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Loudspeakers performance variance due to components and assembly process

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ABSTRACT
This paper presents an experimental study of the main causes of scrap during the production of a typical midrange loudspeaker. After analyzing the most critical components of a transducer, various samples with reference and defected components have been built and characterized in terms of frequency response and distortion. In addition, a second set of samples has been built using reference components but varying the assembly process parameters; these samples also have been characterized as the previous ones. Measurements have been performed both in an anechoic chamber and in a real production line and, by the analysis of acquired data, the authors have individuated the most influential components and assembly parameters in terms of required performance.

1 Introduction

This study has been supported by a loudspeakers manufacturing company among the leader of the market so the research project has been developed at their research and production sites. The company is responsible for the design and production of audio and communication technologies for the automotive industry.

A loudspeaker is an electro-mechanical-acoustic transducer, i.e. a device which converts an electrical audio signal into a corresponding sound. The diaphragm is usually cone-shaped and generally made of paper, and it is supported at the outer edge and near the voice coil, so that it is free to move only in an axial direction. The current through the voice coil creates a magnetomotive force which interacts with the air-gap flux of the permanent magnet and causes a movement of the voice coil and of the cone to which it is attached [1].

A cross-sectional sketch of a typical direct radiator loudspeaker is shown in Fig. 1.

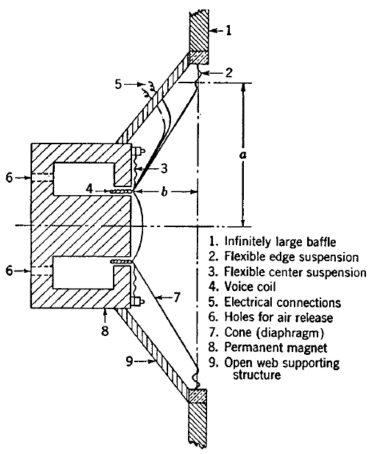

Figure 1: Cross-sectional draft of a Direct-Radiator Loudspeaker assumed to be mounted in an infinite baffle [Beranek, 1954]

Usually the cone is sufficiently rigid at low frequencies to move as a whole; instead, at high frequencies, vibrations from the center travel outward toward the edge in the form of waves. The results of the reflections of these traveling waves is a set of resonances in the cone itself that produce irregularities in the frequency-response curve at the higher frequencies and influence the relative amount of sound radiated in different directions [2].
As any other industrial product, loudspeakers must be evaluated to check their conformity to quality requirements and, if not "good", they are scrapped: the goal of this study is to individuate the most influential components and assembly parameters in terms of scrap percentage, so to optimise product improvement efforts and reduce the number of "bad" parts.

2 Case study: Component and process

The object of the study is a 100 mm midrange loudspeaker, designed to operate between 100 Hz and 12 kHz, used in the automotive sector.
The goal is to improve the quality of the transducer since the development phase reducing the variance and the number of pieces which will fail the End of Line test (EOL)[1].
It has been analysed the influence of each critical component of the loudspeaker on frequency-response curve, on total harmonic distortion (THD) and on electrical, mechanical, acoustical parameters; the same analysis has been also conducted for the assembly process.
Research can be divided in two parts: the first concerns the influence on sound quality of the individual component of the loudspeaker, while the second analyses the influence of the assembly process; so, samples with physical characteristics that slightly differ from those used in production have been realized on purpose. For comparison, also two sets of ideally "perfect" reference speakers have been built. The reference and defected samples were tested both in an anechoic chamber and along a real production line.

2.1 Loudspeaker components

In this part of research, components with physical characteristics that differ from those used in production, but still satisfying the maximum and minimum tolerances required by the customers, have been selected. Based on the ample experience of the company supporting this work, the variables selected for the production of samples are:

- weight of cone
- thickness of membrane's edge
- pulp quality of the membrane
- electrical resistance of voice coil
- stiffness of spider
- weight and thickness of dome

For each variable three pieces were built and it has been decided not to build samples with mixed flaws. So in the end 45 loudspeakers were mounted: 42 defected samples plus three reference pieces with nominal values.
Figure 2, shows three components of the mid-range already assembled together (membrane, spider and voice coil).

Figure 2: Three components of 100mm (membrane, spider and voice coil) assembled together ("moving part").

2.2 Loudspeaker assembling process

During this phase of study, the assembling process between components has been analysed instead. The quantity of glue has been altered fixing a minimum and a maximum tolerance approved for the production. Furthermore, it was altered the position of the voice coil, setting it higher or lower with respect to the nominal set point. Following again indications from the supporting company, the variables selected for the production of samples are:

- Gluing of moving part[2] of speaker
- Gluing between dome and cone

- Black paint for damping on the cone
- Position of voice coil (Coil IN [3] and Coil OUT [4])

For each entry of the above list ten speakers were built (five with maximum tolerances, five with minimum tolerances) and also five reference ones; in this case also samples with mixed flaws were not produced so a total of 45 loudspeakers has been assembled.
In Fig. 3 part of the sequence of the assembling process for the mid-range is shown.

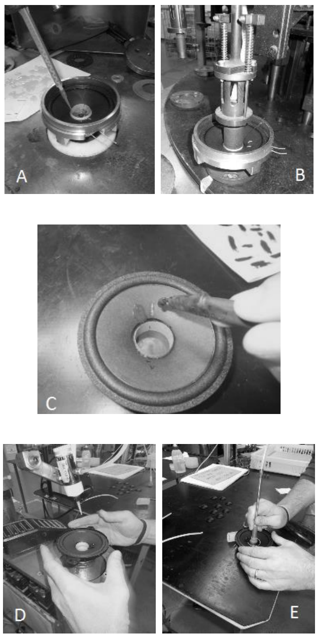

Figure 3: Assembling process of the 100mm midrange: A) distribution of glue between cone and voice coil's former; B) glue hardening; C) distribution of black painting for damping; D) distribution of glue under the dome; E) gluing of dome on cone

3 MEASUREMENTS SET-UP

The measurements of the 90 speakers have been performed both in a reference anechoic chamber and along a real production using the standard EoL equipment.
For both measurements equipment, developed by a German company which has become the standard of measurement for the automotive industry (Klippel) [4], has been used.

3.1 Anechoic chamber measurements

For the measurements in laboratory a system with different modules was used. One module is dedicated to acoustical measurements in the anechoic chamber and it is used to evaluate the transfer function between two signals at the desired resolution and bandwidth; through this measurement it is obtained the frequency-response curve and the graphic of THD.
Two modules, LPM and LSI, are connected to a triangulation laser sensor and permit to identify the lumped parameters of the transducer's equivalent model. A list of electrical, mechanical and acoustical acquired parameters here follows (for the description of each of them refer to [1] and [2]):

- Fs = resonance frequency [Hz]
- Re = DC current resistance [Ω]
- Qts = total quality factor [-]
- Mms = moving mass [g]
- Bl = force factor [N/A]
- XBl, XC = Bl and compliance non-linear factors [mm]

3.2 EOL measurements

To test loudspeakers along the production line a different Klippel system has been employed, namely a Quality Control - QC one. Contrary to the system used in the anechoic chamber, this hides the complicated physics and provides a simplified user interface with the necessary results required for manufacturing. Tests to do can be split into several subtests, each with an individual stimulus. This allows shortest test cycles using most critical signals for testing at the physical limits [5]. A list of acquired curves and parameters here follows:

- Frequency response
- THD
- Fs = resonance frequency [Hz]
- Re = DC current resistance [Ω]
- Qts = total quality factor [-]

4 DATA ANALYSIS

The results of the measurements cannot be shown in their entirety for corporate privacy remembering that the research has been supported by loudspeakers manufacturing company but interesting conclusions will be derived anyhow.

In order to reduce the complexity of data analysis, all curves (frequency response and THD) presented in this work are actually the average ones for each defected component and also for the reference samples. Respective frequency band limits are 100-12000 Hz and 200-10000 Hz, typical values for loudspeakers evaluation in the automotive sector.

4.1 Defected components samples

As a general observation, we may say that the results obtained both from laboratory and EOL lead to the same conclusions, so just a selection of results will be presented. Also, as regards the analysis of electrical, mechanical, and acoustical parameters, their variations are quite evident and never exceeded the prescribed limits and, moreover, are easily predictable: for instance, it has been noted that a loudspeaker with a more rigid spider actually has a higher frequency, or the transducers with a lower Re are more efficient especially at high frequencies as it is well known from basic theory of loudspeakers. For these reasons, no results have been reported about these parameters because they add no significant information for the scope of this work.

On the contrary, the analysis of frequency response and THD brings more interesting results about the contribution of each component; however, for confidentiality reasons, it is not possible to show the legend of graphs, but, as already mentioned, conclusions will be presented anyhow.

Figure 4 and Figure 5 show the frequency responses obtained from anechoic chamber measurements and EOL test respectively, and it can be seen that frequency response curves main variations occur at high frequencies.

Fig. 6 shows the THD measured in the laboratory and it is possible to appreciate some increase around 2 kHz.

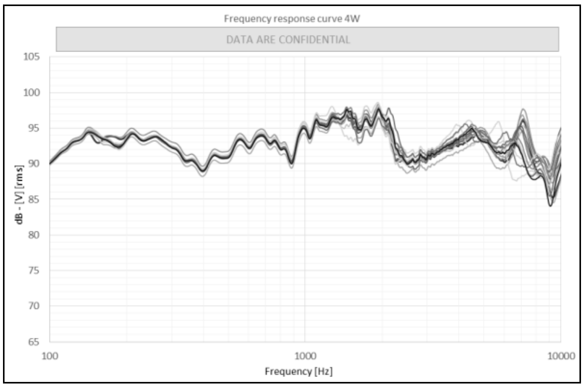

Figure 4: Frequency-response curves of mid-range with defected components, obtained from anechoic chamber measurements.

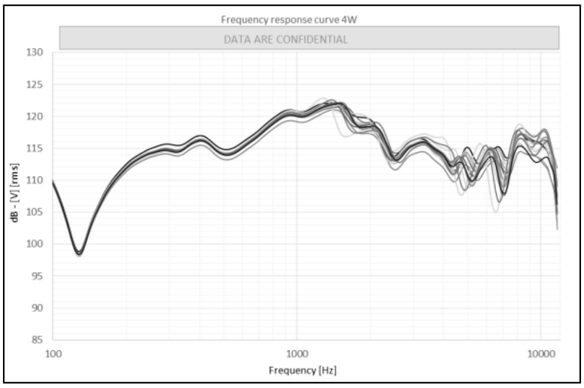

Figure 5: Frequency-response curves of mid-range with defected components obtained from End of Line test.

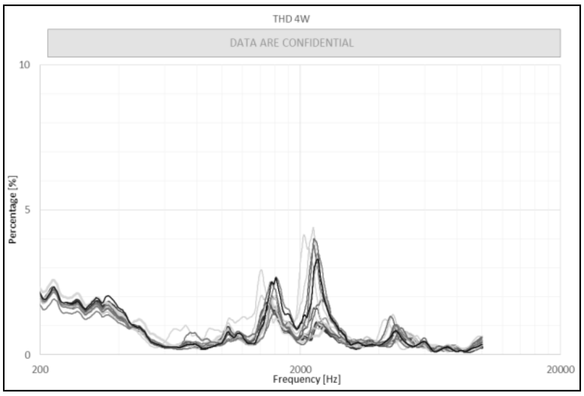

Figure 6: THD curves of mid-range with defected components obtained from anechoic chamber measurements.

4.2 Assembly process samples

In general, at this preliminary stage of the research, the effects of the assembly process deviations seem to be less important than that due to the variations of the properties of the components.
As before, also in this case from the analysis of electrical, mechanical and acoustical parameters there appears to be no significant piece of information for the goal of this work, so no results have been reported.
Instead of frequency responses, Figure 7 and Figure 8 show graphs of the differences calculated between the average frequency response of reference samples and averages of defected samples from the measurements in the anechoic chamber and during the production line test respectively.
From the analysis of measurements any process deviation doesn't influence in a significant way the performance of the samples. Main differences between samples with deviating assembly parameters and the nominal ones happen only at very high frequencies.

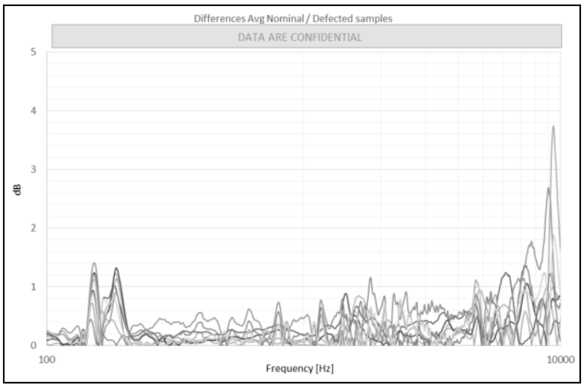

Figure 7: Graphs of differences calculated between the average frequency response of reference samples and defected assembly process samples after the measurements in anechoic chamber.

As can be seen in Figure 9, the THD level is lower for this type of samples, confirming that assembly process variations are less important than components ones.

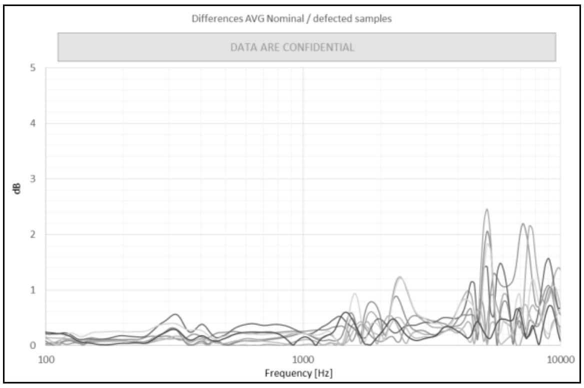

Figure 8: Graphs of differences calculated between the average frequency responses of reference samples and defected samples after the EOL test.

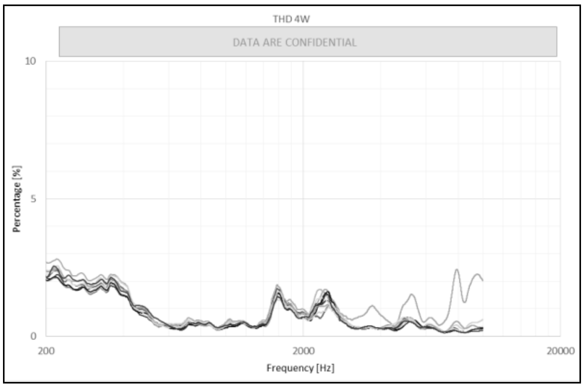

Figure 9: Graphs of differences calculated between the average frequency responses of reference samples and defected assembly process samples after the measurements in anechoic chamber.

5 WoW – "Worst of the Worst"

Through the comparison of the measurements of all samples, the influence of each defected component or assembly process has been evaluated and the most relevant ones in terms of approved loudspeaker performance have been determined.
After the ending of the measurements of the first set of samples (samples with defected components), the components which influence more the response of the loudspeaker had been roughly individuated: to derive more reliable conclusions a 1/6 octave averaging smoothing has been used for frequency

responses to further reduce data variability. Differences between reference samples and defected components ones have been calculated and plotted (like in Figures 7 and 8) and then added on the entire frequency band of 100-12000 Hz. Doing so, it has been possible to concentrate all deviations in a single number for each type of defected component Figure 10 shows the graph of such results for both anechoic chamber and EOL measurements.

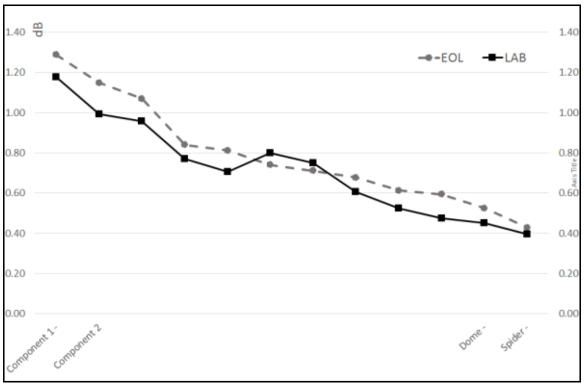

Figure 10: Graphs with the maximum summation value reached by each defected components during laboratory and EOL test (all results not shown for confidentiality reasons).

From the graph above the most relevant components have been individuated (named Component 1 and 2 for confidentiality reasons, least important ones are indicated) and so to verify if the assumption of not using samples with mixed flaws could be acceptable, some special samples have been built, the so called "WoW – Worst of the Worst" ones.

These WoW samples have been built by using a mix of such components: two types of WoW for a total of 10 samples have been realized; in detail WoW1 used Component 1 at its lower tolerance (C1-) and Component 2 at its higher tolerance (C2+), while WoW2 used the complementary components (C1+, C2-).

5.1 Results of measurements

The WoW samples were tested both in the anechoic chamber and during the production line with the system described in the preceding paragraphs.

Figure 11 and Figure 12 show the graph of differences calculated between the reference samples, samples with defected components and WoW samples (curves are calculated from the results obtained in anechoic chamber and production line respectively).

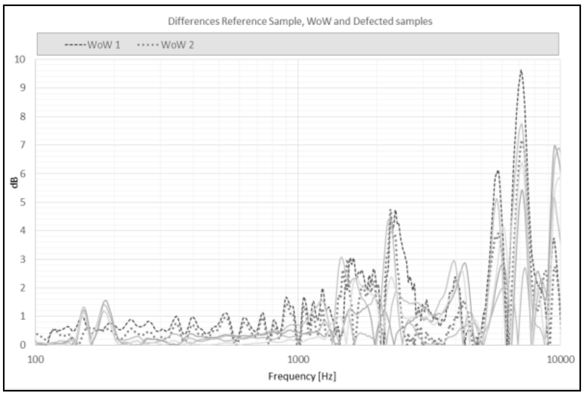

Figure 11: Differences calculated between an average of reference samples, WoW and defected components (Lab).

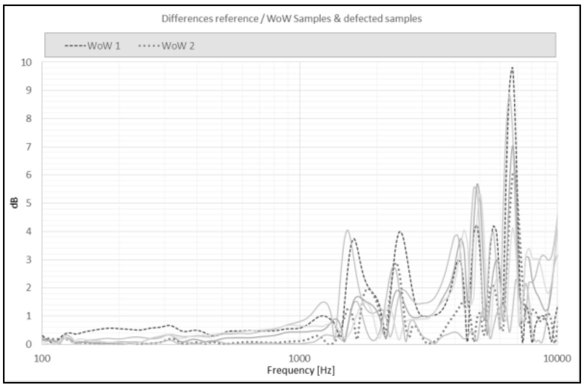

Figure 12 : Graphs of differences calculated between an average of reference samples, WoW and defected components (EOL).

From the images above it can be perceived that actually components don't interact with each other producing much higher deviations with respect to the single defected components.

It can also be observed that the curves representing the WoW pieces don't differ noticeably from the others, but they take very similar values for each frequency, so that the WoW samples follow the behaviour of the single defected components according to the frequency band where each component is more influential.

5.2 Data analysis

For a deeper analysis, each defected component was characterized by a percentage indicating its influence on WoW and the tables below show the value obtained from laboratory and EOL analysis for the mid-range.

Table 1: Percentage of influence of most critical components on WoW samples

		dB	Linear	% WoW 1	% WoW 2
EOL	WoW 1	1.35	1.17		
	WoW 2	0.6	1.07		
	C2-	1.12	1.14		106 %
	C2+	1.07	1.13	97 %	
	C1-	1.30	1.16	99 %	
	C1+	0.70	1.08		101 %
LAB	WoW 1	3.02	1.42		
	WoW 2	2.25	1.30		
	C2-	2.38	1.32		102 %
	C2+	2.38	1.32	93 %	
	C1-	2.6	1.35	95 %	
	C1+	1.96	1.25		97 %

In the table the column of dB contains an average calculated from the differences between reference and flawed sample in the range 100 Hz – 12 kHz, while “Linear” column is a simple conversion of the dB value: the percentages in WoWs columns are obtained by the ratio between the linear value of each component and the linear value of the WoW in which the component has been used. It is evident that the mixing of components does not increase the differences between reference and defected samples: for example, the difference value of C1- is almost identical to the one of WoW1, so again, the decision of not building samples with mixed flaws seems to be reasonable.

6 CONCLUSIONS

The first conclusion regards the comparison between the two measurement systems used in the anechoic chamber and EOL and it can be affirmed that no substantial difference is evident, confirming the reliability of the quality controls utilized along the production line. It does not mean that numerical values are always coincident: for example, “Linear” and “dB” difference values of Table 1 are higher for lab measurements in comparison with the EOL ones, and this is due to the much greater frequency resolution used for these former measurements, but relative percentages and evaluation of the severity of problems are almost perfectly coincident.

At this early stage of the research, first observations seem to indicate that the most critical elements are the single components rather than their assembling process. So, for this reason, it should be mandatory an accurate control of the physical and mechanical properties of components to reach a better design and performance of loudspeakers. Investigation has led to the exact individuation of the most relevant parameters so that any improvement effort can be precisely targeted. On the other side it can be noted how the production process of a modern manufacturing company is quite reliable and stable even in the presence of assembly parameters oscillations.

The second conclusion regards the analysis done on the correlation between the individual components and their possible interactions: the results of the measurements of the WoWs demonstrated that no relevant decrease of the loudspeaker performance derived from such a mixture, confirming that defected components did not interact to worsen samples performance and so that initial assumption was valid.

Although this work considered a loudspeaker that is produced in very large numbers, the results and conclusions we obtained cannot of course be blindly applied to all kinds of transducers, but the procedure defined for samples preparation and data analysis formats will be replicated for future research. Future work will consider different type of transducers (woofers, tweeters) and materials (i.e. plastic cones) and a deeper investigation of the possible correlations between mixed defected components. Another interesting research field will be study of the actual influence on human perception of measured differences in order to guide in a more efficient way the improved design of loudspeakers.

LIST OF TERMS AND ABBREVIATIONS

[1] EOL - *End of Line test*: test used to validate the performance of a loudspeaker in a production line (in short EOL).

[2] *Moving part*: is defined as the whole part that moves in the presence of sounds: cone, dust cap, voice coil and its support, also part of: spider, surround, and cables for connection to the voice coil.
[3] *Coil IN*: is defined as the voice coil placed in a higher way than the symmetrical position.
[4] *Coil OUT*: is defined as the voice coil placed in a lower way than the symmetrical position.

ACKNOWLEDGMENTS

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