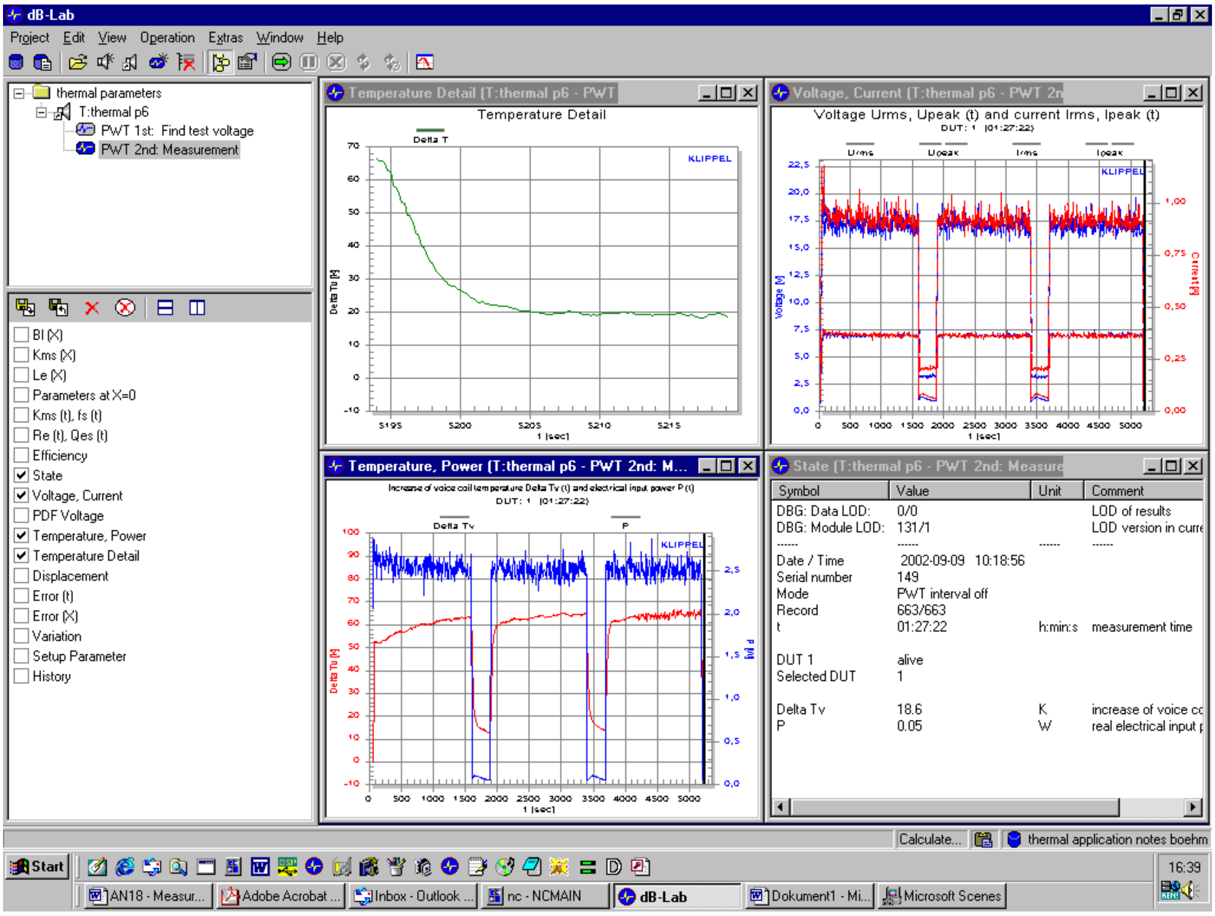
Thermal Parameter Measurement **AN 18**

Application Note to the KLIPPEL R&D SYSTEM

The lumped parameters of the thermal equivalent circuit are measured by using Power Test Module (PWT). The high-speed temperature monitoring makes it possible to measure voice coil resistance R_{TV} and the capacity C_{TV} of woofers, tweeters, headphones, tele-communication drivers and other transducers having a very short time constant. The regular monitoring with adjustable sample rate also allows to measure the parameters of the magnet and frame having usually a very long time constant. The temperature monitoring is based on the measurement of the electrical impedance at 1 Hz.



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updated April 4, 2012

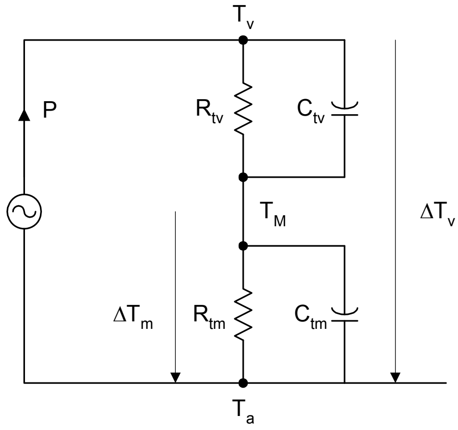
Klippel GmbH
Mendelssohnallee 30
01309 Dresden, Germany

www.klippel.de
info@klippel.de

TEL: +49-351-251 35 35
FAX: +49-351-251 34 31

Thermal Modeling

Equivalent Circuit



The equivalent circuit presented above is used for modeling the thermal behaviors of transducers. This simple model represents the complex temperature field by the mean temperature T_v of the voice coil and the mean temperature T_M of the magnet, pole pieces and frame. This model considers two paths of the heat flow. The main part of the heat goes via the voice coil, pole pieces, magnet and frame to the environment. The second path is the convection cooling transferring the heat from the voice coil directly into the moved air.

We neglect the following processes:

- direct heating of the pole pieces and short cut ring by induced eddy currents
- convection cooling
- distribution of the heat on the voice coil and on the magnet and frame structure

State Variables

$P_{RE}(t)=i_{rms}^2 R_E$ real electric input power dissipated in voice coil resistance R_E

i_{rms} rms value of input current

$T_v(t)$ temperature of the voice coil

$T_m(t)$ temperature of the magnet structure

$\Delta T_v(t)= T_v(t)-T_a$ increase of voice coil temperature

$\Delta T_m(t) = T_m(t)-T_a$ increase of the temperature of magnet structure and frame

T_a temperature of the cold transducer (ambient temperature)

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FAX: +49-351-251 34 31

Thermal Parameters

R_{tv} thermal resistance of path from coil to magnet structure

R_{tm} thermal resistance of magnet structure to ambient air

C_{tv} thermal capacitance of voice coil and nearby surroundings

C_{tm} thermal capacitance of magnet structure

Steady-State Behavior

Applying a stimulus with constant spectral properties the thermal system will go into a thermal equilibrium. Since no heat flows in or out of capacitors C_{TV} and C_{TM} the thermal resistances R_{TV} and R_{TM} determine the steady-state voice coil temperature

$$\Delta T_{vss} = \left(R_{TV} + R_{TM}\right)P_{RE}$$

and the steady-state magnet temperature

$$\Delta T_{MSS} = R_{TM} P_{RE}$$

with P_{RE} is the power dissipated in R_E.

Dynamics

The variation of the temperature $T_M(t)$ and $T_V(t)$ versus measurement time t after switching on and off the input power P_{RE} revels the thermal capacities C_{TV} and C_{TM}.

After switching on the input power $P=P_{ON}$ at the time $t=t_{S\_ON}$ the temperature ΔT_M of the magnet increases by an exponential function

$$\Delta T_M(t) = \Delta T_{MSS} \ \left(1 - e^{-(t-t_{S\_ON})/\tau_M}\right)$$

to the steady-state temperature ΔT_{MSS}. The time constant of the magnet structure is defined by

$$\tau_M = R_{TM} C_{TM} .$$

After switching off the input power at the time $t=t_{S\_OFF}$ the temperature difference

$$\Delta T_v(t) - \Delta T_M(t) = \left(\Delta T_{VSS} - \Delta T_{MSS}\right) \ e^{-(t-t_{S\_OFF})/\tau_v}$$

between voice coil and frame/magnet decreases by an exponential function with the time constant

$$\tau_v = R_{TV} C_{TV} .$$

Equivalent masses

After determining the thermal capacity of the voice coil C_{TV} we may calculate the equivalent mass of copper by

$$m_{copper} = 2.7 \ C_{TV}$$

where m_{copper} is in gram and C_{TV} is in Ws/Kelvin.

Assuming pure steel for the frame/magnet structure we calculate the equivalent mass of steel by

	$$m_{Steel} = 2\ C_{TM}$$ where m_{steel} is in gram and C_{TM} is in Ws/Kelvin.
Principle	For the measurement of the thermal parameters we use a noise signal representing normal audio material as defined by IEC 60268. The measurement is performed by the following steps. 1. In the first step we determine the voltage of the stimulus at the transducer terminals giving a reasonable increase of the voice coil temperature (50 – 100 Kelvin) permissible for the transducer. 2. In the second step we apply the noise at the voltage U and heat up the voice coil and the magnet/frame structure to the equilibrium state. 3. In the third step we activate the high speed temperature monitoring and record the voice coil temperature response after switching off the input power. 4. Based on the measured temperature responses we calculate the thermal parameters

Using the Power Test Module (PWT)

Requirements	The following hardware and software is required for assessing Xmax • Power Test Monitor PM 8 + PC • Software module Power Test (PWT) + dB-Lab
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	1. Open dB-Lab 2. Create a new object DRIVER based on the template **Thermal Parameters AN 18**.
Measurement	1. Start the 1st measurement " **1st : Find test voltage** ". During the measurement the amplitude of the stimulus will be increased by 2dB steps after a cycle time of 30 s. If the voice coil resistance is increased to 130 % corresponding to an increase of the voice coil temperature of 80 Kelvin the measured will be interrupted automatically and a exception message "Driver Failure" will be generated. 2. Open the result window **"Voltage, Current"** and read the **rms** voltage U_{TEST} where the voice coil temperature is about 80 Kelvin. 3. Break. The loudspeaker should cool down. 4. Open the property page "**Stimulus**" of the second measurement "**2nd : Parameter Measurement** " and enter the starting voltage U_{Start}=$U_{Test.}$ Start the second measurement. 5. Open the result window "**Power, Temperature**". Read the voice coil temperature at the end of the ON-phase. If we get similar values at successive ON-phases the speaker is in thermal equilibrium. After beginning the next ON-phase open the property page "**Method**". Select the **fast speed temperature** monitoring to be able to measure the cooling characteristic at high resolution. The temperature measurement in the ON-phase might become more noisy. Under **Temperature Window** press the button **Start** to activate the next detailed temperature monitoring at the start of the next OFF-phase. 6. After finishing the OFF-phase the second measurement may be finished.

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01309 Dresden, Germany
www.klippel.de
info@klippel.de
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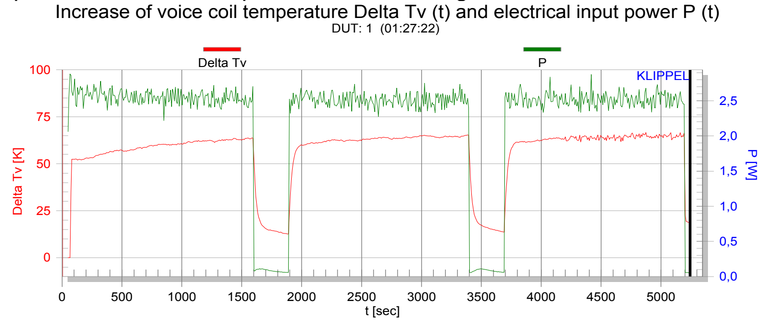
FAX: +49-351-251 34 31

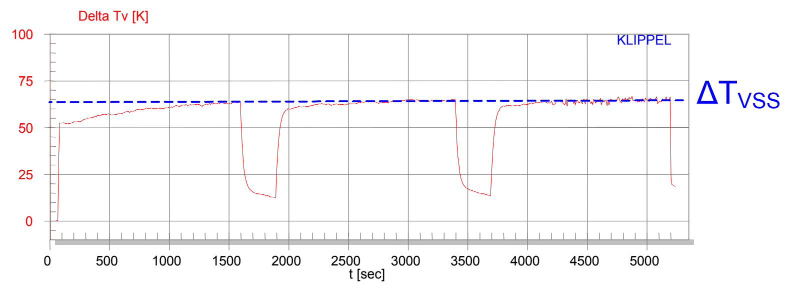
Parameter Calculation

Steady-State Temperatures

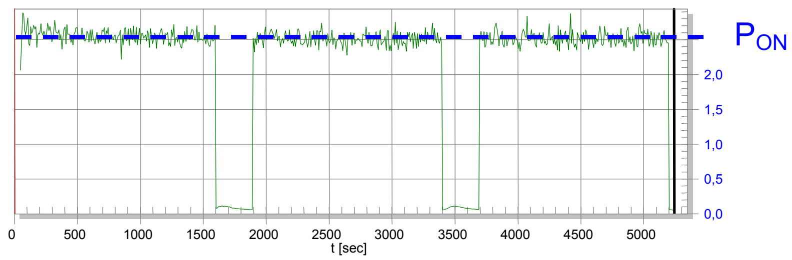
1. Select the second measurement "2[nd] Thermal Parameters" and open the result window "Power Temperature". Ensure that the driver was in the thermal equilibrium and the temperature has converged to the final value.



2. Activate the cursor by using the right mouse button and read the temperature of the coil $\Delta T_{VSS} = \Delta T_V(t_{S\_ON})$ at the end of the ON-phase $t = t_{S\_ON}$. Ensure that the driver is in the thermal equilibrium by comparing the t_{SW_ON} with the final temperature of previous ON-phases.



3. Use the cursor to read the power P_{ON} during the ON-phase.



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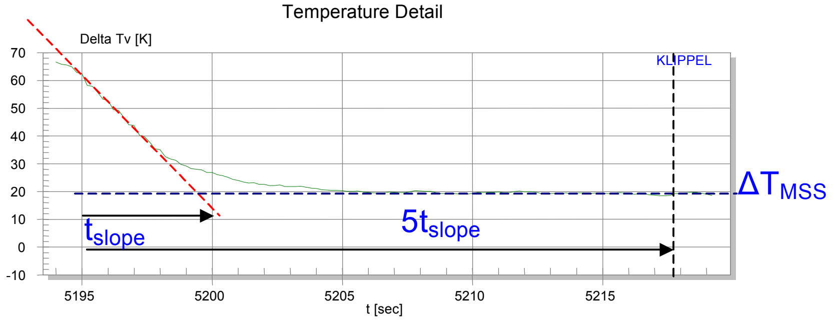
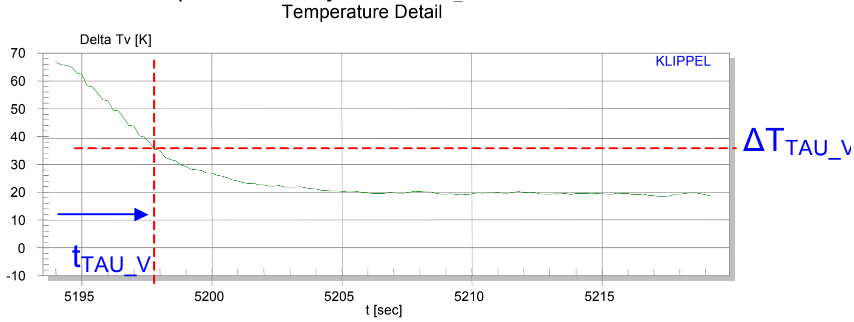
Resistances R_{TM} and R_{TV}	4.	Open the result window "Temperature Detail" showing the cooling down response at the beginning of the OFF-phase. The early decay is caused by the time constant of the voice coil. The magnet/frame structure causes a second decay at later times due to the higher time constant. Approximate the early decay by a straight line. Read the early decay time T_{slope} of the slope. Read the temperature $\Delta T_{MSS}= \Delta(t_{S\_OFF} + 5t_{slope})$ at approximately 5 times of t_{slope} to ensure that the voice coil is in thermal equilibrium. If the time $t_{S\_OFF}+t_{slope}$ is not displayed on the results window "Temperature Detail" use the cursor in the regular window "Power, Temperature" to find ΔT_{MSS}. 
	5.	Calculate the thermal resistance of the magnet/frame structure $$R_{TM} = \Delta T_{MSS} / P_{ON}$$
	6.	Calculate the thermal resistance of the voice coil $$R_{TV} = \frac{\Delta T_{VSS}}{P} - R_{TM}$$
Voice Coil Capacity C_{TV}	7.	Calculate the temperature where the time constant of the voice coil is elapsed $$\Delta T_{TAU\_V}(t_{TAU\_V}) = \Delta T_{TV}(t_{S\_OFF} + \tau_{TV}) = 0.37\ \Delta T_{VSS} + 0.63\ \Delta T_{MSS}$$
	8.	Use the cursor in the result window "Temperature Detail" to read the time $t_{37\%}$ where the temperature decayed to ΔT_{TAU_V}. 
	9.	Calculate the time constant of the voice coil by $$\tau_{TV} = t_{TAU\_V} - t_{S\_OFF}$$
	10.	Calculate the thermal capacity of the voice coil by $$C_{TV} = \frac{\tau_{TV}}{R_{TV}}$$

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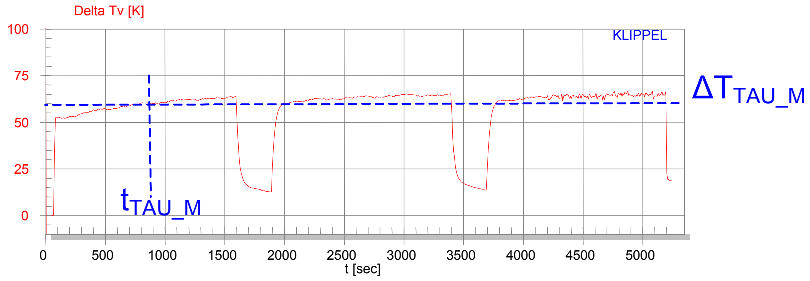
Magnet/Frame Capacity C_{TM}

11. Calculate the temperature where the time constant of the magnet is elapsed

$$\Delta T_{TAU\_M} = \Delta T_V(t_{S\_TM} + \tau_{TM}) = \Delta T_{VSS} - 0.37 * \Delta T_{MSS}$$

12. Use the cursor in the result window "Power Temperature" to find the time t_{TAU_M} where the voice coil temperature is equal to ΔT_{TAU_M}



13. Read the time t_{S_ON} when the time is switched on (with the beginning of the mode GAIN ADJUSTMENT).
14. Calculate the time constant of the magnet by

$$\tau_{TM} = t_{TAU\_M} - t_{S\_ON}$$

15. Calculate the thermal capacity of the magnet by

$$C_{TM} = \frac{\tau_{TM}}{R_{TM}}.$$

Setup Parameters for the Template Measurement

Template

Create a new Object, using the object template **Thermal Parameters AN 18** in dB-Lab. If this database is not available you may generate an object **Thermal Parameters An 18** based on the general PWT module. You may also modify the setup parameters according to your needs.

Default Setting for 1st Measurement

1. Generate a measurement based on the general PWT measurement. Open the PP **INFO** and call it "**1st : Find test voltage**". Open the PP STIMULUS. Select **internal** mode starting at the starting voltage 1 V rms. Enable voltage **stepping** at size G_U 2 dB up to the maximal increase of G_{MAX} =24 dB.

2. Open the PP **GENERATOR** and select noise according **IEC60268**. Disable high-pass and low-pass filtering.

3. Open the PP **CYCLES** and set ON-Interval T_{ON}= 0.5 min.

4. Open the PP **METHOD** and select **Temperature** mode and set Number of DUTs to 1. Keep **fast** temperature monitoring. Select **Edit** and keep the pilot tone frequency at 2 Hz.

5. Open the PP **FAILURE** and set the minimal resistance R_{min} to 10 % and the maximal resistance R_{max} to 130% corresponding to an increase of the voice coil temperature by 80 Kelvin.

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Default Setting for 2nd Measurement

1. Generate a measurement based on the general PWT measurement. Open the PP INFO and call it "**2nd : Parameter Measurement**". Open the PP STIMULUS. Select **internal** mode starting at the starting voltage 1 V rms. Disable voltage **stepping**.

2. Open the PP **GENERATOR** and select noise according **IEC60268**. Disable high-pass and low-pass filtering.

3. Open the PP **CYCLES** and enable **Intermittent excitation**. Set the ON-Interval T_{ON}= 25 min and the OFF-Interval T_{OFF}= 5 min. Set the total measurement time T_{TOT}= 3 h and a regular sampling after T_{UPD}= 8s.

4. Open the PP **METHOD** and select **Temperature** mode and set Number of DUTs to 1. Use **slow** temperature monitoring at the beginning of the measurement. Select **Edit** and keep the pilot tone frequency at 2 Hz. For the result Window "Temperature Window" disable the **auto**matic start but enable the checkbox SYNC with PWT ON/OFF.

5. Open the PP **FAILURE** and set the minimal resistance R_{min} to 10 % and the maximal resistance R_{max} to 150 % or other value.

More Information

Literature

Henricksen, Heat Transfer Mechanisms in Loudspeakers: Analysis, Measurement and Design, J. Audio Eng. Soc. Vol 35. No. 10 , 1987 October

D. Button, Heat Dissipation and Power Compression in Loudspeakers, J. Audio Eng. Soc., Vol. 40, No1/2 1992 January/February

C. Zuccatti, Thermal Parameters and Power Ratings of Loudspeakers, J. Audio Eng. Soc., Vol. 38, No. 1,2, 1990 January/February

Software

User Manual for the KLIPPEL R&D SYSTEN.

Related Application Notes

"Measurement of Nonlinear Thermal Parameters", Application Note 19

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