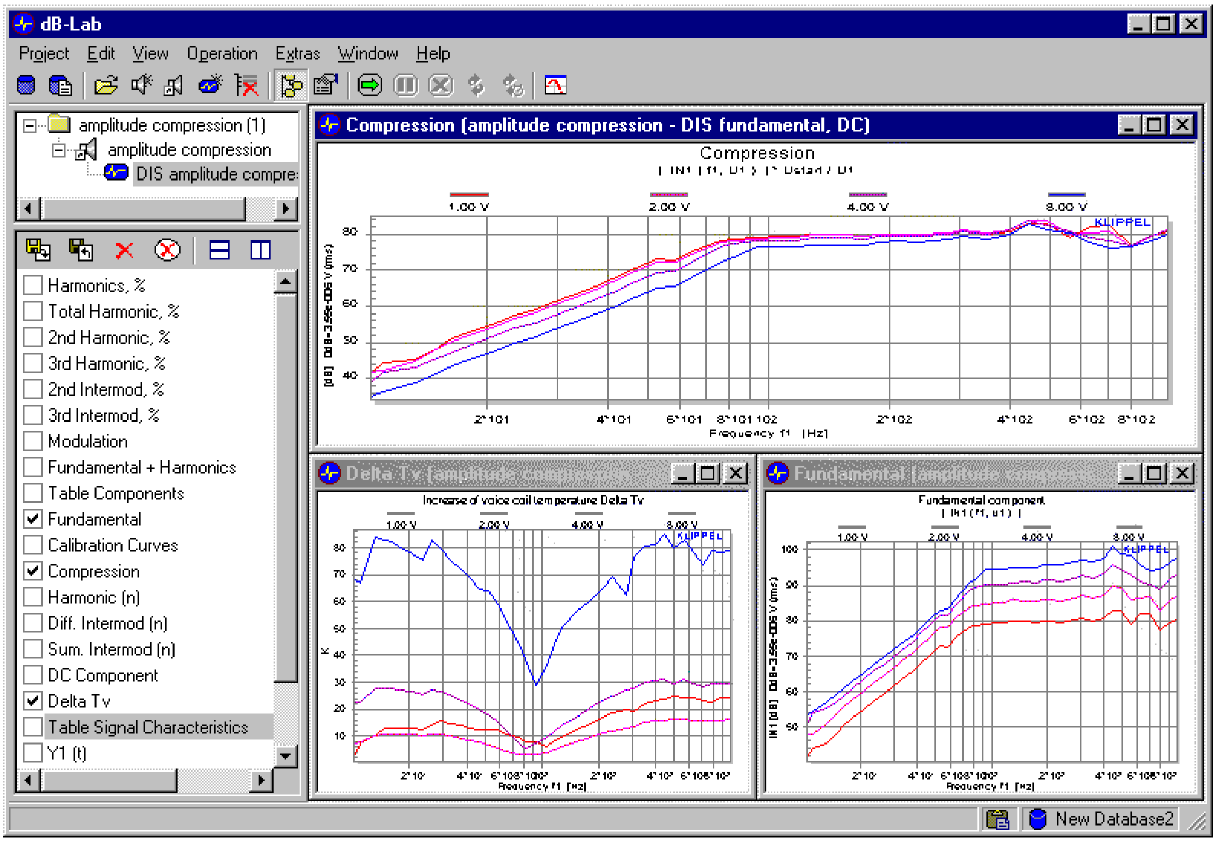
Causes for Amplitude Compression **AN 12**

Application Note to the KLIPPEL R&D SYSTEM

Both thermal and nonlinear effects limit the amplitude of the fundamental component in the state variables and in the sound pressure output. The 3D distortion module (DIS) module of the Klippel R&D System is used to separate the effects from voice coil heating and from nonlinear parameters varying with displacement.



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Updated 19th October 2011

Causes for Amplitude compression

Amplitude Compression	Thermal and nonlinear effects limit the output signal in the large signal domain. Thus the amplitude of the fundamental component in the output signal (e.g. displacement) grows not proportionally with the amplitude of the electrical input signal (e.g. voltage at the speaker terminals). The 3D Distortion measurement (DIS) performs a series of measurements with varied voltage U_1 of the input signal (amplitude sweep). The result window *Compression* in the DIS module presents the amplitude of the fundamental by $$L_C(U_1, f_1) = 20\lg\left(\frac{P(U_1, f_1)U_{start}}{P_{ref}U_1}\right) = L(U_{start}, f_1) - C(U_1, f_1)$$ while compensating the increase of the input signal. The amplitude compression of the amplitude of fundamental component in the measured signal is defined by $$C(U_1, f_1) = 20\lg\left(\frac{P(U_{start}, f_1)U_1}{P(U_1, f_1)U_{start}}\right) = L_C(U_{start}, f_1) - L_C(U_1, f_1)$$ where U_{start} is the starting value of the amplitude sweep applied to U_1.
Heating of the Coil	The heating of the voice coil and the increase of the voice coil resistance $R_e(T_V)$ is a function of the real electric input power supplied to the speaker and the convection cooling depending on movement of the coil. Clearly at the resonance where the input impedance is maximal the heating of the coil is minimal.
Nonlinearities	The second source of amplitude compression of the fundamental component are the dominant nonlinearities of the driver such as force factor Bl(x), inductance $L_e(x)$ and compliance $C_{ms}(x)$ varying with displacement x. At low frequencies where the amplitude of the displacement is high these mechanisms produce the highest compression.
Separating the two effects	The driver is excited by a sinusoidal tone varied in frequency and amplitude. The power compression is measured both in the sound pressure output and in the input current i. Whereas the amplitude compression $C_p(f)$ in the sound pressure reflects both heating and nonlinear effects, the amplitude compression $C_i(f)$ in the current is mainly caused by the heating for frequencies f below and above the resonance frequency f_s. Thus the thermal power compression at low and high frequencies is $$C_{thermal}(U_1, f_1) = C_i(U_1, f_1)$$ and the power compression due to nonlinear effects is $$C_{nonlinear}(U_1, f_1) = C_p(U_1, f_1) - C_i(U_1, f_1)$$ at low frequencies ($f_1 < f_s$) and high frequencies ($f_1 > f_s$), and $$C_{nonlinear}(U_1, f_1) = C_p(U_1, f_1)$$ for $f_1 = f_s$.

Method of Measurement

Excitation Signal	A sinusoidal signal with variable frequency and amplitude shall be connected to the terminals of the loudspeaker. <u>Amplitude Sweep:</u> A series of measurement is performed while varying the amplitude in n_U points spaced linearly or logarithmically between starting amplitude U_{start} and end amplitude U_{end}.. <u>Frequency Sweep:</u> A series of measurement is performed while varying the frequency in n_f points spaced linearly or logarithmically between starting frequency f_{start} and end frequency f_{end}.. *For example:* *U_{start} = 0.1 V rms , U_{end} = 2 V rms (4 points linear spaced)* *$f_{star\ t}$ = 20 Hz , f_{end} = 1 kHz (50 points linearly spaced)*

Loudspeaker Setup

The loudspeaker shall be brought under free-field or half-space free-field condition. The sound pressure is measured in the near field of the driver or taken in 1 meter from the speaker (on axis).

Using the 3D Distortion Measurement (DIS)

Requirements

The following hardware and software is required for assessing Xmax

- Distortion Analyzer + PC
- Software module 3D Distortion Measurement (DIS) + dB-Lab
- Microphone

Setup

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 SPEAKER 1. Switch the power amplifier between OUT1 and connector AMPLIFIER.

Preparation

- Create a new object DRIVER
- Assign an operation *"DIS Amplitude Compression AN12"*

Measurement

1. Start the measurement *"DIS Amplitude Compression AN12"*
2. Select the *Signal at IN1* as *State signal* on property page *Display* and read the power compression $C_p(U_1, f_1)$ at voltage U_1 and frequency f_1 of interest. Calculate the nonlinear amplitude compression $C_{nonlinear.}$
3. Select the *Current Speaker 1* as *State signal* on property page *Display* and read the power compression $C_I(U_1, f_1)$ at voltage U_1 and frequency f_1 of interest.
   Assign the power compression $C_i(U_1, f_1)$ for low frequencies $f_1 < f_s$ and for high frequencies $f_1 > f_s$ to the thermal power compression $C_{thermal}(U_1, f_1)$.
4. Print the compression curves or create a report

Setup Parameters for the DIS Module

Template

Create a new Object, using the operation template *DIS Amplitude Compression AN12* in dB-Lab. If this database is not available you may generate DIS 3D Harmonic measurements based on the general DIS module. You may also modify the setup parameters according to your needs.

Default Setting for Harmonic Measurement

1. Open the property page *Stimulus*.
   Select mode *Harmonics*.
   Switch on Voltage U_1 Sweep, and set U_{start} to 1 V rms and U_{end} to 8 V rms measured in 7 points varied linearly. Make sure the signal level is appropriate for loudspeaker.
   Switch on the Frequency Sweep with 50 points spaced logarithmically between 20 Hz and 1000 kHz. Set additional excitation time to 0.01 s.
   Set *maximal order of distortion analysis* N = 16.

2. Open property page *Input*. Select *Mic IN 1* at the first channel (Y1). Select *Is Current speaker 1* on the second channel (Y2).

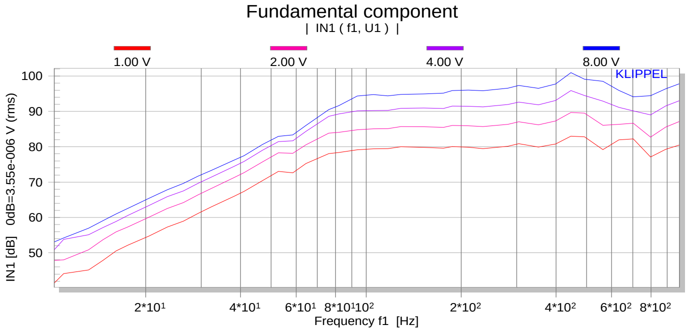
3. On the *Protection* property page, enable temperature measurement and set maximal increase of voice coil temperature to 100 K.

4. Open the *Display* property page. Select *Signal at IN1* as State signal and. *2D plot, versus f1***.**

Example

fundamental sound pressure response

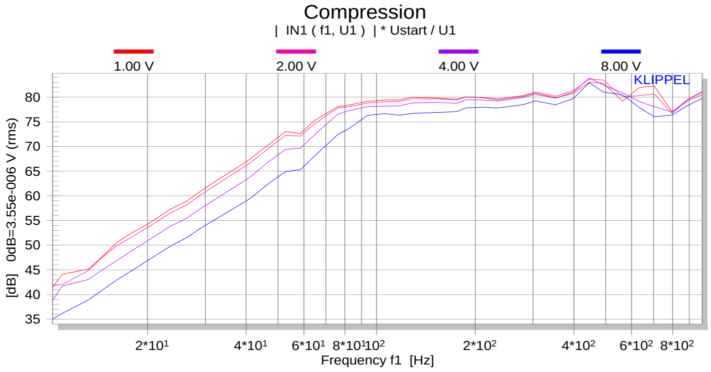
After selecting *Signal at IN1* as State signal on property page *Display* the result window *Fundamental* shows the SPL of the fundamental versus frequency f_1 and amplitude U_1.



Due to the logarithmic spacing of the input voltage the amplitude responses in SPL are equally spaced in the small signal domain.

Compression of fundamental

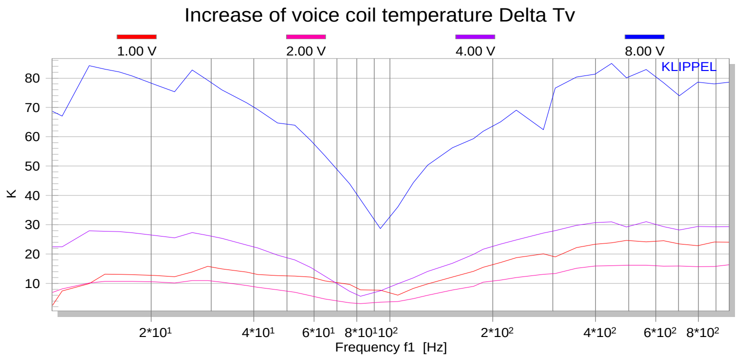
The result window *Compression* shows the SPL of the fundamental referred to the response measured at the starting amplitude U_{start}.



The output amplitude is reduced by $C_p = 7$ dB at low frequencies ($f_1 < f_s$), $C_p = 5$ dB at the resonance frequency f_s and about $C_p = 2$ dB at high amplitude ($f_1 > f_s$), compared by the output of a linear system. Since the heating of the coil is much lower at the resonance frequency the nonlinear compression $C_{nonlinear}(f_s) \approx C_p(f_s)$.

Voice Coil Temperature

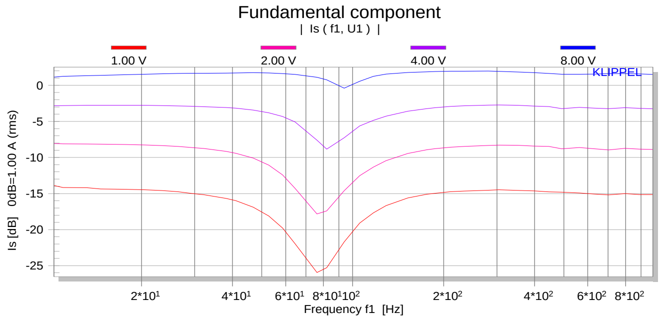
The result window *Delta Tv* shows the increase of the voice coil temperature dT_v in Kelvin measured after each point of the amplitude and frequency sweep.



The heating of the coil is maximal at low and high frequencies and maximal amplitude. There is a distinct minimum of the voice coil temperature at resonance frequency.

Current Fundamental

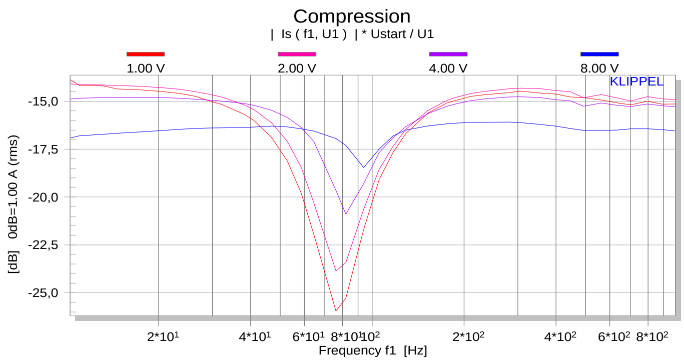
After selecting the *Current Speaker 1* as displayed signal on property page *Display* the results window *Fundamental* shows the amplitude response of the fundamental component.



In the small signal domain the responses are equally spaced according to variation of the terminal voltage U_1. The distinct minimum shows the resonance frequency f_s rising from 75 Hz to 95 Hz with amplitude. The shape of the response also changes dramatically due to variation of stiffness $K_{ms}(x)$ and electrical loss factor $Q_{es}(x)$ with the displacement x.

Thermal power Compression

The result window *Compression* shows the fundamental of input current referred to the response at the starting amplitude U_{start}.



The amplitude of the current is reduced by $C_i = 3$ dB at low frequencies ($f_1 < f_s$) compared by the output of a linear system. This is mainly caused by thermal power compression $C_{thermal}=C_i$. Compared with the compression in sound pressure of $C_p \approx 7$ dB the nonlinear compression is about $C_{nonlinear}=C_p - C_i \approx 4$ dB. At high frequencies ($f_s < f_1$) the thermal power compression is about $C_{thermal} = C_i \approx 2$ dB.

More Information

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 for the KLIPPEL R&D SYSTEM.

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