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Higher Order Harmonic Signature Analysis for Loudspeaker Defect Detection

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ABSTRACT

Loudspeaker assembly faults, such as a rubbing voice coil, bent frame, loose spider, etc., have traditionally been detected using experienced human listeners at the end of a production line. Previous attempts to develop production measurement systems for on-line testing typically analyze only low-order harmonics for the primary purpose of measuring total harmonic distortion (THD), and thus are not specifically designed to detect defective rub, buzz, and ticking sounds. This paper describes a new method wherein the total energy of high-order harmonics groups, for example, 10th through the 20th or 31st through the 40th, are measured and analyzed. By grouping high-order harmonics and resolving their respective total energies, distinct signatures can be obtained that correlate to the root cause of audible rub and buzz distortions (Temme, 2000). The paper discusses loudspeakers tested with specific defects, as well as results of a computer-based electroacoustic measurement and analysis system used for detection.

1. INTRODUCTION

A human “golden ear” listener is the primary method for detecting rub and buzz distortion regarding loudspeaker quality assurance testing. The human ear is very sensitive to buzzing sounds caused by various assembly errors such as misaligned voice coils, improperly glued parts (spider or surround), and air leaks in loudspeaker enclosures. Given enough time to train their ears, the human listener can usually discriminate one defect from another based on the sonic quality of the buzzing sound. However in most production environments, there is not sufficient time to for the human listener to make a PASS/FAIL judgment AND record data related to root cause of failure. The manufacturer may be able to track overall production yield but the opportunity to establish root cause of failure is lost.

By implementing an appropriate analysis method, a computer-based electroacoustic measurement and analysis system can characterize the defect signatures in real-time and provide the manufacturer with root-cause failure data. Depending on how the failure data stream is manipulated, the manufacturer can be notified in real-time if specific manufacturing processes are no longer in control (e.g. voice coil assembly or gluing operations). In addition, the manufacturer can decide whether to rebuild or scrap the loudspeaker.

1.1. Characterizing loudspeaker buzz

A loudspeaker buzz, when analyzed in the time domain, is actually a series of equally-spaced impulses[1,2]. As such, the Fourier analysis of these signals results in a frequency spectrum that contains many harmonics.

Figure 1 shows the time-domain response of a buzzing loudspeaker when excited with a stepped-sine excitation. The starting frequency is 20 kHz and the stop frequency is 20 Hz.

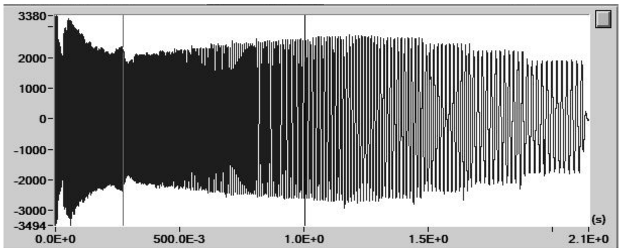

Figure 1: Response to stepped-sine excitation

When analyzed using the Hilbert Transform and high-pass filtering, the repetitive transients caused by the buzzing sound is very evident[1,2].

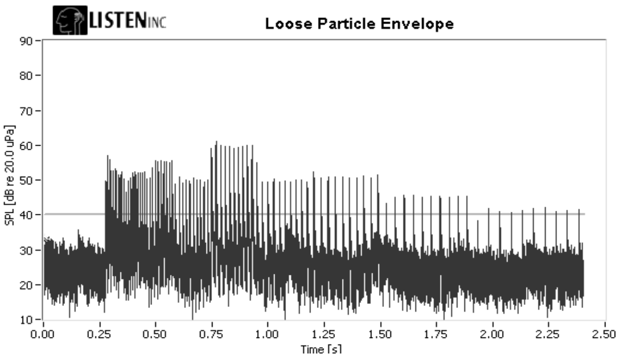

Figure 2: Time envelope of rub and buzz

The resulting frequency spectrum is harmonically rich with significant harmonic energy up to the 100th harmonic or higher. In Figure 3, the time-frequency spectrum that corresponds with Figure 1 is shown in the upper graph with the time signal in the lower graph.

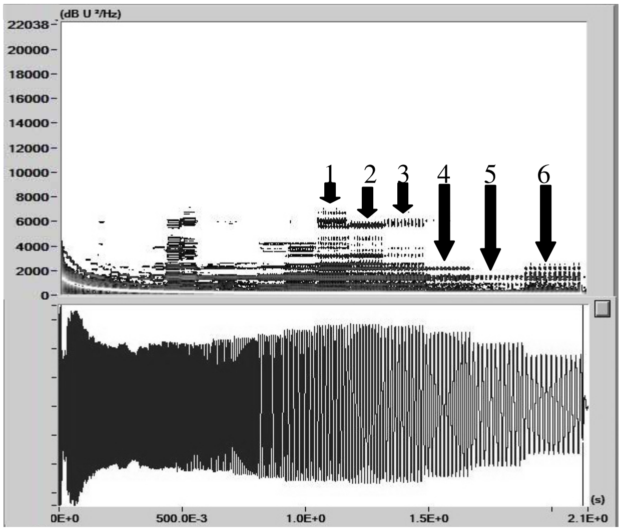

Figure 3: Response to stepped-sine excitation

The corresponding frequencies for the labeled sections and the harmonic content of the buzzing energy are summarized in Table 1.

Section	Excitation (Hz)	Highest Harmonic (Hz)	Highest Order
1	63	6300	100
2	50	5000	100
3	40	6000	150
4	31.5	2000	63
5	25	1500	60
6	20	2000	100

Table 1 Harmonic energy in buzzing loudspeaker

2. METHOD OF ANALYSIS

The basis for analysis relies on the assumption that the so-called "unique harmonic signature" will be determined by power summing harmonics 10 and above. This harmonic range correlates very well to audible rub and buzz distortion [3].

The rub and buzz energy is a ratio of the power sum of harmonics 10 and higher divided by the energy of the Fundamental and Total Distortion (TD). TD is described in Equation 1 and the Rub and Buzz calculation used in this paper is shown in Equation 2.

$$TD = \sqrt{\left(H_2^2 + H_3^2 + \ldots + H_N^2\right)} \qquad (1)$$

$$\%\,Rub\&Buzz = \frac{\sqrt{\left(H_{10}^2 + H_{11}^2 .. H_N^2\right)}}{\sqrt{\left(H_1^2 + TD^2\right)}} \times 100 \qquad (2)$$

The equipment used allowed analysis out to the 40th harmonic (H40), when testing up to 1 kHz. This limitation is due to the data acquisition rate being limited to 96 kHz. With higher sampling rates, analysis up to the 100th harmonic is possible. Although the human ear cannot hear tones in the ultrasonic range, these ultra-high frequencies contribute to the timbre, or contour, of all frequencies within the ear's range.

2.1. Subjectively assessing loudspeakers

The first step of this project was to make an initial evaluation of the loudspeakers. This was done in the same manner as an inspector evaluating loudspeaker performance at the end of a production line. Using the manually operated Signal Generator included in the Listen SoundCheck Electroacoustic Test System, sine waves of varying amplitude and frequency were generated using a Digital Audio Labs CardDeluxe sound card. The frequencies ranged from 20 Hz to 1 kHz and stimulus levels varied from 1.00 V_{RMS} to 5 V_{RMS} at the speaker terminals. The sound card sampling rate was set to 44.1 kHz.

A 26 dB gain audio amplifier, with flat response out to 70 kHz, amplified the sound card output. The loudspeakers consisted of a sample of fifteen (15) 5-inch by 7-inch oval speakers used in factory-installed automotive sound systems. By listening to the acoustic output, audible defects were detected aurally. This was followed by a visual inspection to determine root-cause of each defect.

2.2. Objective performance measurements

After every loudspeaker in the sample group was inspected visually and audibly, a software sequence was created in the test system. Figure 4 is a generalized flow chart of the test sequence.

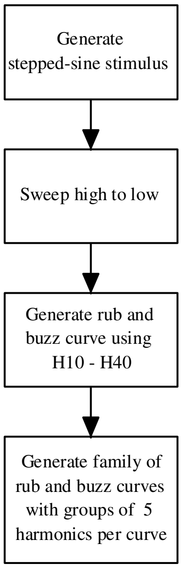

Figure 4: Flowchart of objective test procedure

Based on the frequency range and signal voltage at which the defects were audible, a stimulus was created as the first step in the sequence. The stepped-sine excitation was swept from high frequency to low frequency with a minimum of R80 resolution (80 steps per decade). This approximates 1/24th octave resolution. The sound card sampling rate was set to 96 kHz in order to measure up to the 40th harmonic when the excitation frequency was 1 kHz.

Following the stimulus was an acquisition step that simultaneously played and recorded the signal. This signal was generated from the sound card, through an amplifier and to the loudspeaker inside an anechoic chamber. The loudspeaker's output signal was then measured using a B&K Type 4006 microphone connected to a 48V phantom supply. The balanced output was then connected to the sound card's input channel. Once the signal was recorded, several rub and buzz distortion analysis steps compared the loudspeaker rub and buzz signatures.

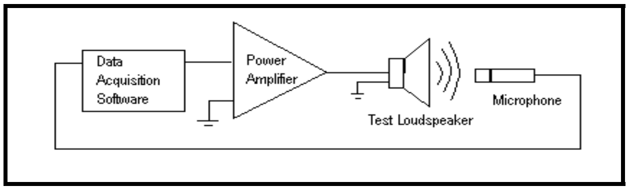

Figure 5: Test set-up

2.2.1. Harmonic Grouping

The measurements included harmonics 10 through 40 (H10-40) in addition to the Fundamental (H1). A total of five (5) rub and buzz curves were calculated. The first curve included H10-40 and four subgroups included H10-15, H16-20, H21-30, and H31-40. This allowed the harmonics, which contained most of the energy of a defect, to be easily found. The final step was a display step that allowed all of the curves created by the analysis steps to be shown on a graph (Figure 6).

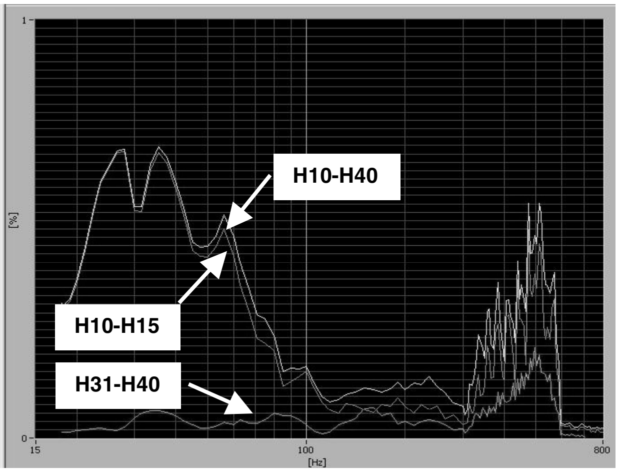

Figure 6: Percent distortion versus harmonic grouping

The individual harmonics were plotted at the excitation frequency. This allowed the user to easily compare graphs containing multiple harmonics. The degree of similarity of each harmonic group was the basis for determining whether a buzzing defect was dominated by lower or higher-order harmonics.

In Figure 7, harmonics 36 though 40 (H36-40) are displayed at the excitation frequency. All five harmonics generate considerable acoustic energy when the excitation frequency varies from 30 Hz to 90 Hz This similarity would then guide the process of determining a unique signature for a specific defect.

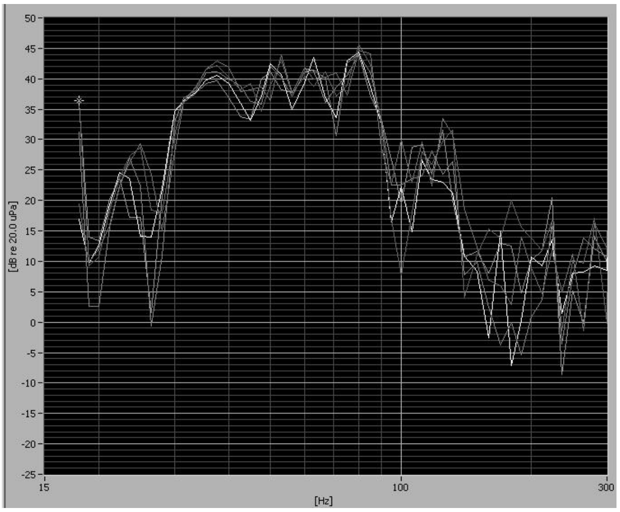

Figure 7: Similarity of harmonics 36 - 40

2.3. Test results

Of the fifteen loudspeakers tested, thirteen exhibited audible rub and buzz distortion. The initial visual and aural inspection of the loudspeakers resulted in the identification of five unique defects. The first defect found was an improperly glued spider. The spider, which is located at the base of the loudspeaker, is attached to the cone at the center and to the base of the basket around the outside. Where the spider was supposed to be glued to the basket around the entire circumference, there were gaps that were not glued. The defect sounded like a buzzing at higher frequencies and like flapping paper at lower frequencies.

Once the defect was detected audibly, the loudspeaker was inspected for tears, gaps or touching components that would produce such a sound. The length of the unattached section varied between loudspeakers from approximately one quarter of the circumference to less than half an inch.

The next defect that was detected only appeared prominently in one loudspeaker. This was a rubbing voice coil. Since this defect was internal it could not be inspected visually, although it could be easily heard. As the sine sweep approached lower frequencies and the displacement of the voice coil increased, a metallic slapping could be heard. The defect could also be felt in the loudspeaker as the cone was manually pushed in and extended out. Through this manual method of moving the cone, the rubbing of the voice coil against the magnet could be felt in other loudspeakers.

The last defect that could be detected audibly was the unattached surround at the basket. This defect is similar to the unattached spider in that it could be caused by improper application of the glue. The resulting sound of the unattached surround was similar to the spider except it was a softer, more airy sound. The visual detection of the defect was easily found as it was on the top of the loudspeaker at the edge of the cone where it meets the basket. The last two defects were the dented cone and the bubble in the loudspeaker surround. These defects were noted visually but did not appear to cause an audible buzzing sound.

In the time allotted for this research project, one defect was considered for automatic identification. This was the misglued spider, as shown in Figure 8.

Figure 8: Spider improperly glued

This specific defect was chosen because it occurred in the greatest number of loudspeakers. Four out of the fifteen loudspeakers tested had misglued spiders.

Detecting a misglued spider based on a unique rub and buzz curve was consistently accurate. The Pass/Fail limit curve was developed by arithmetically averaging the rub and buzz curves of the four defective loudspeakers.

$$Fail(\%) = \frac{\sum_{1}^{4}\left[\frac{\sqrt{\left(H_{10}^{2}+H_{11}^{2}..H_{N}^{2}\right)}}{\sqrt{\left(H_{1}^{2}+TD^{2}\right)}}\times 100\right]}{4} \tag{3}$$

The Limits Curve resulting from this calculation is shown in Figure 9. The curve is the Misglued Spider Limits Curve. An excitation frequency of approximately 360 Hz generated the buzzing distortion from these four loudspeakers.

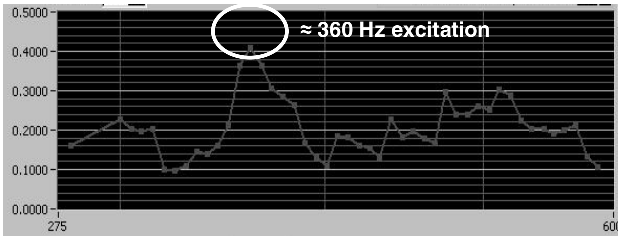

Figure 9: Misglued Spider Detection Curve

Every loudspeaker that had no pronounced audible defect, or a defect other than a misglued spider, was passed when compared to the Limits Curve. The one exception was Loudspeaker #10. It passed the misglued spider test using the Limits Curve in Figure 9. A resulting visual inspection showed that the spider was not fully glued. The excitation frequency of this loudspeaker's defect was outside of the Limits Curve as shown in Figure 10.

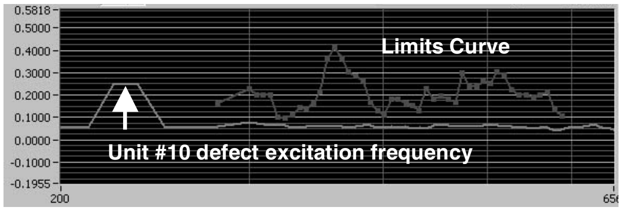

Figure 10: Unit #10 with a false PASS

For this particular loudspeaker, almost 25 percent of the spider circumference was not attached. For the other loudspeakers with misglued spiders, a much smaller portion of the circumference was unattached. If the Limits Curve had been extended downward to 200 Hz or lower, the automatic detection routine would probably have failed this loudspeaker.

All loudspeakers were visually and aurally inspected at the beginning of this project. Loudspeaker #3 originally did not have a spider defect. However two months into this research effort, it failed the detection sequence. After a second visual inspection, it was determined that during bench testing the loudspeaker was over-exerted, which excessively heated the voice coil. This in turn heated the basket and the spider glue. This caused small bubbles to form in the glue therefore forming a spider defect. Thus, the automatic detection routine utilizing the Limits Curve actually detected a defect that was inadvertently created through the testing process.

A summary of the results is in Table 2.

	Visual Inspection		Sequence	
Speaker #	PASS	FAIL	FAIL	PASS
1	X			X
3	X	X	X	
4	X			X
5	X			X
7		X	X	
8		X	X	
9		X	X	
10		X		X
11	X			X
12	X			X
13	X			X
14	X			X
15	X			X

Table 2: Test results summary

3. CONCLUSIONS

The automation of loudspeaker defect detection could be extremely beneficial to the loudspeaker industry. Full automation of one defect was nearly achieved in this project. With a reliable defect-detection sequence, computer hardware and software could be integrated into a loudspeaker assembly line. Through the use of a mechatronic system, the results of such an automated test could allow a given loudspeaker to be automatically sent to a rework area or a scrap pile.

Although a signature for the misglued spider was found, it is believed that a more accurate signature can be identified through further research. The Limits Curve used by the test sequence was based on the total rub and buzz energy summed between H10 and H40. A Pass/Fail limit that was based on continuity between higher-order harmonics would be preferred. Future experimentation to be done in this field will require the use of higher-end equipment that is capable of measuring to the 100th harmonic and beyond. In addition, this project will hopefully serve as a stepping-stone towards utilizing harmonic signatures as a way to automatically identify audible loudspeaker defects.

4. ACKNOWLEDGEMENTS

This work was supported by the College of Engineering Acoustics Department at the University of Hartford and Listen, Inc.

5. REFERENCES

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