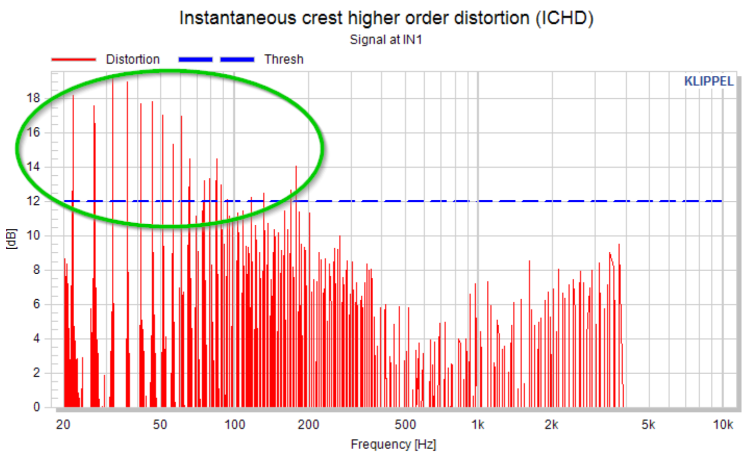
Rub & Buzz Detection without Golden Unit AN 22

Application Note to the KLIPPEL Analyzer SYSTEM (Document Revision 2.0)

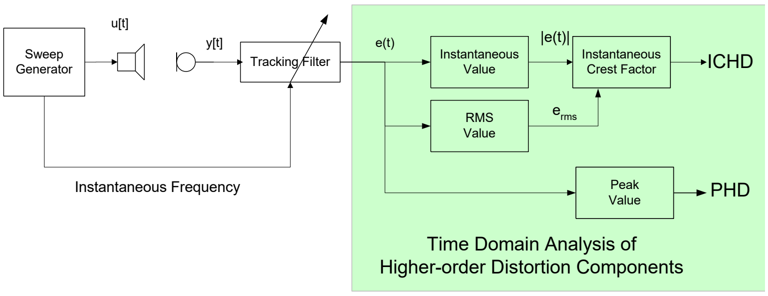
A rubbing voice coil, buzzing loose part, hard limiting of voice coil former, loose particles in the gap and other loudspeaker defects cause signal distortion which are audible and have a high impact on perceived sound quality. The symptoms of those defects are more impulsive than the distortion of regular nonlinearities (e.g. force factor Bl(x)) producing higher peak values in the time domain while the rms value of the distortion is usually low. The TRF-Pro module measures the crest factor and the peak value of the higher-order harmonic distortion which are reliable symptoms for detecting loudspeaker defects. The crest factor can be plotted versus voice coil displacement to show the position of the voice coil when the impulsive distortion is generated and to give further indications of the physical cause. In this application note a test is described for checking unique drivers, where no reference drivers ("golden units") without rub and buzz defect is available.



CONTENTS:

1 Theory

What is rub & buzz	A class of irregular, "impulsive" disturbances which are not produced by the regular driver nonlinearities (motor, suspension, etc.) is usually described by the general term rub & buzz. Usually rub & buzz is caused by some sort of defect (voice coil is hitting the back plate, beating wire leads, etc.). From a physical point of view often a resonator with a strong nonlinearity is involved. One example is wire leads that beat at diaphragm. This vibrating system generates disturbances only under very special conditions (frequency, critical amplitude).
Audibility of rub & buzz	Rub & buzz effects are annoying, high frequency distortion effects. These disturbances are very good audible due to the following properties of rub & buzz effects: 1. The distortion components appear as separated tones from the fundamental with a high frequency difference (3 octaves and more). 2. The human ear has the highest sensitivity at about 1 kHz. Rub & buzz effects are mostly correlated to high displacements which usually occur around the resonance frequency. Since the rub & buzz distortion components are at frequencies above 10^{th}…20^{th} order of the fundamental component, they fall therefore in the range of highest sensitivity of the ear. They are often much easier to detect than regular frequency distortion components (due to motor, suspension, etc.) which may even have a considerably higher amplitude. 3. Lower harmonic distortion components (2^{nd}, 3^{rd}) may be masked by the psychoacoustic masking effect. The human ear can't detect tones located in a narrow frequency around a dominant single tone. This makes the higher-order distortion components generated by rub & buzz even more audible. 4. Usually rub & buzz effects are not pure harmonics of the fundamental. There are also resonance effects which are excited by the movement of the coil and starts vibrating at its own natural resonance (e.g. mass and stiffness of the wire). 5. Often rub & buzz causes small glitches that are present only for short time periods. Due to the "impulsive" nature such disturbances are clearly audible.
THD not useable	The commonly used THD measure is not suitable, since rub & buzz distortion are much lower in amplitude (about 20-40 dB below fundamental) than the unavoidable, low order harmonic distortion components due to the regular speaker nonlinearities. So the effects which shall be detected do barely contribute to the integrated THD value. Furthermore rub & buzz effects are usually very small glitches in time domain. THD is a pure frequency measure and neglects the phase information. By applying a Fourier transformation to the whole signal, these small time disturbances are even more obscured by the integrating nature of the transformation.

New time domain analysis	 The rub & buzz detection algorithm is based on a time domain analysis to overcome the disadvantages of the THD measure and to show impulsive distortion at high temporal resolution. A sinusoidal sweep u(t) is used as stimulus to excite the loudspeaker under test. The instantaneous frequency f_i (t) of the sweep is used to control the high-pass frequency $f_{hp}=n_{hp}f_i$ of a tracking filter and to extract all higher-order distortion e(t) with order $n>n_{hp}$ in the time domain. The high-pass factor n_{hp}=20 suppresses the regular distortion generated by motor and suspension. From the higher-order distortion *e(t)* at the output of the tracking filter some important measures are derived: ▪ Instantaneous Crest factor ICHD of higher-order harmonic distortion ▪ Peak value PHD of higher-order distortion The TRF uses a logarithmic sweep, so the linear time scale corresponds to a logarithmic frequency scale $f_i(t)=f_0\log(t/t_o)$. If a sine sweep is used for exciting the driver, any measurement time *t* can be mapped uniquely to the instantaneous excitation frequency *f*. Hence each distortion measure can either be plotted versus time *t* or frequency *f*, as long as the dependency is known. Both measures exploit both magnitude and phase information of all n^{th}-order harmonic distortion.

Instantaneous Crest factor of distortion ***(ICHD)***	Instead of the overall THD now an instantaneous distortion measure is calculated. It turned out that this leads to a very useful measure. The traditional measure to quantify the peaky-ness is the crest factor. To preserve the fine structure of the distortion an "instantaneous" crest factor is used. The *Instantaneous Crest Higher-Order Distortion (ICHD)* is defined as the ratio of the instantaneous value and the short term RMS value e_{RMS} of *e*(*t*). $ICHD(f) = \frac{\lvert e(f)\rvert}{e_{RMS}(f)}$ with $e_{RMS} = \sqrt{\frac{1}{t_{k+1}-t_k}\int_{t_k}^{t_{k+1}} e^2(t)dt}$ Where e_{RMS} is the rms-value of the higher-order distortion. Note that the ICHD reveals the complete fine structure of the distortion as the full temporal resolution is preserved. The instantaneous crest factor ICHD describes the peaky-ness of the higher-order harmonics *e*(*t*) at full temporal resolution. This measure is independent of the amplitude of the distortion but exploits the phase information of all higher-order harmonic distortion components. Rub and Buzz defects cause harmonic components which are strongly related with their phase response and produce a distinct impulse in the time domain. Noise from the measurement equipment will produce a very low crest factor on contrary. One of the advantages of the ICHD is that an absolute threshold of 12 dB can be used to detect impulsive distortion. Distortion from regular nonlinearities and measurement noise will generate a lower instantaneous crest factor while rub and buzz defect generate a higher value. The ICHD is perfect symptom for finding the causes of the rub and buzz problems. Note that the audibility of the impulsive distortion mostly depends on the amplitude so the peak value of the higher-order distortion PHD is also very important to look at.
Peak values of higher- order Harmonics ***(PHD)***	The peak value of the higher-order distortion PHD is defined as a relative measure $PHD(f) = \frac{e_{peak}(f)}{y_{RMS}(f)}$ with $y_{RMS} = \sqrt{\frac{1}{t_{k+1}-t_k}\int_{t_k}^{t_{k+1}} y^2(t)dt}$ and the peak value e_{peak} detected within one period of the fundamental frequency. The PHD is a relative measure which can be expressed in dB or in percent. It is a useful measure to describe the magnitude of the impulsive distortion and the quantitative impact on sound quality. Note: the PHD or the absolute magnitude e_{peak}(f) is a powerful measure to detect rub and buzz defects in QC application.
Impact on sound quality	Impulsive distortion of high magnitude becomes audible because the higher-order components are distributed over the frequency band and are not masked by the fundamental components. Thus the combination of high ICHD and high PHD can be checked in two steps: 1. Search for frequencies where the crest factor ICHD is larger than 12 dB (in window "Instantaneous Distortion"; the threshold of 12 dB may be changed on property page I-DIST) 2. At the same frequencies where the ICHD value is above the 12 dB threshold, search for high peak values PHD > PHD_{lim} of the impulsive distortion. If they exceed a permissible limit PHD_{lim} then the impulsive distortion have also a high magnitude and a large impact on sound quality. This limit PHD_{lim} depends on the particular application and may also be set on property page I-DIST. A good starting value is -40 dB (1%).

Rub and buzz with reference AN23	The present application note describes a test procedure where no good reference unit ("golden unit") without any rub and buzz defect is required. However, a reference unit provides valuable information. In Application Note 23 "Rub & buzzBuzz detection with Golden Unit" an application is presented where this information is exploited. It shows an example where the rub & buzz detection without reference actually fails.

2 Performing the Measurement

Requirements

The following hardware and software is required:

- Klippel Analyzer hardware (either DA1 / DA2 or KA3)
- Microphone, (Laser Sensor)
- Software (dB-Lab with "TRF Pro" Licence)
- PC
- **No** anechoic chamber needed

Template

Create a new dB-Lab operation based on the operation template *TRF rub+buzz w/o Golden Unit* for measuring the ICHD and PHD.

You may change any settings of this template operation and save the modified ooperation as your own template via the button *Save as Template* in the dB-Lab toolbar.

Measurement

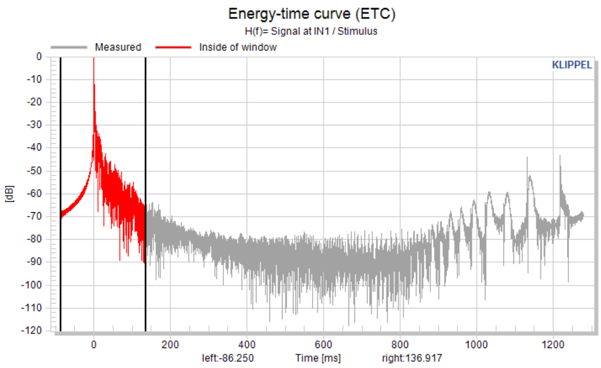
1. Start the measurement *TRF rub+buzz w/o Golden Unit.*
2. Open the window *Instantaneous Distortion*. If the instantaneous crest factor ICHD is less than 12 dB, no impulsive distortion is generated. In this case the 3D window *Instantaneous distortion 3D* will show no black dots (in case you have a laser sensor connected). It is recommended to increase the voltage on property page STIMULUS and repeat the measurement.
3. If you find significant impulsive distortion which are reproducible then you should check the window *Fundamental + Harmonics* if the curve *Absolute PHD* is above the *PHD Limit* in the same frequency region as the ICHD. Only if both conditions are fulfilled for the same frequencies, the rub & buzz effect is critical.
4. If the voltage in property page STIMULUS is above the maximal voltage permissible to the driver stop the measurement. Otherwise you may damage it.

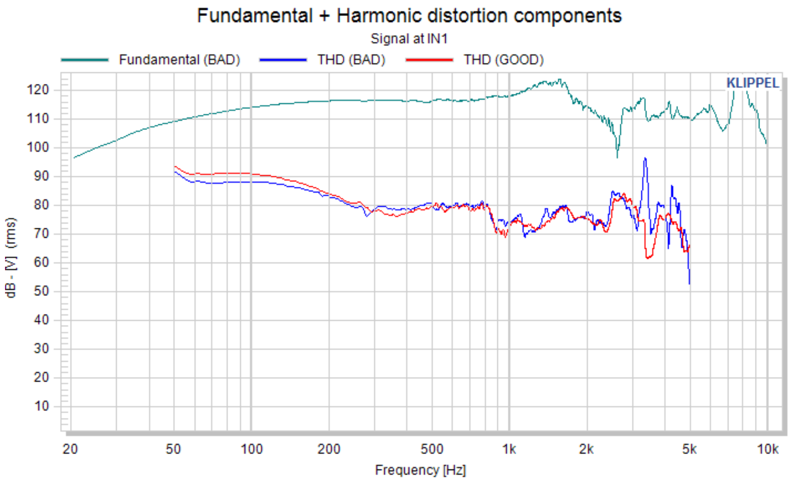
NOTE: Ambient noise or vibrating cables or clips at the loudspeaker terminals can also cause impulsive distortion. It is strongly recommended to use a non-vibrating fixture or simply laying the driver on a foam piece for the rub & buzz measurement to avoid any parasitic rub & buzz effects.

Post processing

1. Open the result window *Energy-Time Curve* and ensure that the maximum of the ETC is included in the window. This is important for the time delay calculation in both operations.
2. Open the result window *Instantaneous Distortion 3D*. The ICHD measure is shown as color versus voice coil position and frequency. The color code of the 3D graph can be controlled by the parameter *Limit Absolute PHD* on property page I-DIST. Black color indicates distortion that exceed the defined threshold. A threshold of 10-15 dB is a good choice. If no laser is available the distortion may be mapped versus frequency and sound pressure signal. Since the sound pressure is proportional to the voice coil acceleration the distortion appear phase inverted (e.g. positive sound pressure corresponds with negative displacement).

3 Example

<table>
<tr><td>Drivers under test</td><td>Two oval drivers with f_s=100 Hz and a sensitivity is about 86 dB/W/m have been investigated. One driver has a clearly audible rub and buzz problem.</td></tr>
<tr><td>Energy-time curve</td><td>


Using the two markers some region of the ETC can be selected for Analysis. In this application the marker positions are not critical, as long as the main impulse is inside the window (important for time delay calculation). However, for separating linear and nonlinear response it is good practice to set the left marker at the left border and the right marker in the minimum of the ETC (use Shift and CTRL + Mouse click).</td></tr>
<tr><td>THD</td><td>


For comparison the THD curves of a good and a bad driver are presented. It is obvious that the THD is not a suited measure to describe and detect rub & buzz phenomena. The regular distortion, caused by motor and suspension nonlinearities, mask the much smaller rub & buzz distortion.</td></tr>
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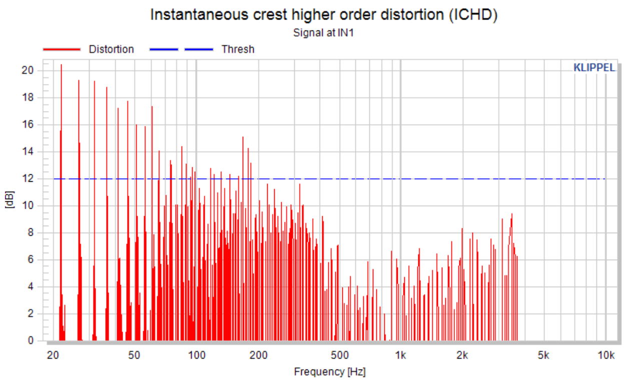
<table>
<tr>
<td>Instantaneous crest harmonic distortion (ICHD)</td>
<td>


The ICHD is the instantaneous crest factor of the residual *e*(*t*). It quantifies the peaky-ness of *e*(*t*) and reveals the fine structure of the rub & buzz distortion.

The bad driver shows strong peaks at 20-150 Hz which have a crest factor ICHD > 12 dB. These kinds of peaks are typical for R&B effects.

The good driver has a crest factor ICHD which is always smaller than 12 dB. Thus the ICHD is a reliable criterion for detecting rub & buzz problems.
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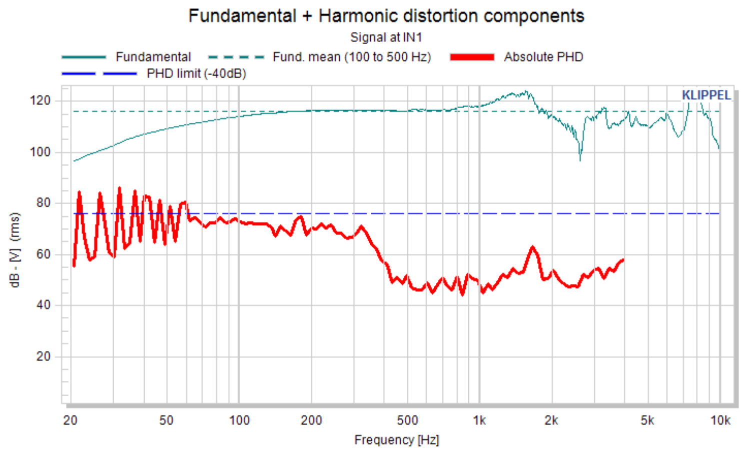
<tr>
<td>Peak value of Higher-order Distortion (PHD)</td>
<td>


The window *Fundamental + Harmonics* shows the Peak value PHD of the harmonic distortion. The PHD is higher than the allowed limit value for frequencies at 20-150 Hz where the crest factor is above the limit. The impulsive distortion has a high impact on sound quality.
</td>
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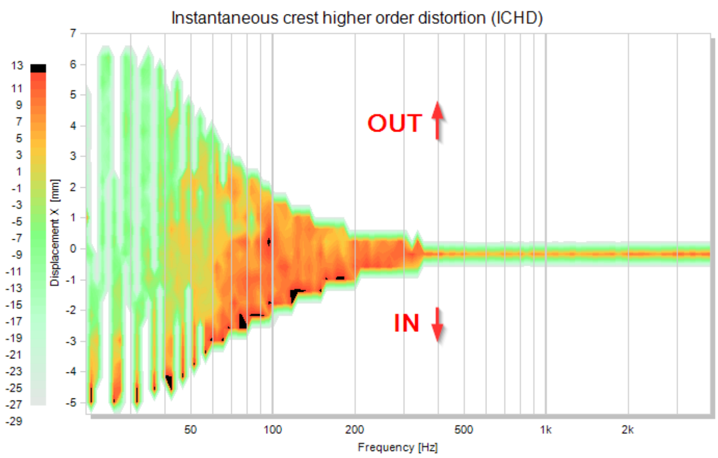
<tr>
<td>3D-representation</td>
<td>


The result window *Instantaneous Distortion 3D* shows the crest factor ICHD (as color) versus voice coil displacement (y axis) and frequency (x axis). This reveals valuable information about the location of the R&B defect. Black spots at frequencies 20-200 Hz and for negative voice coil displacement indicate a voice coil rubbing maybe caused by a tilting of the voice coil.
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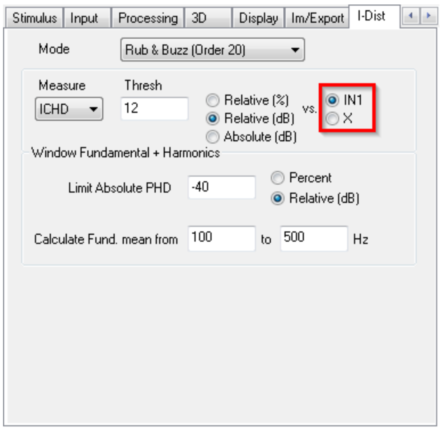
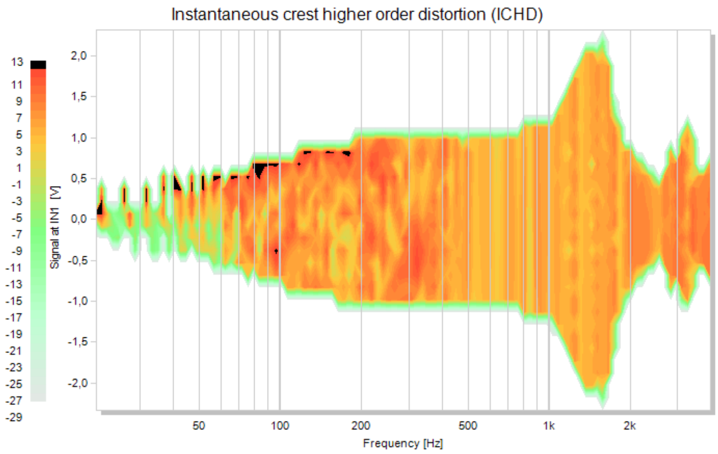
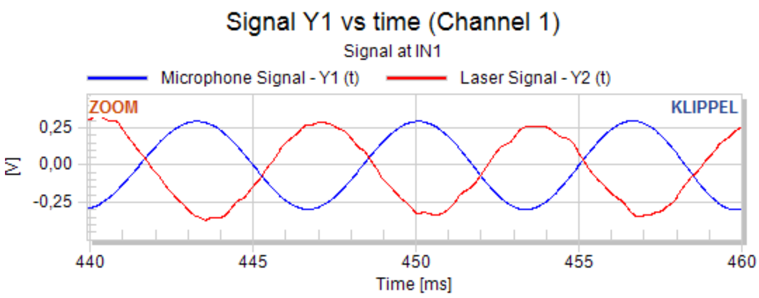
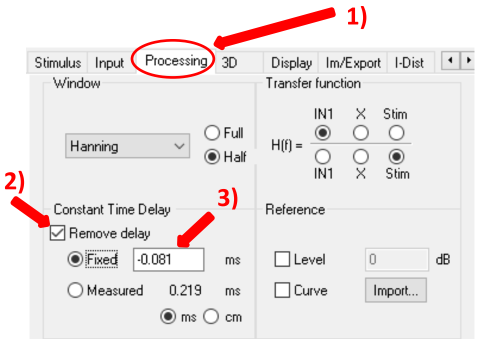
</table>

	By changing the properties on property page I-DIST you may review the ICHD values over the microphone signal instead of displacement. This will also be shown if there is no laser sensor connected.   Please note that there is a 180° phase shift between displacement and microphone signal (for a loudspeaker that is measured in free air). You can also check this when comparing the waveforms of displacement and microphone signal in the windows *Y1 (t)* and *Y2 (t)* (in the picture below). Thus you will get the black spots of high ICHD values at the positive maximum in this example (according to the negative peak displacement). 

4 Hints and Troubleshooting

3D Plot

The currently recommended Keyence laser sensors have built-in digital signal processing and therefore a significant time delay compared to the microphone signal. Since in the 3D graph both signals are overlaid you have to ensure correct time delay compensation in property page PROCESSING. Otherwise the black spots may occur at wrong displacement values.



Hints:

$$\Delta t_{mic} - \Delta t_{remove} = \Delta t_{laser}$$

Δt_{mic}: measured Mic delay

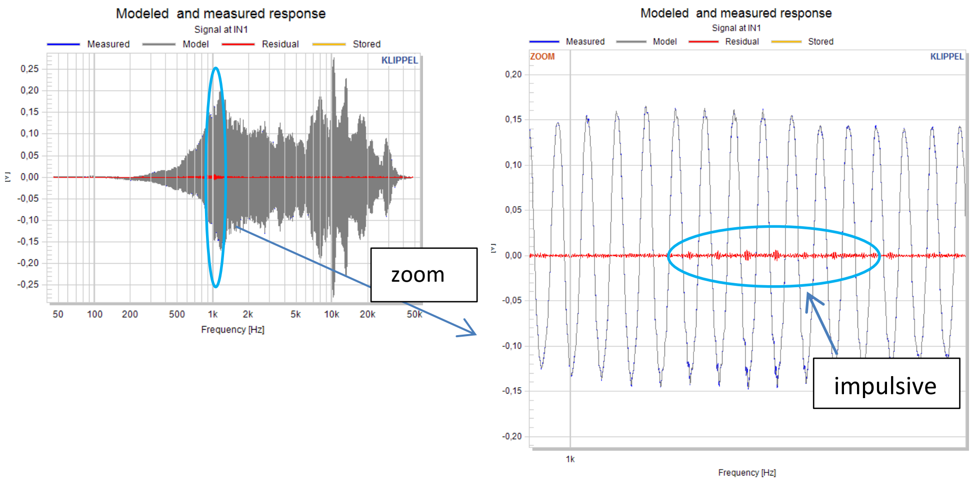
Δt_{laser}: laser delay

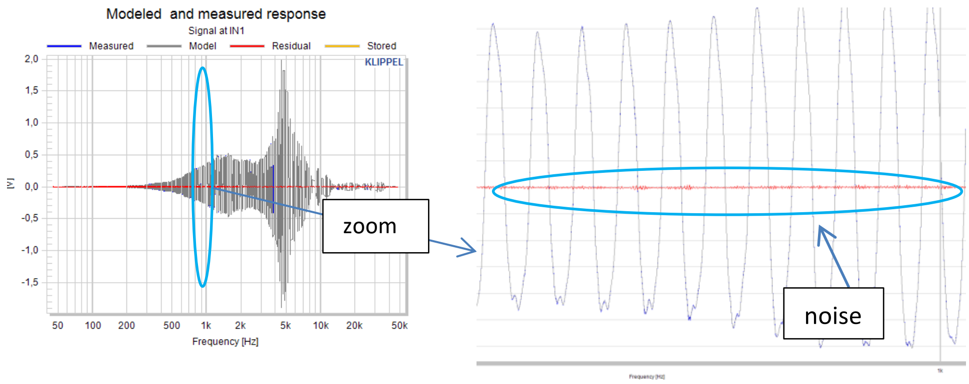
Δt_{remove}: calculated remove delay

the used laser in this example is LK-G32 which has a time delay of 0.3 ms. The measured Mic delay is 0.219 ms. So the removed delay can be calculated as: 0.219-0.3 = -0.081 ms

The known time delay values for different Keyence lasers are listed as follows:

- LK-H052 / 022 / 082 (with Klippel setting) = 580 +/- 10 µs
- LK-G32 / 82 (with Fmax 10kHz Klippel setting) = 120 µs
- LK-G32 / 82 (with Fmax 25kHz Klippel setting) = 300 µs

<table>
<tr>
<td>Instantaneous Distortion</td>
<td>
The red curve in the result window Modeled Response shows the instantaneous distortion e(t) in the time domain signal. As you can see, impulsive distortion are only generated for a half wave of the measured, non-processed time signal y(t) represented as blue curve.


In contrast to the above results there are also some cases where noise corrupts the measurement which sometimes has parasitic influence on the rub & buzz measure. In this case only reviewing the Residual curve may show a root cause. In the below picture you clearly see that there is no impulsive distortion but only fluctuating noise.


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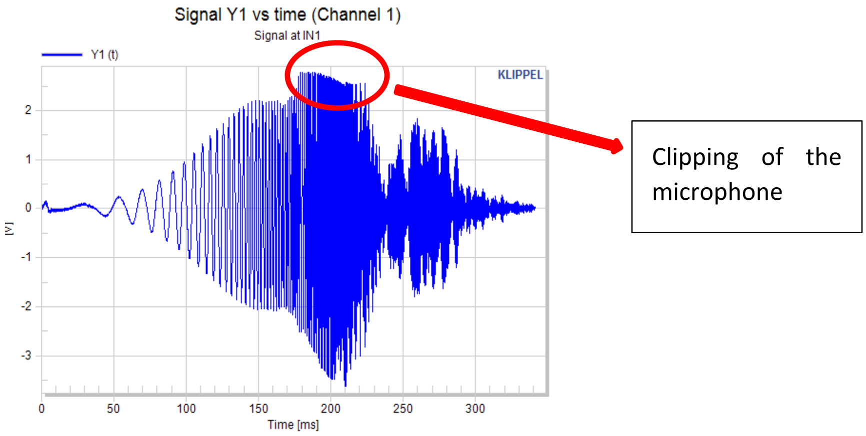
Microphone signal	Since the rub & buzz analysis requires proper SNR and therefor small distance between microphone and DUT it might happen that the microphone signal is clipping because of too high SPL values. In this case you would see in window *Fundamental + Harmonics* that the curves *Absolute PHD* and *Fundamental* have peaks at the same frequencies. This is an indicator for a clipping of the microphone signal. Go to window *Y1 (t)* and check the time signal for any clipping effects. The below picture shows a typical microphone signal at too high sound pressure level. 

5 More Information

Documents	AN23 – Rub & buzz effects with Golden Unit W. Klippel, U. Seidel: Measurement of Impulsive Distortion, Rub and Buzz and other Disturbances, Presented at the 114th AES Convention 2003 March, Amsterdam.
Related Specification	“TRF”, S7
Software	User Manual for the KLIPPEL R&D SYSTEM.

Find explanations for symbols at:

http://www.klippel.de/know-how/literature.html

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