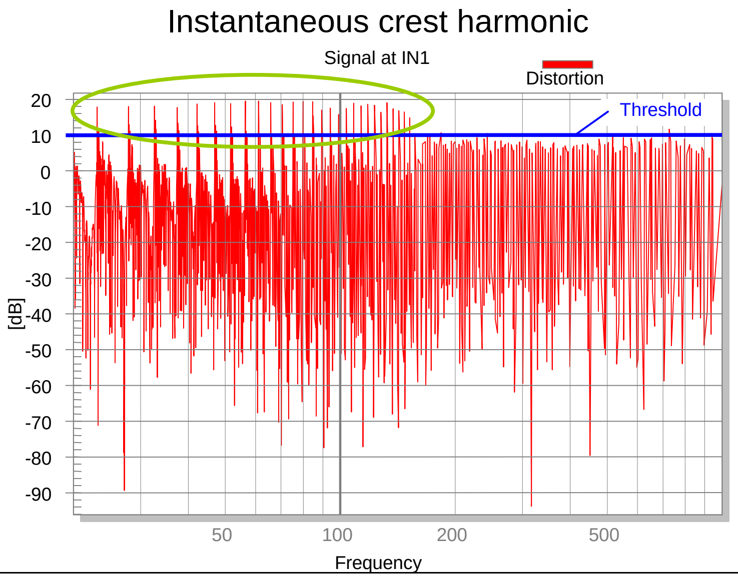
Rub & Buzz Detection without Golden Unit **AN 22**

Application Note to the KLIPPEL R&D SYSTEM

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.



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updated 21st October 2011

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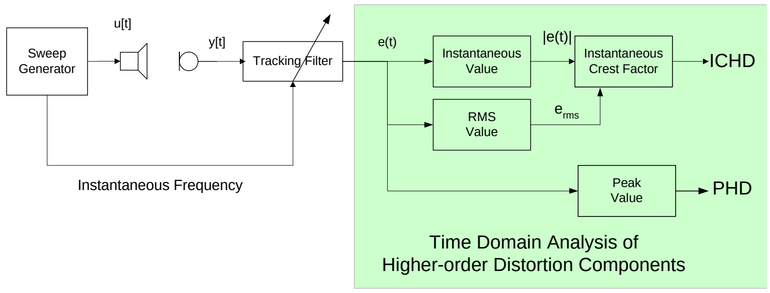
Theory

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 1kHz. Rub & buzz effects are mostly correlated to high displacements and the highest displacement usually occurs around the resonance frequency. The rub & buzz distortion 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) 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.

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 harmonic 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 the 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 Harmonic Distortion (ICHD)* is defined as 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 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 problem. Note that the audibility of the impulsive distortion also depends on the amplitude and a measurement of the peak value PHD is also recommended.
Peak values of higher-order Harmonics ***(PHD)***	The peak value of the harmonic 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 become 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 f_i with i=1,2,3, ..N where the crest factor ICHD > 12 dB and impulsive distortion are generated 2. If the peak value $PHD(f_i) < PHD_{lim}(f_i)$ of the impulsive distortion at those frequencies f_i exceeds a permissible limit $PHD_{lim}(f_i)$ then the impulsive distortion have also a high magnitude and a large impact on sound quality. This magnitude of the limit $PHD_{lim}(f_i)$ depends on the particular application. A good starting value is 1.. 3 %.

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 & buzz 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.

Performing the Measurement

Requirements

The following hardware and software is required:
- Distortion Analyzer
- Laser Sensor, Microphone
- PC
- Software modules (TRF pro, dB-Lab)
- **No** anechoic chamber needed

Template

Create a new object *DRIVER* and add a new TRF operation based on the object template *R&B without Golden Unit AN22* for measuring the ICHD.

Customize Setup

If this template is not available you may generate a new operation based on the general TRF module.

First measurement

1. Create a new TRF operation based on the **Default** template. Name the operation ***TRF Crest Harmonics (x,f)*** measurement.
2. Open the property page **I-Dist**. Set **Mode** to **Rub & Buzz(Order 20)** and ***Measure*** to **ICHD**, respectively. Set the Threshold to **12dB** and select diagram **X**.
3. Open the property page **Stimulus.** The voltage should be adjusted to your specific driver. You should operate the driver at different amplitude levels, where possibly rub & buzz effects are occurring. Note, that at high levels some defects may be mask, so try intermediate levels also.
   Set 20Hz for F**min** and 10kHz for **Fmax**. Select the resolution 1.46Hz or 16384 points.
4. Open the property page **Input**. Select **(Mic) IN 1** for the **channel 1** and **X** for the **channel 2**.
5. Open the property page **Processing**. Set **Window** to **Hanning.**

Second measurement

1. Create a new TRF operation based on the **Default** template. Name the operation **TRF Peak harmonics, time domain** measurement.
2. Open the property page **I-Dist**. Set **Mode** to **Rub & Buzz(Order 20)** and ***Measure*** to **PHD**, respectively. Set the Threshold to **12dB** and select diagram **X**.
3. Open the property page **Stimulus.** Set 10Hz for F**min** and 10kHz for **Fmax**. Select the resolution 0.37Hz or 65536 points.
4. Open the property page **Input**. Select **(Mic) IN 1** for the **channel 1** and **X** for the **channel 2**

Measurement

1. Start the measurement *TRF Crest Harmonics (x,f)*
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. 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 or the voltage is above the maximal voltage permissible to the driver stop the measurement *TRF Crest Harmonics (x,f)*.
4. Read voltage used in property page STIMULUS in operation *TRF Crest Harmonics (x,f)* and enter the same value in the operation *TRF Peak harmonics, time domai*n. Start this measurement.

NOTE: Ambient noise or vibrating cables or clips at the loudspeaker terminals can also cause impulsive distortion.

Post processing

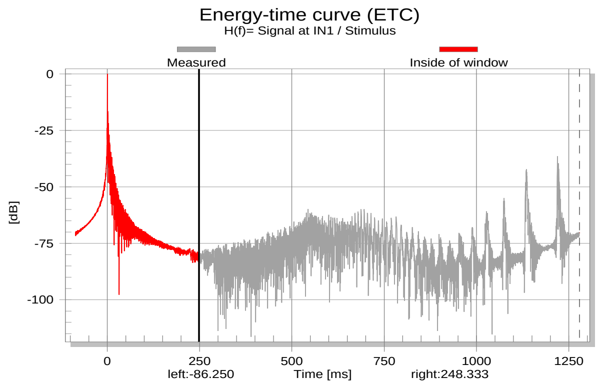
1. Open the result window *Energy-Time Curve* and ensure that the maximum of the ETC is included in the window. This is important for the time delay calculation in both operations.
2. Select the operation *TRF Crest Harmonics (x,f)*. Open the results window *Instantaneous Distortion* and search for frequencies f_i with i=1,2,3, ..N where the crest factor ICHD > 12 dB or where black spots are generated in window *Instantaneous Distortion 3D.*
3. Select the operation *TRF Peak harmonics, time domai*n. Open the window Instantaneous Distortion read the peak value of the higher-order harmonics PHD(f_i) at those critical frequencies. If the PHD(f_i) is larger than a permissible threshold (for example -30dB or 3 %) then the impulsive distortion are not negligible.
4. Open the result window Instantaneous Distortion **3D.** The ICHD measure is as color versus voice coil position and frequency. The **color code of the 3D graph** can be controlled by the parameter *Thresh* on property page *I-Dist*. Black color indicate distortion that exceeding 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).

Example

Drivers under test

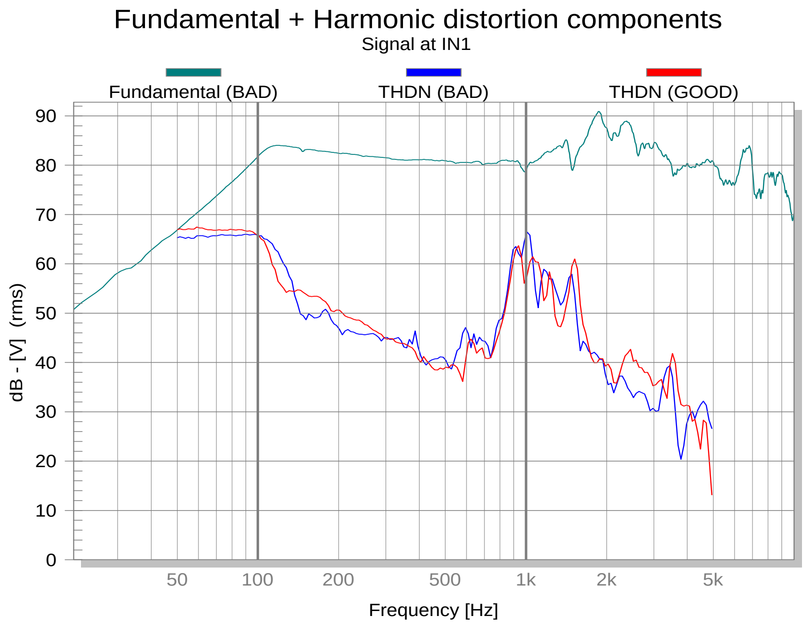
Two oval drivers with f_s=100 Hz and a sensitivity is about 86 dB/W/m have been investigated. One driver has a clearly audible rub and buzz problem.

Energy-time curve



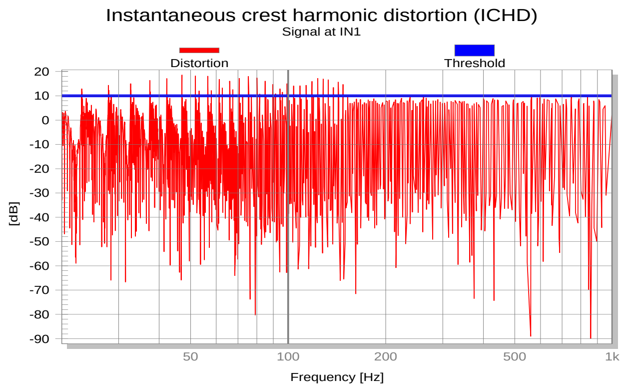
Using the two markers some region of the ETC can be selected for Analysis. In this application the marker positions are not critical, as long as the main impulse is inside the window (important for time delay calculation). However, for separating linear and nonlinear response it is good practice to set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

THD



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 R&B phenomena. The regular distortion, caused by motor and suspension nonlinearities, mask the much smaller rub & buzz distortion.

Instantaneous crest harmonic distortion (ICHD)

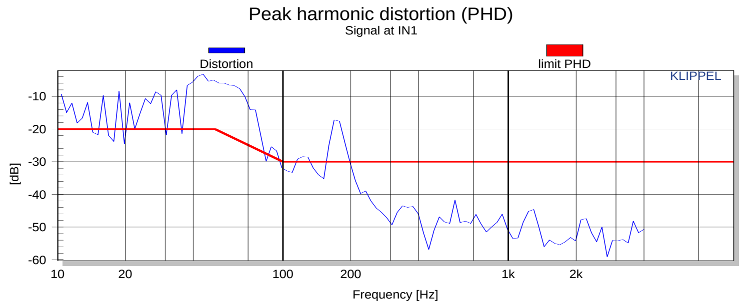


The ICHD is the instantaneous crest factor of the residual *e*(*t*). It quantifies the peaky-ness of *e*(*t*) and reveals the fine structure of the rub & buzz distortion.

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.

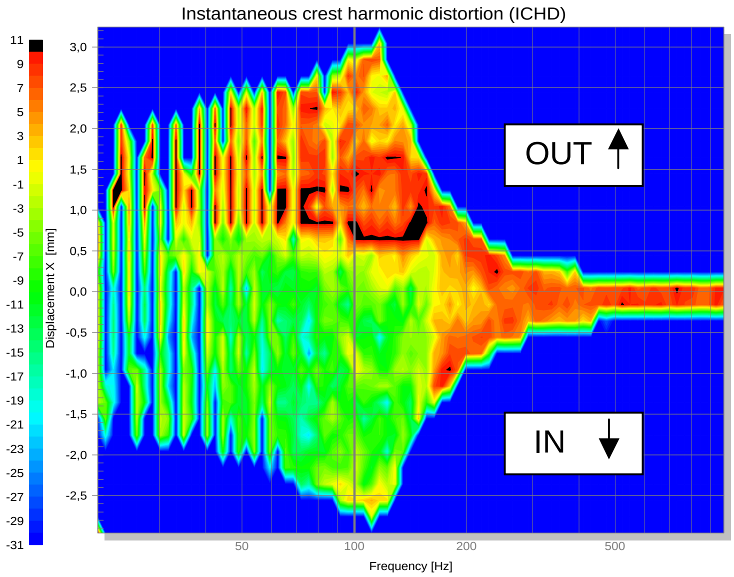
The good driver has a crest factor ICHD which is always smaller than 12 dB. Thus the ICHD is a reliable criterion for detecting rub and buzz problems.

Peak value of Harmonic Distortion (PHD)



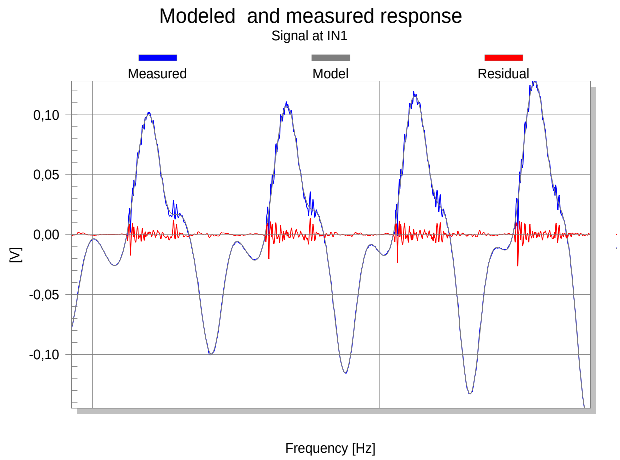
The second operation *TRF Crest Harmonics (x,f)* shows the Peak value PHD of the harmonic distortion. The PHD is higher than the allowed limit value for frequencies at 20-150 Hz where the Crest factor is above the limit. The impulsive distortion has a high impact on sound quality.

3D-representation



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 20-150 Hz and for positive voice coil displacement indicate a voice coil rubbing.

Instantaneous Distortion



The red curve in the result window Modeled Rsponse shows the instantaneous distortion e(t) in the time domain signal. Impulsive distortion are only generated for a half wave of the measured, non-processed time signal y(t) represented as blue curve. Clearly the defect only occurs for positive displacement of the voice coil.

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.

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