Transforming Sound into Knowledge

Are You Shipping Defective Loudspeakers to Your Customers?

by

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Introduction

Loudspeaker distortion is undesirable. The type and level of distortion, however, can greatly influence the perceived annoyance. In addition, identifying the type of distortion can also help pinpoint the mechanism or mechanisms in the loudspeaker that are causing the distortion. “Rub & Buzz” is a good example of a particularly annoying type of distortion that is very difficult to measure. Pinpointing the cause of the problem from the measurement is an even more difficult task. Understanding why this type of distortion is so annoying and how to measure it is critical in being able to properly test loudspeakers on the production line.

Psychoacoustics

The human ear's sensitivity to sound varies with frequency and level. Fletcher-Munson loudness curves describe this relationship. These curves indicate that tones at the low and high frequency end of the audio band are less audible than tones of the same amplitude in the middle frequency band. This also applies to distortion products. For example, Moir found that harmonic distortion below 400 Hz became increasingly harder to detect than harmonic distortion above 400 Hz.[1]

Distortion audibility is also a function of sound duration. The ear has a finite time resolution. Moir has found that distortion due to clipping of a 4 millisecond tone burst reached about 10% before it was detectable. However, increasing the pulse length to 20 milliseconds reduced the “just detectable” distortion point to around 0.3%. This is equivalent to reducing the distortion by 20 decibels.

Another important psychoacoustic phenomenon is masking. Sounds in our environment rarely occur in isolation as pure tones. The study of masking is concerned with the interaction of sounds. Tonal masking, for instance, deals with the change in the perception threshold for a particular tone in the presence of another tone (Fig. 1).

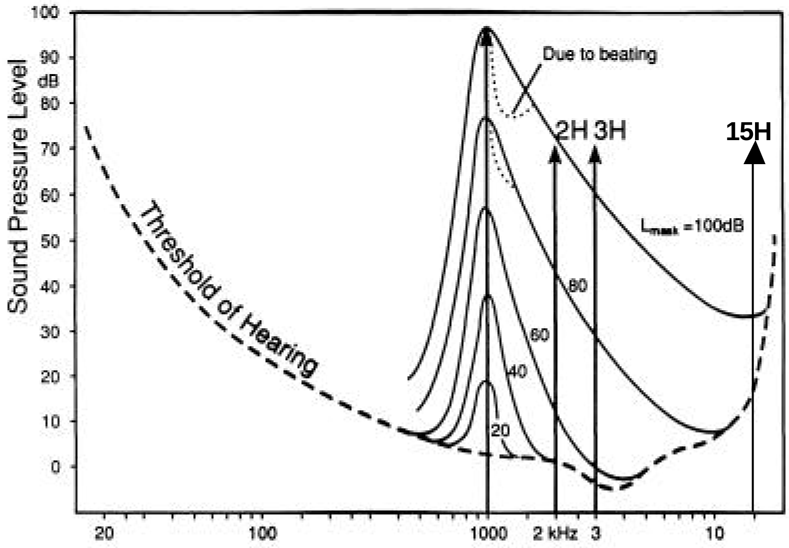

Figure 1 *Masking Threshold for a pure tone in the presence of narrow band noise centered at 1 kHz (Zwicker, 1975). For a masking tone of 100 dB SPL, the 2rd Harmonic is masked for levels below 70 dB and the 3rd Harmonic is masked for levels below 60*

dB SPL But the 15th Harmonic is hardly masked at all (below 35 dB SPL)

Narrow band noise is used instead of a pure tone for the masking frequency in order to reduce "beating"- low frequency modulation when the probe tone approaches the same frequency of the masking tone. Fig. 1 indicates that more masking occurs for low order harmonics than for high order harmonics.[2] This becomes significant when discussing the audibility of different kinds of distortion such as rub &buzz.

In the case of harmonic distortion, the fundamental masks the 2nd harmonic component more than the 3rd harmonic and very little for the higher harmonic components. This is another frequency and level dependent phenomenon. The masking threshold widens in the low and high frequency end of the audio band. It also widens with increasing sound pressure level.

Rub & Buzz

"Rub & Buzz" is a good example of a defect which can easily go undetected by traditional measurement methods. For example, look at the spectrums of two different car loudspeakers in Fig. 2, which are both reproducing a 200 Hz tone close to their resonance frequency at a fairly high level.

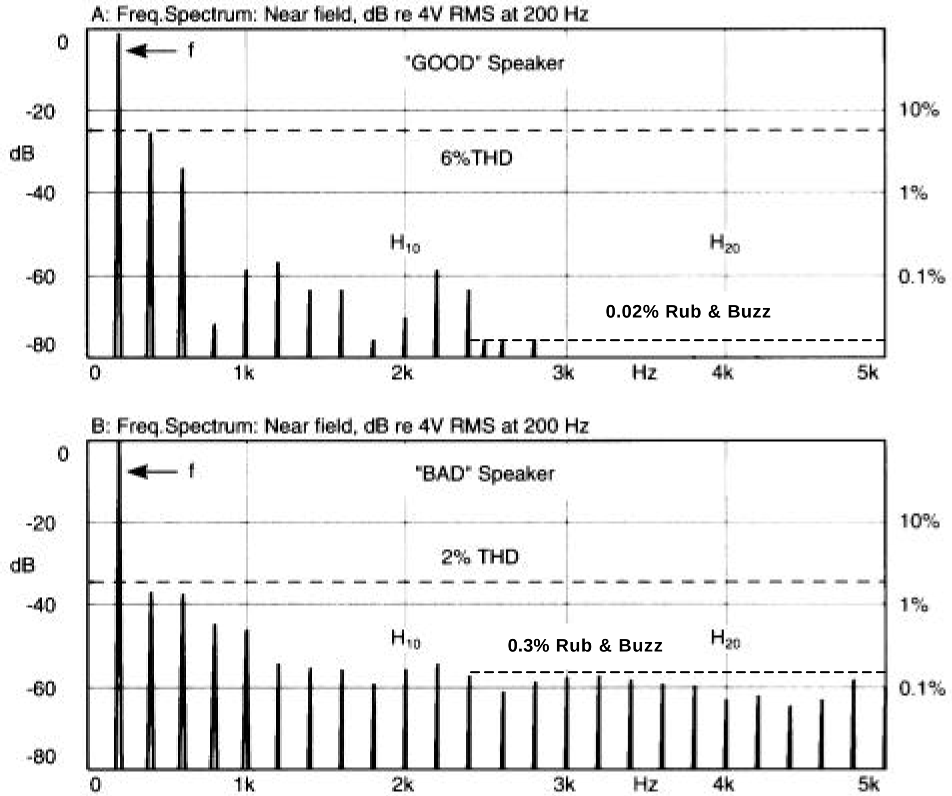

Figure 2 *Resulting spectrum for a pure tone excitation (f) at 200 Hz*

a) Upper curve shows a distortion spectrum of a normally functioning loudspeaker. THD=6%, Rub&Buzz=0.02%

b) Lower curve shows a distortion spectrum containing high order harmonics resulting from a "rubbing" voice coil caused by a bent frame. THD=2%, Rub&Buzz=0.30%

The significant difference between the two loudspeakers in Fig. 2, is the dramatic rise in level of the harmonics above the 12th harmonic. High order harmonics as low as 60 dB below the fundamental can be quite audible.[3] The ear perceives these high order harmonics independent of the fundamental because of the large difference in frequency. In addition, the high order harmonics typically fall in the frequency range most sensitive to the ear.

Notice that in the "good" loudspeaker (Fig. 2a), the total harmonic distortion (THD) is actually higher than that for the "bad" (Fig. 2b), buzzing loudspeaker. This is because the 2nd and 3rd harmonic components dominate in level compared with the high order harmonics. When calculating the THD as traditionally done in Equation I, only harmonic levels within 6 dB of the highest amplitude harmonic, appreciably add to the overall level. **Power summing** the high order harmonics, as indicated in Equation II, gives a more accurate representation of the distortion due to rub & buzz.[4] As a result, the “bad” loudspeaker’s rub & buzz distortion is greater than the “good” loudspeaker.

Equation I

$$\%THD = \frac{\sqrt{(H_2^2 + H_3^2 \cdots H_N^2)}}{\sqrt{(H_1^2 + H_2^2 + H_3^2 \cdots H_N^2)}} x100$$

Equation II

$$\%Rub + Buzz = \frac{\sqrt{(H_{15}^2 + H_{16}^2 \cdots H_{20}^2)}}{\sqrt{(H_1^2 + H_2^2 + H_3^2 \cdots H_N^2)}} x100$$

H_N = Harmonic response of the N^th harmonic.
H_1 = Fundamental response.

Therefore, to detect rub & buzz it is necessary to measure high order harmonics independent of both low order harmonics and background noise.

HARMONICTRAKÔ

Many loudspeaker faults can be determined by analyzing the frequency and level of different harmonics produced by the loudspeaker. The standard measurement technique is to use either a tracking filter to measure individual harmonics or a tracking notch filter and measure the remaining distortion energy and noise (see Figure 3). This technique, however, is slow and must be repeated if additional harmonics are desired.

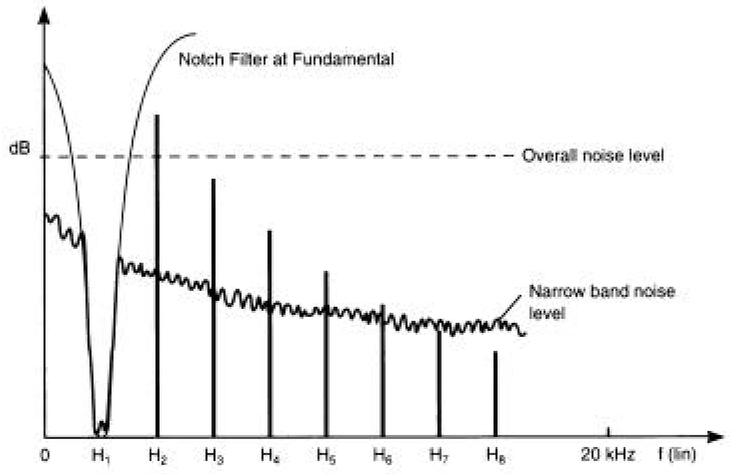

Figure 3 THD +N measured with a “notch” filter (includes overall noise level)

This measurement technique, however, cannot distinguish the amplitude of individual harmonics (e.g., 2nd, 3rd, and 4th harmonics) or distinguish distortion from noise. Moreover, these measurements are typically performed in the presence of high background noise, such as on the factory floor. In this situation, it is impossible to discern distortion from noise.

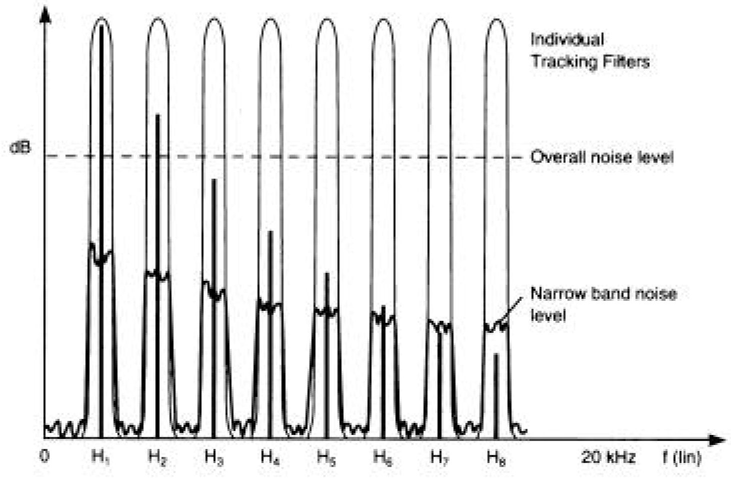

Figure 4 Total Harmonic Distortion (THD) measured with HarmonicTrakÔ

(includes selected distortion components)

Instead of using a tracking filter that can only measure one harmonic at a time, a special FFT-based algorithm, called HarmonicTrak™, was developed to measure all the harmonics simultaneously in a single sine sweep (see Fig 4). This is equivalent to a parallel bank of individual tracking filters that measure all selected harmonics simultaneously. This parallel analysis technique saves considerable measurement time over the traditional serial analysis method. The ability to single out individual harmonics is ideal for detecting and analyzing different kinds of transducer faults, such as rubbing voice coils, loose particles in the gap and buzzing or rattling.

The effects of background noise are greatly diminished by using this technique. Each frequency step can contain numerous cycles that are synchronously averaged to further improve the effective signal-to-noise ratio (see Figure 5). Increased averaging has the effect of narrowing the filter bandwidth for better noise rejection.[5]

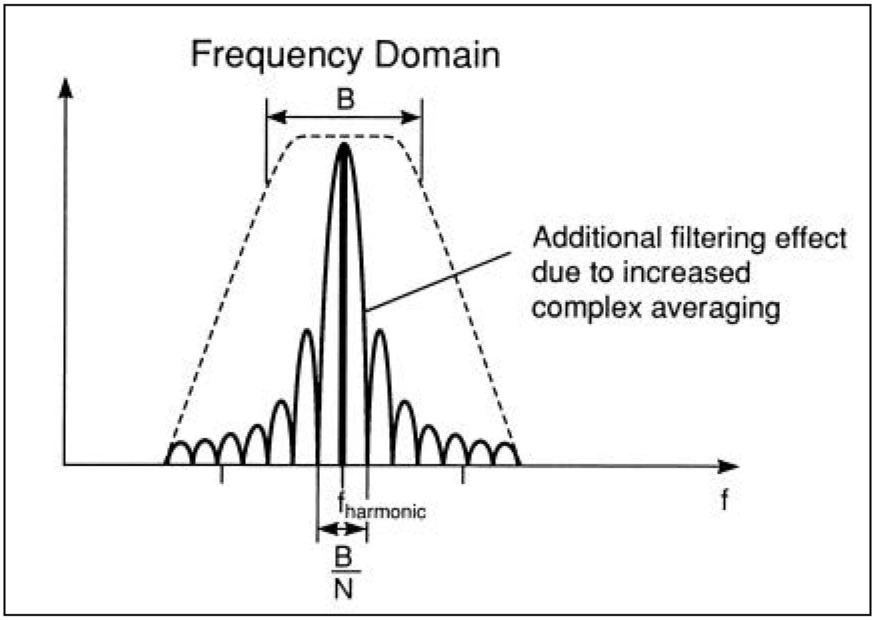

Figure 5 *Increased complex linear averaging results in a narrowing of the effective filter bandwidth, further suppressing background noise (N = number of cycles)*

Conclusion

Rub & buzz measurements require a large dynamic range and high signal to noise ratio because of the very low distortion levels. HarmonicTrak's filtering and averaging algorithms provide excellent accuracy even in noisy environments such as on factory floors.

Quite often, factory background noise is usually higher than the distortion harmonics. Since most test systems simply notch out the fundamental (as in Figure 3) and report the remaining energy as total harmonic distortion plus noise (THD+N), there is no way to differentiate how much energy is related to the distortion or the background noise. This probably will lead to rejecting perfectly good loudspeakers due to excessive background noise. HarmonicTrak lets you choose which harmonics to measure and power sums them appropriately to calculate total harmonic distortion and rub & buzz distortion while suppressing background noise. Without utilizing HarmonicTrak's capabilities for detecting rub & buzz, **"bad"** loudspeakers may still pass and make their way into the customers' hands.

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[1] J. Moir, "Just Detectable Distortion", Wireless World, vol. 87, no. 1541, Feb. 1981.

[2] W. Yost and D. Nielsen, "Fundamentals of Hearing", Holt, CBS College Publishing, 1985.

[3] J. Bareham, "Automatic Quality Testing of Loudspeaker Electroacoustic Performance", Brüel & Kjær Application Note, BO 0141-11, 1989

[4] S.F. Temme, "Why and How to Measure Distortion in Electroacoustic Transducers," Proc. AES 11th Int. Conf. On Audio Test and Measurement, Portland, OR, 1992 (May 29-31)

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[5] C.J. Struck, "An Adaptive Scan Algorithm for Fast Response Measurements", presented at the AES 91st Convention – New York, (1991 October 4 – 8)