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Loudspeakers performance variance due to components and assembly process – Field assessment

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ABSTRACT

This paper is the continuation of the study presented at the past convention "AES Berlin 2017 – 142nd International Convention" regarding the main causes of scrap during the production of a typical midrange loudspeaker. Various samples with reference and modified components parameters have been built and characterized in terms of frequency response, total harmonic distortion and electrical-mechanical parameters. In addition, a second set of samples has been built using reference components but varying the assembly process parameters and these samples also have been characterized as the previous ones. After measurements performed both in an anechoic chamber and in a real production line, a new set of measurements has been done inside a production car, in order to check if the results obtained in the preceding study would have been confirmed by field measurements. In more detail, authors aim was to verify that critical components individuated in the former paper would also have a relevant role after samples installation in a vehicle.

1 INTRODUCTION

This study is the continuation of the investigation presented at the past convention of AES "Berlin 2017 – 142nd International Convention" with the title *"Loudspeaker performance variance due to components and assembly process"* [1].

The investigation 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.

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. Furthermore, the research wants to investigate the influence of the latter in their working condition, in other words, inside a production car.

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 goals are 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] and to examine the actual influence of measured differences in a loudspeaker working environment.

The influence of each critical component of the loudspeaker has been analysed only in terms of the frequency-response curve; the same analysis has

been also conducted for the assembly process samples.
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 modified samples were tested both in an anechoic chamber, during a real production line and inside the vehicle.

2.1 Loudspeaker components

Components with physical characteristics that differ from those used in production, but still satisfying the maximum and minimum tolerances used internally in the company and however accepted 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 [1]. So in the end 45 loudspeakers were mounted: 42 modified samples plus three reference pieces with nominal values.

2.2 Loudspeaker assembling process

During this phase of the 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.

3 MEASUREMENTS SET-UP

The measurements of the 90 speakers have been performed both in a reference anechoic chamber, during a real production line using the standard EoL equipment and inside a car.
For the first two measurements, an equipment developed by a German company, which has become the standard of measurement for the automotive industry (Klippel), has been used. Instead, inside the car it has been used the SpectraRTA software, the external sound card "Roland – UA – 25EX" and two microphones "Behringer ECM-8000".

3.1 Anechoic chamber measurements

For the measurements in laboratory it was used a Klippel Analyzer [2]. The system, linked to the anechoic chamber, permits 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 total harmonic distortion.
The measure is done with a standard baffle and the microphone is put at 1 meter of distance from loudspeaker according to the normative IEC EN 60268 – 5 [3].
Figure 1 shows the anechoic chamber used for the measurements.

Figure 1: Anechoic chamber used for the measurements

3.2 EOL measurements

To test loudspeakers during 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 [4].
Figure 2 shows the box used for the measurements done during the production line.

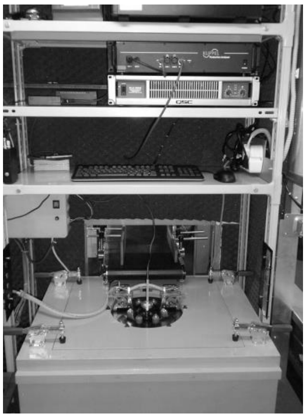

Figure 2: Box used during the production line to do the Klippel QC measurements

3.3 Measurements inside the car

For the measurements inside the car it was used the software *SpectraRTA* [5].
The software is a PC-Based FFT Spectral Analysis program. Spectra works in conjunction with the sound card of the computer or any other external A/D - D/A converter system. After plugging the signal to be analyzed into the Line-In or Mic Input of the sound card or converter system, the software uses the sound system to perform an "Analog-to-Digital" conversion of the audio signal. This digitized audio signal is then passed through a math algorithm known as a Fast Fourier Transform (FFT) which converts the signal from the time domain to the frequency domain.
In addition, SpectraRTA allows the use of an external signal generator and implements functions like the evaluation of the total harmonic distortion, the intermodulation distortion and the signal to noise ratio, but they are not evaluated in this study due to the complexity of working environment.
The tools used in the study for the measurement are:

- A CD reproducing a pink noise
- External amplifier
- SpectraRTA installed in a PC
- Sound Card linked to PC through USB
- Two microphones (the actual recorded signal is the average of those)

The microphones are positioned on the driver seat and the horizontal distance between them is 17cm.

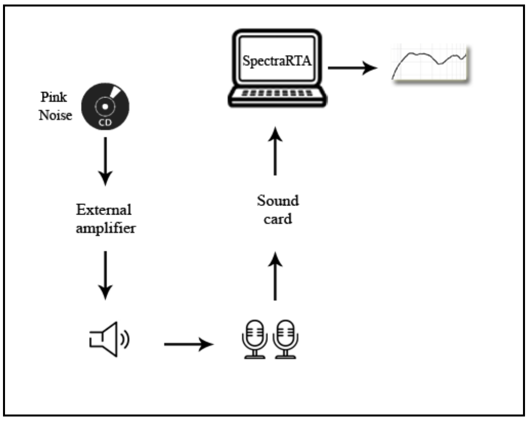

Figure 3: Set-Up for the measurements inside the car

Fig. 3 shows the set-up of the measurement and Fig 4 shows the position of the microphones inside the car.

Figure 4: The microphones are positioned on the driver seat inside the car

The midrange is positioned on the dashboard of the production car used for the measurements: Figure 5 shows the system configuration.

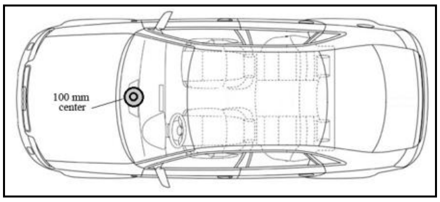

Figure 5: Position of midrange in the car production used for the measurements

4 MEASUREMENTS AND DATA ANALYSIS

In this paper only the frequency response curves have been compared among anechoic chamber, production line and car measurements because of the complexity of acquiring reliable distortion curves inside the vehicle due to the several reflections created by different materials and surfaces.
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 presented in this work are actually the average ones for each modified component and also for the reference samples; both actual curves and curves of differences between reference and modified samples will be presented.

4.1 Modified components parameters samples

As a general observation, we may say that the results obtained from the three measurements situations lead to the same conclusions, so just a selection of results will be presented.
In this section only the graphs regarding the curves obtained inside a car will be showed, therefore to have a better analysis and comparison between measurements it is suggested to read the paper mentioned above. [1]

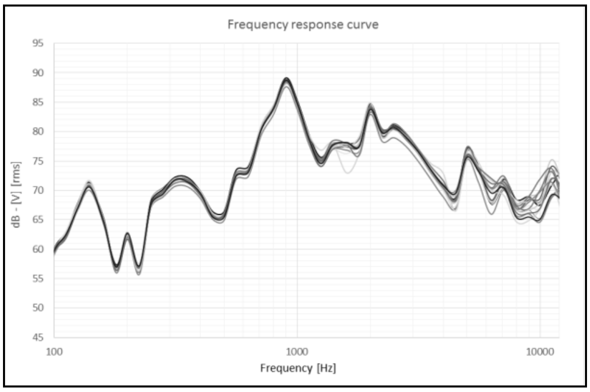

Figure 6: Frequency response curve of samples with modified component parameters obtained from the measurement inside the car

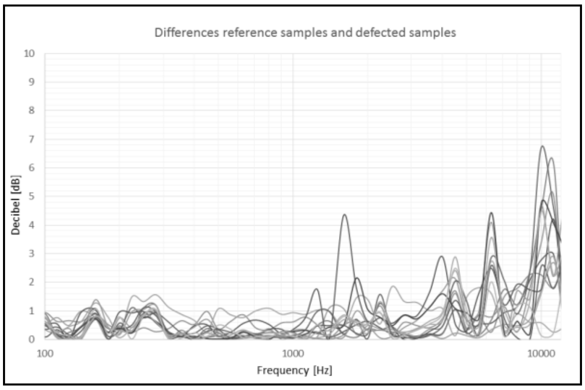

Figure 7: Differences calculated between an average of reference samples and modified components parameters (Car).

Figure 6 shows the frequency response curve obtained from measurements inside the car, instead Figure 7 represents the differences calculated between the reference samples and samples with modified components.
From the images above it can be seen that frequency response curves main variations occur at high frequencies and there is a dispersion of at least 7 dB after the break up frequency.

4.2 Assembly process samples

In general, at this stage of the research, the effects of the assembly process deviations seem to be less important than those due to the variations of the properties of the components.

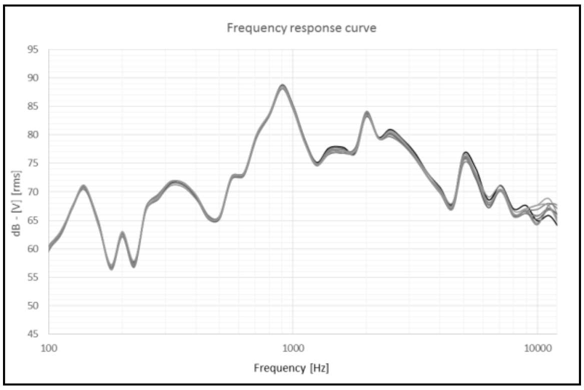

Figure 8: Frequency response curve of samples with variation in the assembly process obtained from the measurement inside the car

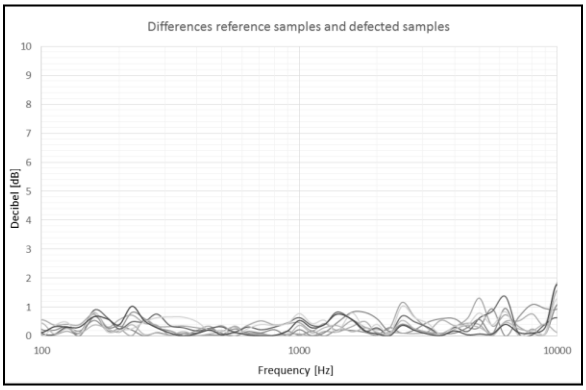

Figure 9: Differences calculated between an average of reference samples and samples with variations of the assembly process (Car).

Figure 8 and Figure 9 show the graphs of the frequency response curve and the differences calculated between the average frequency response of reference samples and averages of modified samples from the measurements inside the car 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 (10 kHz), but they are not so relevant (less than 2dB).

5 WOW – "WORST OF THE WORST"

Through the comparison of the measurements done in the anechoic chamber, the influence of each modified 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 modified 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 modified components ones have been calculated and plotted (like in Figures 7) and then averaged on the entire frequency band of 100-12000 Hz.

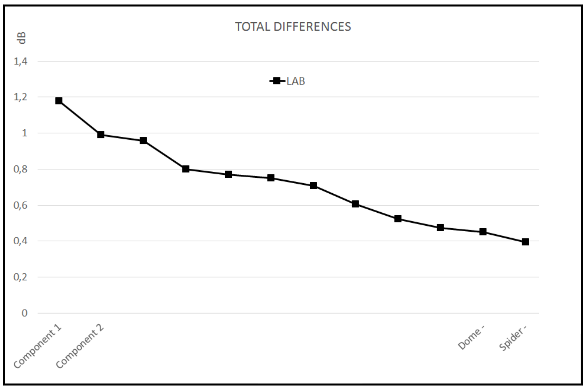

Figure 10: Graphs with the maximum summation value reached by each modified component during lab test

Doing so, it has been possible to concentrate all deviations for each type of modified component in a single number, and a summarizing graph has been traced (Figure 10) where most influential components are clearly individuated.

WoW samples have been built 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-).

In Figure 11 we show the graph of Figure 8 completed with data from EoL and car measurements.

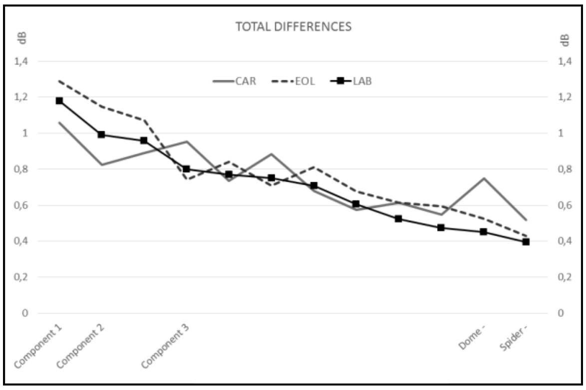

Figure 11: Graphs with the maximum summation value reached by each modified component during laboratory, EOL test and Car measurements (all results not shown for confidentiality reasons).

5.1 Results of measurements

The WoW samples were tested also inside the car, and Figure 12 illustrates the graph of differences calculated between the reference samples, samples with modified components and WoW samples.

From the image it can be perceived that actually components don’t interact with each other producing much higher deviations respect to the single modified 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 and almost always their curve is lower than the curve of the single defect. The WoW samples follow the behaviour of the single modified components according to the frequency band where each component is more influential.

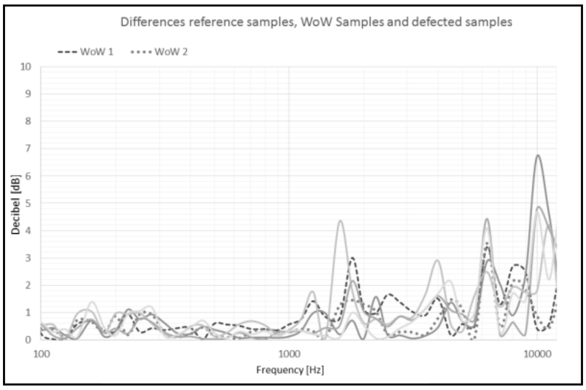

Figure 12: Differences calculated between an average of reference samples, WoW and modified components of the 100mm midrange(Car).

However, these conclusions refer to this model of loudspeaker (midrange) and are not blindly applicable to all loudspeakers. For example, the same study was applied also to a woofer (165mm), and Figure 13 shows the results obtained in laboratory for this type of transducer. This study (woofer) is not object of that paper, but it will be presented as soon as possible, because the measurements are not finished yet.

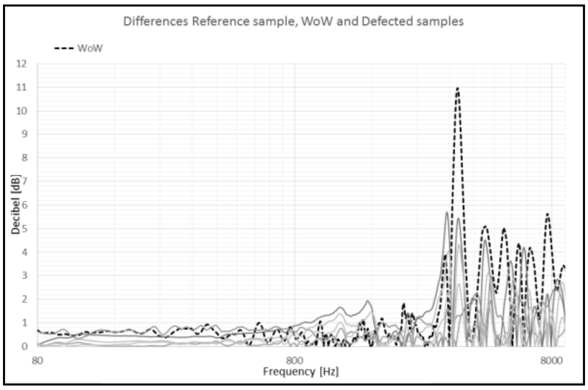

Figure 13: Differences calculated between an average of reference samples, WoW and modified components for a 165mm Woofer (laboratory measurements).

5.2 Data analysis

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

Table 1: Percentage of influence of most critical components on WoW samples after three measurements and with an analysis of 1/6 octave.

		dB	Linear	% WoW 1	% WoW 2
CAR	WoW 1	1.01	1.12		
	C2+	0.89	1.11	99 %	
	C1-	1.06	1.13	101 %	
	WoW 2	0.65	1.08		
	C2-	0.82	1.10		102 %
	C1+	0.95	1.12		104 %
EOL	WoW 1	1.34	1.17		
	C2+	1.07	1.13	97 %	
	C1-	1.29	1.16	99 %	
	WoW 2	0.6	1.07		
	C2-	1.15	1.14		107 %
	C1+	0.74	1.09		102 %
LAB	WoW 1	1.55	1.20		
	C2+	0.96	1.12	93 %	
	C1-	1.18	1.15	96 %	
	WoW 2	1.12	1.14		
	C2-	0.99	1.12		99 %
	C1+	0.80	1.10		96 %

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 modified 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 measurements inside the car confirm the thesis already presented for the laboratory and production line analyses: the most critical elements are the single components rather than their assembling process.

The modified components produce a dispersion of a maximum of 7 dB above the break up frequency, instead the variation of assembly process seems to be not influential in the performance of the transducer.

Another point is the relevance of the modified components which is not perfectly coincident among laboratory, EoL and car: if we examine Figure 11, it is evident that Component 1 is the most important one for all situations, but, while Component 2 is the second one for lab and EoL, it is not so for the car measurements, where Component 3 predominates. However, a correlation analysis considering all modified parameters shows that a minimum Pearson coefficient of 0.73 exists among the three sets of measurements, see Table 2 confirming that, apart from minor oscillations, the conclusions about the most relevant components have a general significance.

Table 2: Averaged on the entire frequency band of 100-12000 Hz of the differences between reference samples and modified components after the analysis of 1/6 octave. It's a numerical representation of Figure 11

	CAR	EOL	LAB
Component 1	1,06	1,29	1,18
Component 2	0,82	1,15	0,99
	0,89	1,07	0,96
Component 3	0,95	0,74	0,80
	0,74	0,84	0,77
	0,88	0,71	0,75
	0,68	0,81	0,71
	0,57	0,68	0,61
	0,61	0,61	0,52
	0,55	0,59	0,47
Dome -	0,75	0,52	0,45
Spider -	0,52	0,43	0,40
Pearson (Car/EoL)	0.73		
Pearson (EoL/Lab)		0.97	
Pearson (Car/Lab)	0.84		

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 works will consider different type of transducers (woofers, tweeters) and materials (i.e. plastic cones) and a deeper investigation of the possible correlations between mixed modified components. Another interesting research field will be the 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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