SPEAKER FOCUS

Fast and Reliable End-of-Line Acoustic Defect Detection

This article discusses end-of-line testing, a crucial step in production, which requires very specific procedures and measurements. Specifically, the authors focus on testing irregular acoustic defects (also known as Rub & Buzz) to reduce the test time and optimal solutions to speed automatic testing in a production environment.

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The primary goal in end-of-line (EoL) testing is to reliably separate faulty from fault-free devices under test (DUT) and to minimize false positive or false negative verdicts. However, some defects only generate minor symptoms, which might not be audible or critical during the EoL test but could become unacceptable during product life in the final application and should not be shipped to customers.

While acoustical, electrical and sometimes mechanical checks of specified properties such as frequency response or speaker parameters (Thiele-Small, stiffness asymmetry, and voice coil rest position) are mandatory for comprehensive testing, they are discussed in greater detail in the articles mentioned in our References [1], [2], [3]. This article focuses on testing irregular defects (also known as Rub & Buzz) [4], which in most cases can only be detected by acoustic measurement, because detecting these defects, unlike fundamental or harmonic testing, is the most limiting factor in reducing the test time. This article investigates the physical constraints limiting sensitivity and speed of automatic testing in a production environment and searches for optimal solutions that can be realized with minimal effort [5].

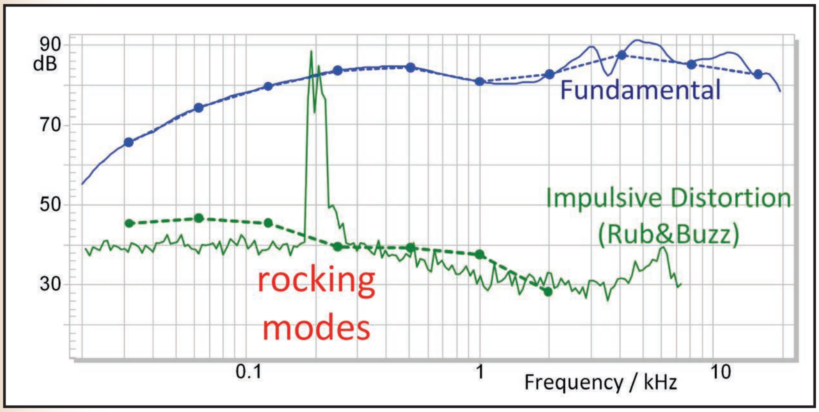

Figure 1: Frequency response of SPL fundamental component and impulsive distortion measured with a stepped sine stimulus (dashed line) and continuous log chirp with speed profile (solid line) using the same total stimulus length of 200 ms.

Particularities of EoL Testing

Typical measurements performed during product development are usually not time restricted and are applied to selected samples only. A high signal-to-noise ratio (SNR) can be achieved by averaging the monitored signals (noise suppression) and by using an IEC baffle in an anechoic and climate-controlled environment.

The production environment has restrictions that need to be addressed to make the testing of all DUTs (100% testing) feasible. Those restrictions include a short test time, and the fact that the properties of DUT may change over time (e.g., glue not completely dried, higher temperature from drying process, break-in effects, etc.). Further restrictions include the need to use a measurement microphone in the near field, test boxes that provide ambient noise shielding, and differing conditions at EoL test stations.

Efforts must be made to suppress undefined conditions and influences that limit the reproducibility of the results such as clamping and positioning of DUT and sensors, handling by human operators, acoustic load changes (box leakage) and connection problems. Variable conditions can also cause verdict (Pass/Fail) corruption due to external acoustic or mechanical disturbances, as well as significant temperature/humidity variations.

Repeatability and reproducibility of test results should be verified. For EoL testing, this is more important than comparability with standard R&D measurements. Responses from the DUT are captured and analyzed, extracting characteristics for Pass/Fail classification.

Optimum Stimulus

The stimulus is crucial for fast EoL testing. A chirp is the most popular stimulus for acoustic testing in manufacturing.

Steady-State Measurements

The most accurate way of measuring a DUT's behavior is through steady-state measurements. The acquisition begins when the amplitudes of all state variables (e.g., pressure, excursion, and current) are settled and constant. The settling time depends on the resonance frequency and quality factor of the fundamental and other higher-order modal resonators (cone breakup modes).

For example, a subwoofer operated in a sealed enclosure generating a quality factor Q0 = 1 and resonance frequency f0 = 50 Hz must be excited for 40 ms until an amplitude accuracy of 0.2% is reached. In a vented enclosure, the higher quality factor Qp = 10 of the port resonance of 50 Hz would increase the pre-excitation time to 400 ms. Instead, allowing an error of 4% in the measured amplitude would cut the pre-excitation time in half, an exchange that is accepted and inconsequential in EoL testing.

Stepped Sine Stimulus

The stepped sine stimulus contains multiple steps, each containing full oscillations at fixed logarithmically spaced frequencies. With knowledge of the maximum quality factor found in the regular and irregular modal resonances of the DUT, the optimum frequency spacing and number of periods for every step could be calculated that ensures every critical resonator is properly excited. In practice, the minimum period number is between 2 and 5.

The minimum number of excited frequencies in one octave is the most critical requirement for exciting resonators by stepped sine stimuli. If too low, a defect in the transducer could be missed. This is illustrated in a practical example in the next section.

Logarithmic Chirp

A continuous sinusoidal chirp is defined as a sine-based signal with continuously changing frequencies using a constant sweep speed. The benefits of a chirp will be illustrated with a woofer with two rocking modes near 200 Hz having a high quality factor Q ≈ 25. These generate impulsive distortion due to voice coil rubbing.

Figure 1 shows the result of a measurement in which both the stepped sine and the chirp stimulus have the same length of 200 ms. The chirp signal excites all frequencies and provides symptoms of voice coil rubbing in the impulsive distortion (ID) at high resolution [6] [7]. The frequency spacing of the stepped sine stimulus at this speed is unable to sufficiently excite the rocking modes. In fact, the optimum frequency spacing and period number for this woofer results in a stimulus length of 4.4 s (20 Hz to 20 kHz). Furthermore, the low number of excitation tones also severely limits the frequency responses' resolution.

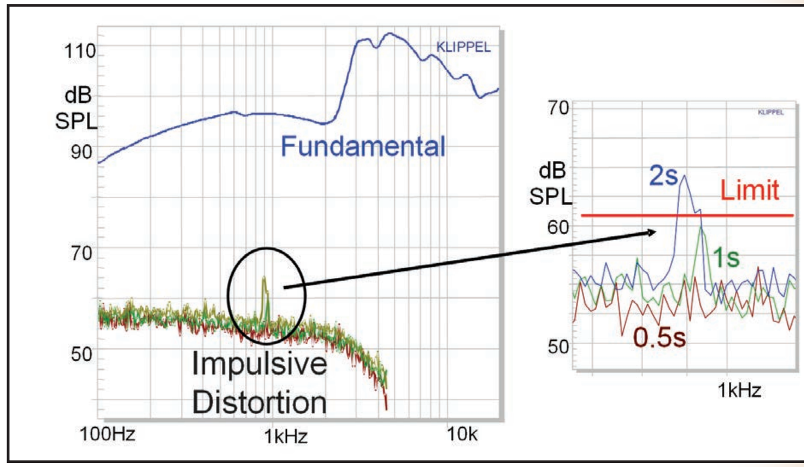

Figure 2: Impulsive distortion generated by a parasitic resonator (defect) with high Q-factor in a headphone measured with chirps of different lengths (0.5 s, 1 s, and 2 s)

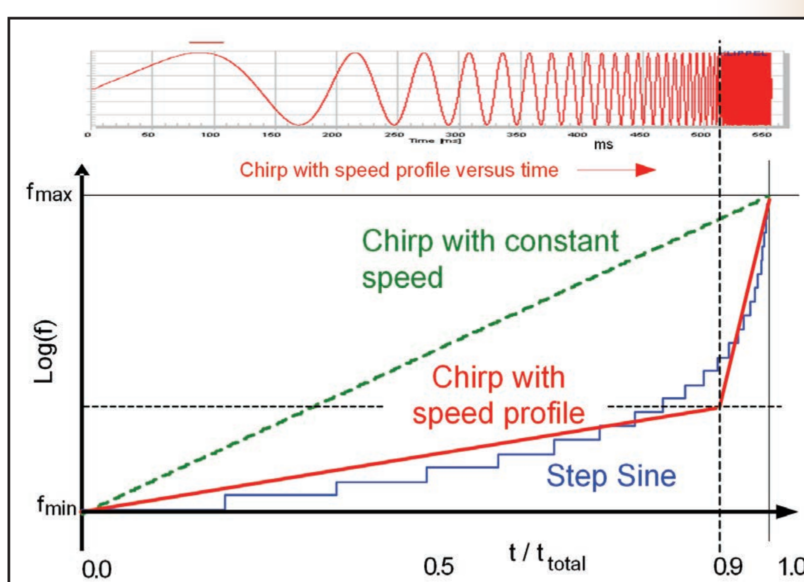

Figure 3: Time-frequency mapping of a stepped sine sweep, a logarithmic chirp with constant sweep speed, and a logarithmic chirp with two different sweep speeds

While the chirp is more effective for fast EoL testing, a defect could still be missed if the chirp is too fast. The relationship between sweep speed and amplitude of the resonator response is illustrated in **Figure 2**. A loose part generates parasitic vibration in a headphone at 900 Hz with a high-quality factor of Q > 20. With a 2 s long chirp from 100 Hz to 20 kHz, the critical vibration of the resonator can be excited and detected as impulsive distortion. Doubling the sweep speed to 1 s reduces the symptom by approximately 4 dB. At 0.5 s length, the symptom is covered by measurement noise. Increasing the stimulus amplitude in the critical resonator frequency band (applying frequency dependent amplitude shaping) by 3 dB can partly compensate for the reduced energy resulting from doubling the sweep speed.

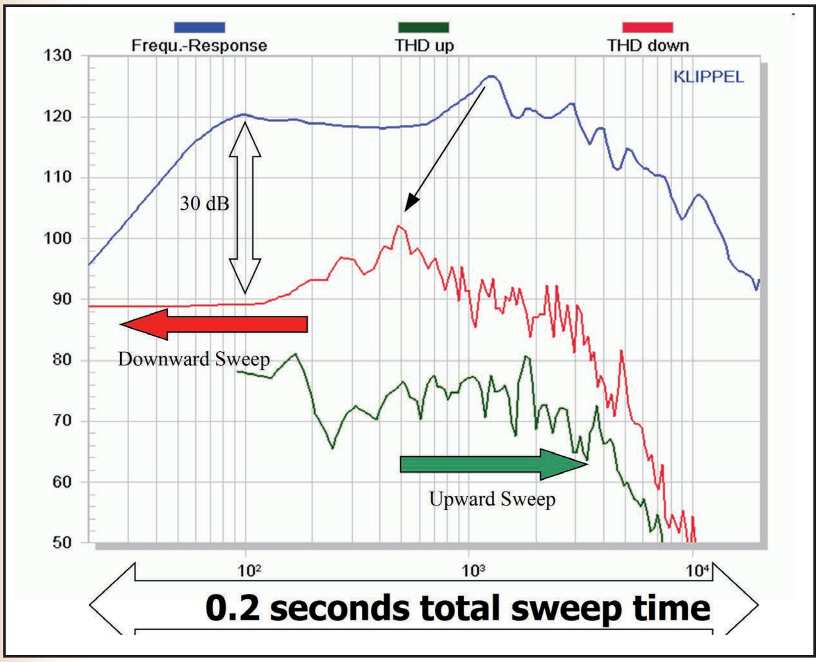

Figure 4: Errors caused in the harmonic distortion of DUT with modal resonances using a chirp sweeping downward in 200 ms

About the Authors

Stefan Irrgang studied electrical engineering at the University of Technology in Dresden, Germany and received a Ph.D. in Technical Acoustics in 1997. In 1998, he joined Klippel GmbH as one of the first employees. Since 2016, Irrgang is the company's head of development for measurement applications. His team provides unique test solutions for lab use, quality assurance, and product validation to the audio industry. His special interests are signal processing and test optimization. He gives lectures and workshops on loudspeaker testing, diagnostics, and optimization.

Wolfgang Klippel studied electrical engineering at the University of Technology in Dresden, in the former East Germany, where his initial studies focused on speech recognition. Afterward, he joined a loudspeaker company in the eastern part of Germany where he was engaged in transducer modelling, acoustic measurement and psychoacoustics. He later returned to his studies and received a Ph.D in Technical Acoustics in 1987.

After spending a post-doctoral year at the Audio Research Group in Waterloo, Canada and working at Harman/JBL in Northridge, CA, he returned to Dresden in 1997 and founded Klippel GmbH, a company that develops novel control and measurement systems dedicated to loudspeakers and other transducers.

Klippel has also been engaged as Professor of Electro-acoustic at the University of Technology in Dresden since 2007. His papers and tutorials on loudspeaker modelling and measurement—particularly those on large signal behaviour and physical distortion mechanisms—are considered reference works in the field.

Variable Sweep Speed

Figure 3 compares a chirp signal with constant sweep speed (dashed line) with a stepped sine wave (stair-case line) within the same total measurement time. The slope of the chirp in the time-frequency mapping at low frequencies is greater than that of the stepped sine but smaller at higher frequencies. The optimal sweep speed is limited by the maximum quality factor at lower frequencies. This slow speed is not required at high frequencies and unnecessarily increases the measurement time.

For fast testing of electroacoustical devices, the ideal stimulus is a combination of the dense excitation inherent in the chirp while using the time-frequency mapping of the stepped sine shown in Figure 3. Thus, the sweep speed is not constant but rises with higher frequencies. This is the basis for ultrafast testing at the physical limits. The chirp would be fastest if the sweep speed was continuously changing. In practice, only two sections of different but constant speed are required to get a sufficient approximation, shown as a thick solid line in Figure 3. This technique is implemented in the Klippel QC system [8]. For a full audio band chirp (20 Hz – 20 kHz) with a sweep speed above 1 kHz that is five times higher than at lower frequencies, the test time is reduced to 53% of a traditional chirp with constant sweep speed.

Sweep Direction

The direction of the sinusoidal sweep is crucial in fast EoL tests because the ringing of modal resonances generates artifacts in the harmonic distortion measurements. For example, **Figure 4** shows that sweeping downwards within 200 ms generates 12 dB more distortion at 500 Hz than sweeping upwards. The modal resonance at 1 kHz corresponds with the THD maximum at 500 Hz in the downward sweep due to the measured second-order component. By sweeping downward, the modal resonators in the DUT, box or room will be excited and the post-ringing generated by high quality factors will be interpreted as harmonic and higher-order distortion. Sweeping upward gives the correct total harmonic distortion (THD) values that match the results of slower steady state and chirp measurements by generating the harmonic components before the excitation causes ringing at the modal resonances in higher frequencies.

Another benefit of sweeping upward is that initial low frequencies help break-in the transducer when operated for the first time after production. An additional low-frequency, high-displacement signal can be used before the first measurement for not only breaking-in the transducer but also for settling the response for the low start frequency.

Production Noise

R&D tests are performed in well-defined conditions without significant external disturbances—this is not the case in the production environment. Acoustic and structure-born disturbances are unpredictable and are in the same magnitude as the defect symptoms being detected. There are multiple strategies for coping with production noise.

Typical passive solutions include well-damped test enclosures that attenuate disturbances up to

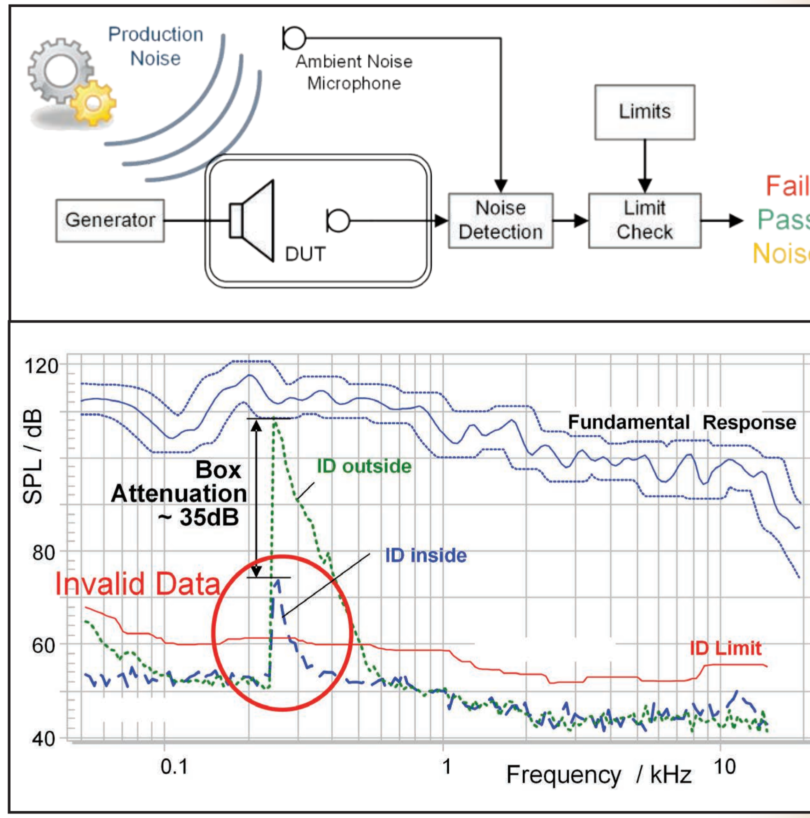

Figure 5: Detection of invalid data is found by comparing the impulsive distortion (ID inside) at the test microphone with the impulsive distortion (ID outside) at the ambient noise microphone located outside of a well-designed test enclosure.

40 dB. While this is sufficient for amplitude frequency response, and usually also THD, it is insufficient for impulsive distortion.

Figure 5 shows a corrupted measurement caused by an impulsive ambient noise (e.g., dropped part) outside a well-made test enclosure with almost 35 dB attenuation. However, this disturbance generates ID at the test microphone that exceeds the allowed limit by 15 dB and would cause a false Fail verdict.

Thus, in addition to insulation, further steps are required. Simple approaches such as an automatic repetition of failed tests do not reliably determine the root cause (defect or production noise). The repeated measurement may also be disturbed, so there is no reliable prevention of false verdicts.

Using additional mechanical or acoustical sensors in parallel to the test microphone, as shown in Figure 5, to monitoring ambient noise can identify corrupted data. Since ambient noise is usually random, the number of test repetitions can be minimized by merging valid parts of several partially corrupted repetitions together to form a completely uncorrupted data set. More details and available products can be found in the References [2] [9].

Timing in EoL-Testing

A complete EoL test cycle consists of:

1. Positioning the DUT on the test station
2. Fixing the DUT and connecting
3. Excitation of the DUT and signal acquisition
4. Release of the DUT
5. Moving the DUT out of test station, proceeding with step 1

Initial setup and product changeover are ignored in this discussion since they are usually negligible relative to the total test time for large production batches.

The actual measurement (point 3) is defined from the trigger of the test (e.g., a barcode scan or a hard- or software switch) until the last captured signal sample. The final verdict may appear slightly later without consequences as long as the start of the next test is not delayed.

The order of the measurement tasks or steps also influences the total measurement time. It is useful to start with the task that requires the largest processing load and use the acquisition time of the following task for finishing the calculation of the previous task. When using a chirp, some processing can even be started before the acquisition is completed.

Modern test systems can capture sound pressure, voltage, current, and displacement in parallel, so checking some electrical or mechanical properties might not increase the measurement time.

Conclusions

The stimulus properties limit the speed of the measurement and sensitivity for detecting defective units [10]. Adjusting the stimulus to the transient behavior of the DUT through frequency dependent speed and amplitude shaping is required for minimizing the error in the PASS/FAIL decision. The chirp with rising sweep speed at higher frequencies is the optimal stimulus for speeding up EoL testing. The time savings provide interesting opportunities for manufacturing.

Partly or completely repeating measurements is the best way to cope with a high probability of random ambient noise that cannot be completely attenuated by passive means. An optional second measurement may also be useful for verifying inconsistent defects like loose particles in case of suspicious symptoms (e.g., just below limit threshold) in a first measurement. This may significantly reduce the amount of costly field rejects. The saved time can also be invested in additional test steps for nonlinear parameters [1], [3] or other criteria [4], which are helpful for deeper diagnostics.

Machine learning and defect classification can reveal the root cause of a failed unit, automatically assigning it to a known defect class [2]. The more independent aspects of the DUT that are measured, the better these processes work. If a failed unit does not fit into an existing defect class, an operator can investigate it at a diagnostic station close to the production line by performing additional tests, listening to its acoustical output and dissembling it to find visual clues for the root cause.

Thus, the smooth combination of a fast EoL measurement system with machine learning, automatic classification and further testing at a diagnostic station generates a learning process in manufacturing and engineering. This helps maximize the yield rate, improve product reliability, and design future products with higher benefit-cost ratio that are easier to manufacture.

Resources

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