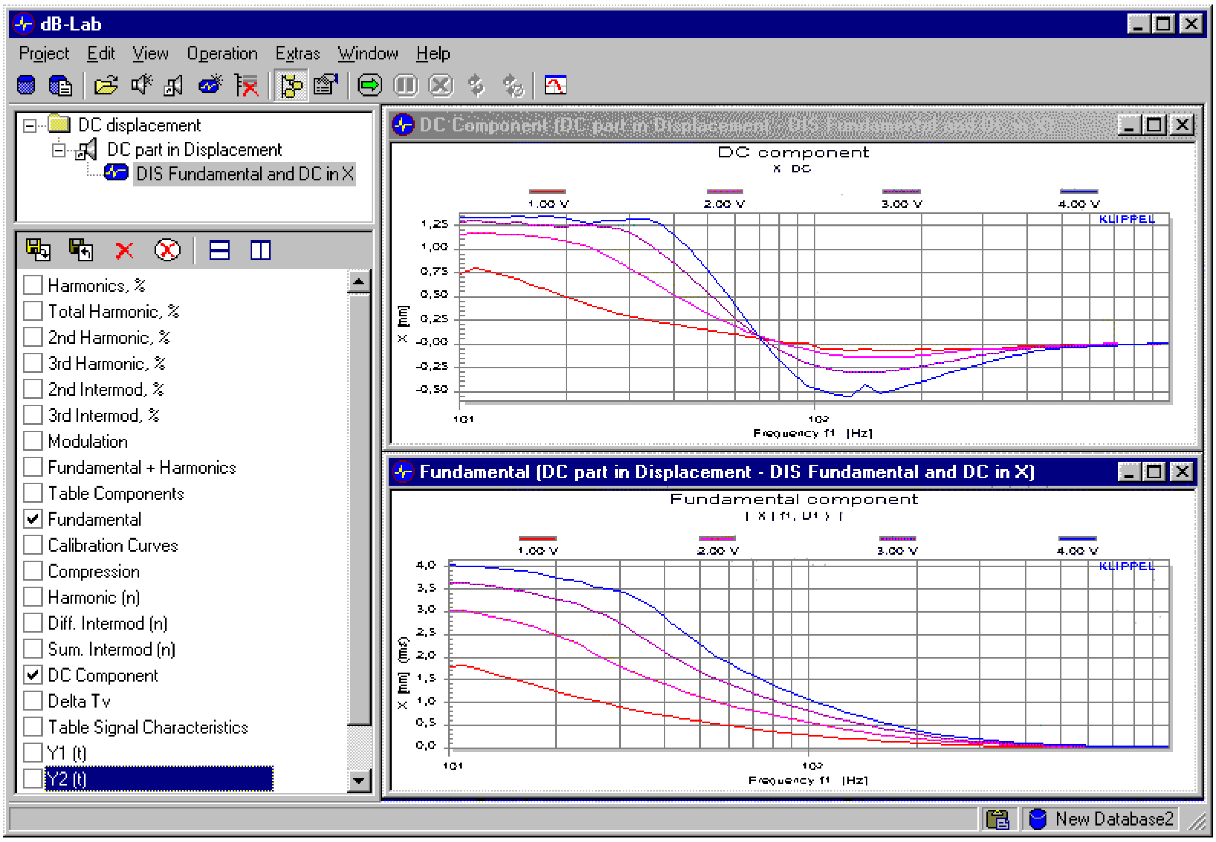
Dynamic Generation of DC Displacement **AN 13**

Application Note to the KLIPPEL R&D SYSTEM

Nonlinearities inherent in the transducer produce a DC component in the voice coil displacement by rectifying the AC signal. Magnitude and direction of the dynamically generated DC component depend on the type of nonlinearity and on the frequency and voltage of the excitation signal. The DIS module (3D distortion measurement) is used to measure the DC component versus voltage and frequency. The results reveal the stability of the driver, the cause of distortion and complicated interaction between driver nonlinearities.



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Physics of generating a DC-displacement

Causes	There are two mechanisms that generate a DC component in the displacement. 1. Any asymmetry in the nonlinear characteristic of the electrical and mechanical parameters (partly) rectifies the AC signal and produces a DC component as well as second-order and higher-order distortion. The DC component has a much higher amplitude than any other harmonic and intermodulation component if the transducer is excited by a complex signal. The reason for this is that the DC component is accumulated by rectifying any fundamental component whereas the other distortion components are distributed over the whole frequency band. 2. An electro-dynamical motor which has a perfect symmetrical *Bl(x)* characteristic may become unstable if the stiffness of the suspension is very low and the driver is operated above the resonance frequency. Any small dc force caused by motor asymmetries or an external disturbance (fingertip) will generate a DC displacement moving the coil down the *Bl(x)* slope until the restoring force of the suspension will stop this process.
Orientation	The sign of the DC displacement determines the direction of the voice coil shift. In this application note positive displacements *x* denote shifts that the coil move away from the backplate (coil out).
Direction	The direction of the DC displacement depends on the shape (extrema, asymmetry) of the transducer nonlinearities such as $C_{ms}(x)$, *Bl(x)* and $L_e(x)$ and on the frequency of the excitation tone. The DC displacement caused by an asymmetric compliance moves the coil always towards the direction of the stiffness minimum. An asymmetric inductance causes a DC component that moves the coil towards higher inductance values – similar to the attraction force in a electromagnet. The DC component produced by the force factor *Bl(x)* depends on the frequency of the fundamental component. For frequencies below the resonance frequency the coil is moved towards the maximum of the *Bl(x)* curve. This means that the coil is self-centring which is a nice feature. Unfortunately, the same motor will push the coil away from the *Bl(x)* maximum for any frequency above the resonance.
Crossing point	Some loudspeakers produce both a positive and negative DC displacement depending on the frequency of the excitation tone. At the point where positive displacement changes to negative and vice versa (crossing point) all the DC forces produced by the different rectification processes cancel out each other. This point is quite reproducible and almost independent of the magnitude of the DC component.
Influence of the suspension creep	The DC displacement of real world transducers varies with active operation. After starting to operate the transducer an initial DC component is generated. The magnitude of the DC displacement depends among others on the stiffness of the suspension at very low frequencies (f ≈ 0 Hz). However, the stiffness of the suspension of real transducers is frequency dependent. Usually, the suspension is much stiffer at the resonance frequency than at very low frequencies (corresponding to very slow cone movements). Any displacement of the suspension will cause changes in the geometry of the fibres of the rubber and fabric and the relocation time has a time constant in the order of magnitude of 1s. The loss of stiffness at lower frequencies is described by the creep factor which can be measured with LPM software module of the Klippel R&D System. The DC force will produce a variable DC displacement depending on the creep factor and the measurement time.
Critical ratio	The ratio between DC displacement and magnitude of the fundamental displacement $$\alpha_{DC} = \frac{X_{DC}(U_1, f_1)}{X_{fund}(U_1, f_1)} * 100\ \%$$ is a critical measure for the stability of the driver. The DC displacement is negligible if $\alpha_{DC} < 10$ %. Please note that in the DIS module X_{fund} is presented in mm <u>rms</u> and X_{DC} in mm <u>peak</u>.

Effects of dominant nonlinearities

NONLINEARITY	**FREQUENCY OF THE EXCITATION TONE**			
	$f < f_s$	$f = f_s$	$f > f_s$	$f >> f_s$
Bl(x) (motor)	moves to *Bl(x)* maximum	no DC component	moves coil away *Bl(x)* maximum **(unstable)**	negligible
$C_{ms}(x)$ (suspension)	moves coil to stiffness minimum	moves coil to stiffness minimum	negligible	negligible
$L_e(x)$ (reluctance force)	moves coil to $L_e(x)$ maximum	negligible	moves coil to $L_e(x)$ maximum	moves coil to $L_e(x)$ maximum

Method of measurement

Excitation signal	A sinusoidal signal with variable frequency and amplitude is applied to the terminals of the transducer. Voltage Sweep: A series of n_U subsequent measurement with different excitation voltages is performed. The n_U voltages are spaced linearly between the starting voltage U_{start} and final voltage U_{end}. Frequency Sweep: A series of n_f subsequent measurement with different excitation frequencies is performed. The n_f frequencies are spaced logarithmically between the starting frequency f_{start} and final frequency f_{end}.
Loudspeaker setup	The driver has to be mounted in the driver stand and the laser sensor adjusted to the diaphragm. A dot of white ink shall be used to increase the signal to noise ratio of the measured displacement signal.

Using the 3D distortion measurement (DIS)

Requirements	• Distortion Analyzer + PC • DIS software module + dB-Lab • Laser sensor head and laser controller
Setup  Don't forget ear protection!	Connect the microphone to the input **IN1** at the rear side of the DA. Set the speaker in the approved environment and connect the terminals with the output **Speaker 1**. Switch the power amplifier between the connectors **OUT1** and **Amplifier**.
Preparation	1. Create a new object 2. Assign a new DIS operation based on the template *DIS X fundamental, DC AN13*.
Measurement	1. Start the measurement 2. Open the windows *Fundamental* and *DC Component*. If the voltage U_{end} is too low for the particular driver adjust U_{end} in property page *Stimulus* and repeat the measurement. 3. Calculate the ratio α_{DC}. 4. Print the results or create a report

Setup parameters for the DIS module

Template

Create a new Object, using the operation template *DIS X fundamental, DC AN13* in dB-Lab. If this database is not available you may adjust the default DIS setup as described below. You may also modify the setup parameters according to your needs.

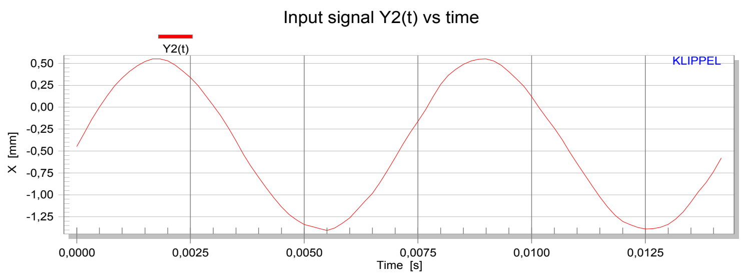
Default settings

1. Open property page *Stimulus*. Select *Harmonics* in the drop down box *Mode*. Select *Sweep* in group *Voltage* U_1. Set U_{start} to 1 V_{rms}, U_{end} to 4 V_{rms}, *Points* to 4 and *Spaced* to *lin* in the same group. Select *Sweep* in group *Frequency f1* and specify an sweep with 20 points spaced logarithmically between 10 Hz and 1000 Hz. Select *Additional excitation before measurement* and set it to 0.5 s. Set *Maximal order of distortion analysis* to 4.
2. Open property page *Protection*. Unselect *Monitoring: Voice coil temperature and amplifier gain.*
3. Open property page *Input*. Select *X (Displacement)* in group *Y2 (Channel 2)* and *Off* in group *(Channel 1) Y1*.
4. Open property page *Display*. Select *Displacement X* in drop down box *State signal* and *2D plot versus f1* in group *Plot style*.

Example

Waveform

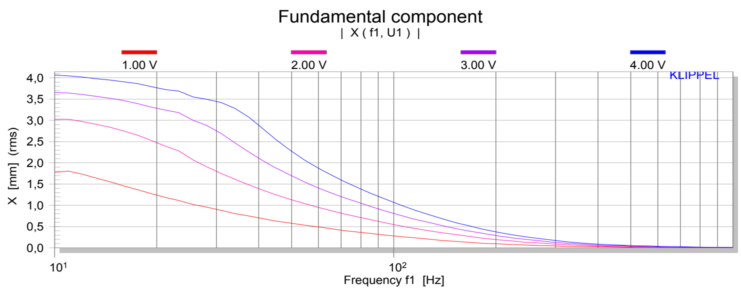
After pausing the measurement for U_1=4 V rms and f_1=150 Hz the result window *Waveform Y2* shows the displacement versus time.



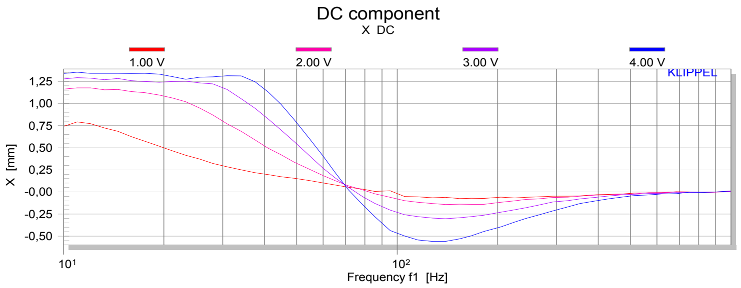
The waveform of the displacement reveals a dynamically generated DC part of -0.43 mm whereas the corresponding AC part is 0.7 mm rms.

Fundamental displacement

The result window *Fundamental* shows the rms displacement versus frequency f_1 and amplitude U_1.



Due to the linear spacing of the input voltage the amplitude responses are equally spaced in the small signal domain. At low frequencies there is a amplitude compression at high signal amplitudes due to the nonlinear mechanisms.

DC component	The result window *DC Component* shows the DC Displacement versus voltage U_1 and frequency f_1.  The speaker in the example produces both a positive and negative DC component depending on the frequency of the excitation tone. The crossing point at 70 Hz is close to the resonance frequency of the loudspeaker. These are typical characteristics for a motor with asymmetric *Bl(x)* characteristic. Shifting the rest position of the coil to positive displacement (out) would increases the *Bl(x=0)* value and improve the stability of the driver.

More information

Related application notes	Motor Stability, Application Note AN 14
Related Specification	“DIS”, S4
Papers	W. Klippel, “Loudspeaker Nonlinearities – Causes, Parameters, Symptoms” preprint #6584 presented at the 119th Convention of the Audio Engineering Society, 2006 October 6-8, San Francisco, USA Updated version on http://www.klippel.de/know-how/literature/papers.html
Software	User Manual of the KLIPPEL R&D SYSTEM.

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