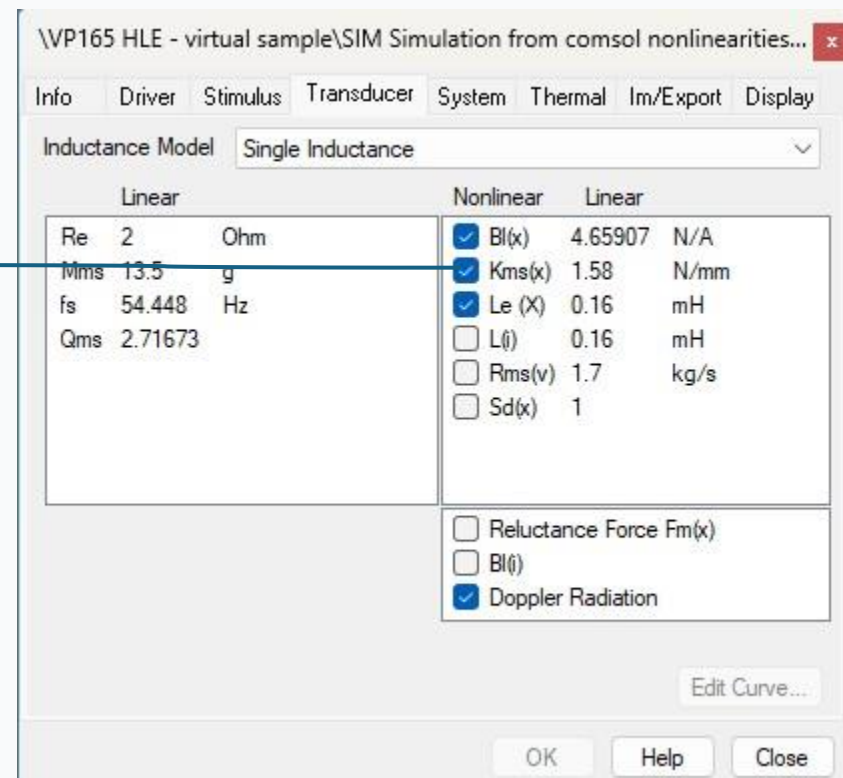


# Distortion – Comparison between THD simulated based on simulation and real measured non-linearities

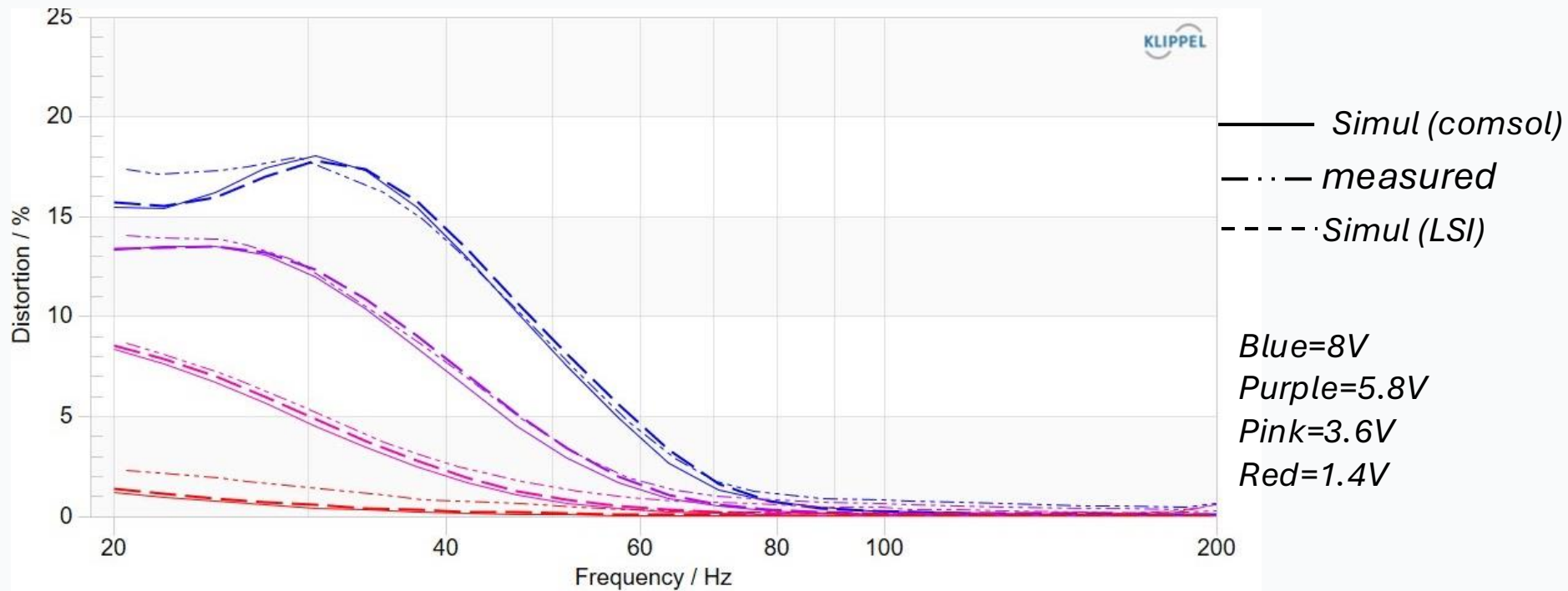
Let's adjust  $K_{ms}(0)$  to match  $f_s$  value from simulation based on LSI

It will keep the curve unchanged, just shift it to get  $K_{ms}(0)=1.58$  N/mm

Goal is to check if we get results matching simulation based on LSI

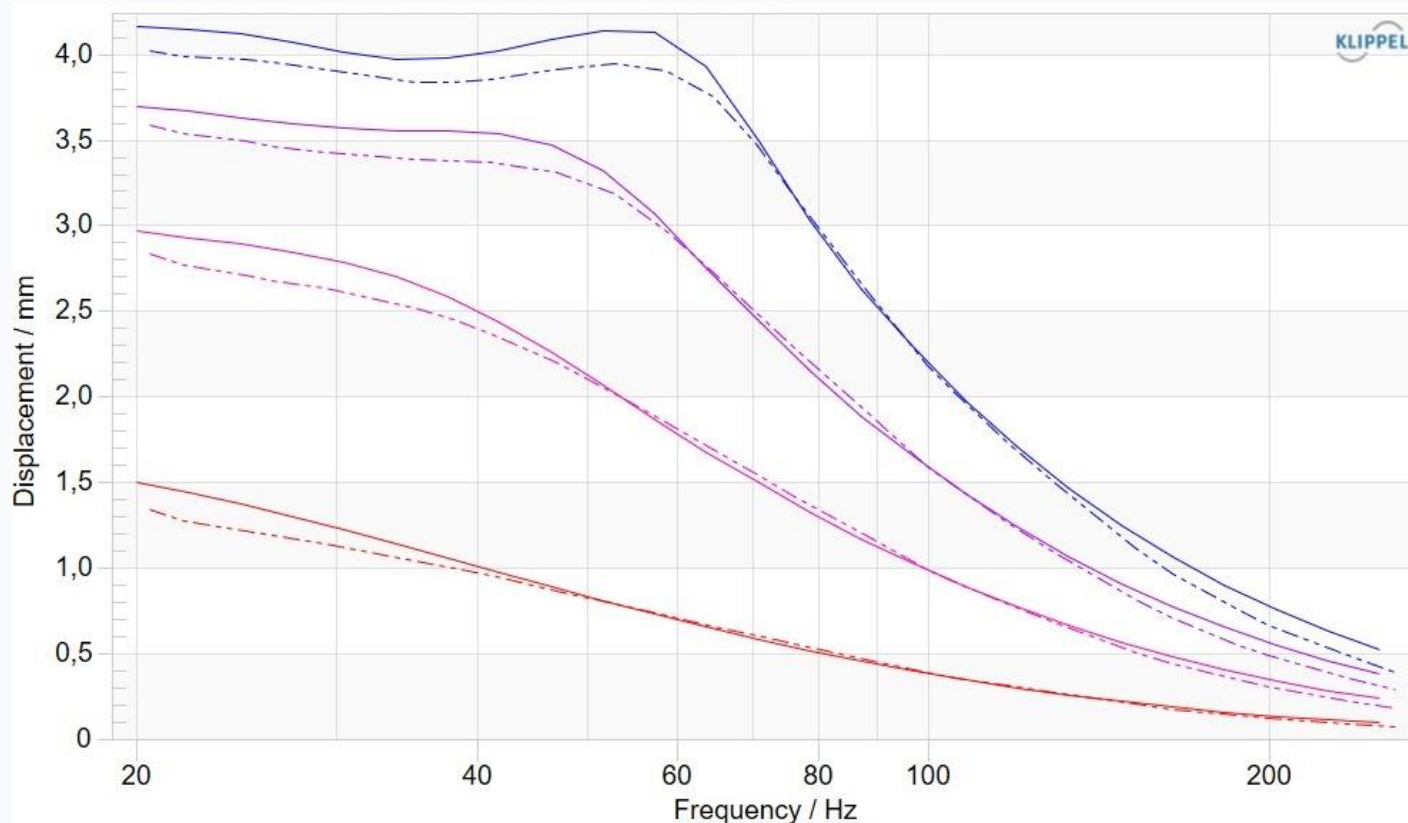


# Comparison between THD simulated based on simulation and real measured non-linearities with Le+Kms adjusted



*THD (excursion)*

# Comparison between excursion simulated based on simulation and real measured non-linearities with Le+Kms adjusted



— *Simul (comsol)*  
 - - - *measured*

*Blue=8V*  
*Purple=5.8V*  
*Pink=3.6V*  
*Red=1.4V*

*excursion*

## Conclusion

- We have presented a methodology to simulate THD in development stage based on a combination of Comsol and Klippel simulation tool
- We have seen that we have a good accuracy in simulated non-linearities with Comsol
- Klippel simulation tool is very efficient (simple to use, very fast computing time, flexible) to simulate accurately THD below frequency resonance.
- Klippel simulation tool has very nice feature allowing user to easily tune manually non-linear curves to look for how to improve THD and so define target non-linear curves that could be used in an iterative development approach