CASE STUDY

Orona, MGEP, Ikerlan
Gipuzkoa, Basque Country
Research and Development of Sound Quality in Lifts

Spain, Europe
PULSE Sound Quality

Brüel & Kjær's Head and Torso Simulator (HATS), binaural microphones and PULSE Sound Quality software were used to analyse the sound quality behaviour of different types of Orona lifts, to correlate the sound quality with the different noise sources and to study the most appropriate ways to improve lift comfort.

Model photographs © 2009 Brüel & Kjær Sound & Vibration Measurement A/S

The Consortium

Orona S. Coop. (manufacturer of lifts), Mondragon Goi Eskola Politeknikoa (MGEP) S. Coop. (Engineering Faculty of Mondragon University) and Ikerlan S. Coop. (Research Centre) have formed a consortium and established a stable working group of engineers to investigate the Sound Quality in Orona's lifts.

MGEP, Ikerlan and Orona

MGEP, the Engineering Faculty of Mondragon University, has an acoustic and vibration group that works with local companies mainly in noise and vibration source identification and transfer path analy-

Brüel & Kjær

sis, acoustic materials characterisation (absorption, damping and transmission), and sound quality.

IKERLAN is a reference centre for the innovation and comprehensive development of mechatronic and energetic products. It also actively innovates in design and production processes. Ikerlan has over 30 years of experience in combining and applying mechanics, electronics, computing, microtechnology and fuel cell technologies.

ORONA is a consolidated Business Group that is the leading independent lift manufacturer in Spain and an important reference supplier on the world scene. Orona is capable of meeting every demand for vertical transportation, however tough the design, safety and performance specifications might be.

Aim of Sound Quality Project

Unai Galfarsoro, the coordinator of the Acoustic and Vibration Group at Mondragon University

Orona started the sound quality project with the aim of increasing the comfort of passenger lifts. According to Unai Galfarsoro, the coordinator of the Acoustic and Vibration Group at Mondragon University, "The reason of establishing the sound quality project is the need to go beyond the traditional A-weighted sound pressure level, which is usually used to rank different noise sources, because we believe that a complete sound quality analysis gives wider and more reliable results".

He adds, "The objective is to analyse the actual sound quality performance of the various types of Orona lifts, to correlate the sound quality with the different noise sources and to study the most suitable approaches to improve the comfort of the lifts".

Endika Cocho, Coordinator of the Sound and Vibration department at Orona comments, "We research, manufacture, personalise, install, and assume integral maintenance services of lifts and escalators. Our continuous policy of improving and searching for excellence makes the vibrational and acoustical performances of our lifts a must".

Methodology

Before carrying out the sound quality process, the types of lifts to be analysed were selected and six of each type were tested. Three up and three down full travelling cycles (doors closing, acceleration, constant speed, deceleration, and doors opening) were measured from the bottom to the top floor and back, and the time data was the basis for the following sound quality analysis. The equipment used consisted of Brüel & Kjær's Sound Quality Head and Torso Simulator (HATS) Type 4100-D equipped with two microphones for binaural noise measurements. The two signals were recorded using a PULSE IDA^{e} front-end and Time Data Recorder software. Unai Galfarsoro, from Mondragon University, says, "When we decided to purchase a system to acquire and analyse noise and vibration signals, we were looking for a modular and scalable system from a manufacturer well-known for consistency, high-quality and ability to offer the broadest range of state-of-the-art applications. The immediate and excellent support of the local Brüel & Kjær office was another vital factor". He adds, "The PULSE front-end is very useful for measurements inside a moving lift, as it makes no noise at all [its fan can be switched off during measurements] and it can be battery-operated. Besides, Time Data Recorder software is extremely simple to configure and use for time data measurements".

In the second phase, Brüel & Kjær's Sound Quality software was used to listen to the recorded time signals binaurally and in detail. "This is a very important phase to detect possible rattles, squeaks and important phenomena in this type of product, and act accordingly," says Unai. He continues, "We have decided to work on the region of constant speed first since it is the most straightforward approach to start with”. Cutting the time signals to keep only the constant speed region comes next.

Unai Galfarsoro explains why Brüel & Kjær was chosen, “We have been working on several areas of noise and vibration analysis for many years, but we realised that we lacked experience in sound quality analysis. We contacted Brüel & Kjær and established a cooperation project. Brüel & Kjær, with its vast experience in this area, is guiding the process. The outcome is excellent, and we have learnt how to carry out an entire sound quality analysis. The end results have also been successful”.

The next step of the process is the objective analysis, that is, the values of several metrics are calculated for each signal using the Sound Quality software. “This has given rise to one of the most complex tasks in the whole process,” explains Unai, “as you have to understand and interpret the results, deciding which metrics are suitable for the subsequent process and which ones need to be disregarded”. As a result of the listening process and the values of the metrics obtained, the travelling cycle with the median noise level was chosen for the rest of the analysis.

Then the subjective analysis is carried out. This consists of getting the opinion of lift users via jury tests. Investigations are made for different jury types – young people (<35 years) versus older people (> 65 years), and experts (engineers involved in the design of lifts) versus non-experts (everyday lift users). Jury tests with jurors sitting at a meeting-room table are made first, and they are compared with jury tests made with jurors standing inside a real lift cabin which is stationary with doors closed. In all cases, the recorded sounds are played to jurors by means of headphones. The analysis is carried out using two techniques:

- **Paired Comparison Tests:** All sounds are presented to jurors in pairs so that the juror chooses the preferred one by asking the simple question “Which sound do you prefer?”. The reliability of the jurors’ answers is examined by statistical concepts like circular triads and consistency, and jurors with non-consistent answers are removed from the analysis.
- **Semantic Differential tests:** Jurors listen to one sound at a time, and then they are asked several questions to assess different aspects of sounds, “Does it sound Rough/Smooth”, “Does it sound Noisy/Silent”, “Does it sound Unpleasant/Pleasant”, and so on.

The complete process of organising and carrying out the jury tests are done using Brüel & Kjær’s Psychoacoustic Test Bench software. “It is a very useful and helpful software, easy to use and guides you step by step through the entire process,” comments Unai.

A correlation process is then performed between the objective analysis (metrics) and the subjective analysis (jury test) in order to obtain, with a multiple linear regression analysis, a personalised psychoacoustic model or metric that shows the comfort of lifts.

Results

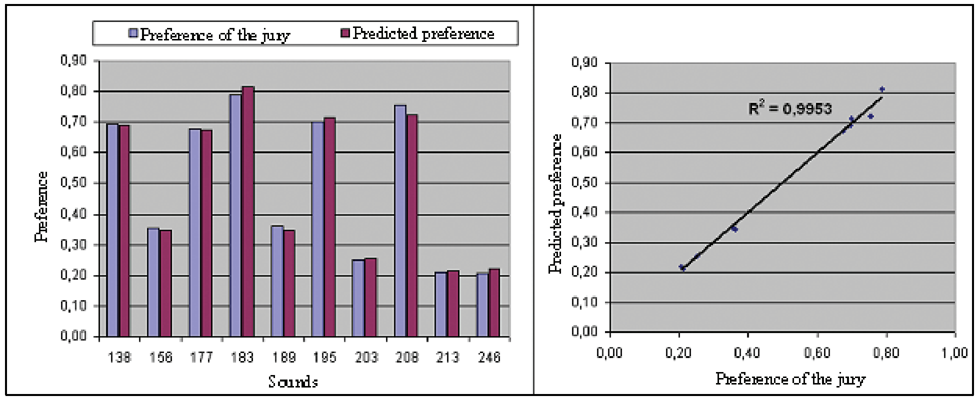
Jury tests with jurors standing still inside a real, stationary lift cabin with its doors closed have a consistency that is about 20% better than jury tests with jurors sitting at a table, so the importance of the environment for jury tests is clear. Therefore, all results are referred to jury tests carried out with jurors standing still inside a real lift cabin. The percentage of consistent jurors is 87.5% for young people and around 33% to 67% for older people, lower than expected. The consistency of non-expert jurors is slightly greater than that of the experts – 75% compared to 67%. This might be due to the fact that expert jurors focus their attention on the lift’s construction and don’t pay sufficient attention to the comfort, which is the whole object of the exercise. However, a study with more jurors would improve the statistical accuracy and provide more definitive results. Jurors with non-consistent answers are completely removed from the analysis, and the following analyses are made separately for each type of jury as well as for the total jury.

The multiple linear regression analysis with the data from the paired comparison has yielded a psychoacoustic model for each type of lift, but also a general model for all lifts considered altogether. All these models are of this type:

$$\text{Preference} = -A \cdot R + B \cdot AS_{mean} - C \cdot LS_{max} + D \cdot LS_{min} - E \cdot FS + F$$

where A, B, C, D, E and F are constants, R stands for Roughness, AS for Aures Sharpness, LS for Statistical Loudness, and FS for Fluctuation Strength. The regression coefficient for this general model is R2 = 0.9953, and it is even closer to 1 for the regressions for each individual type of lift. Therefore, it can be concluded that the models obtained have very good agreement with the preferences revealed by jurors.

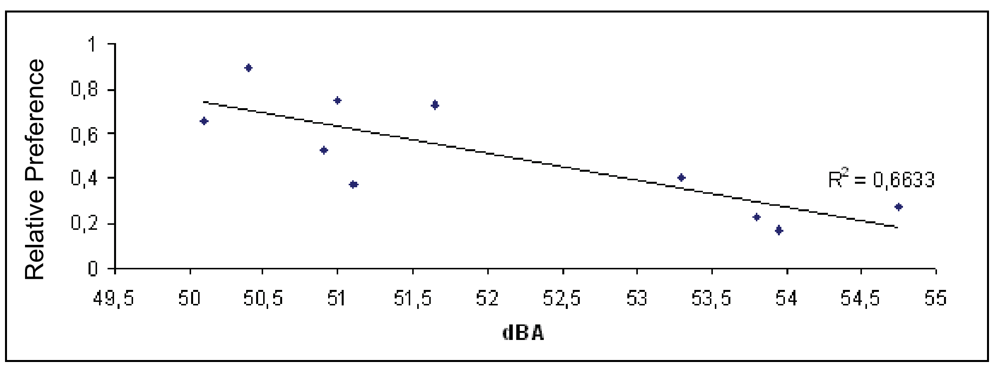
Fig. 1
Graph of comparison of jury´s preference to predicted preference



Unai reports, “Having a psychoacoustic model that describes the acoustic comfort of lifts has made it possible to have rankings of all lifts, of the same or different type, including even some competitors’ lifts, and to know which ones are the best, which ones need to be improved most, and so on”.

Before the realisation of this project, A-weighted sound pressure level measurements were used to quantify the comfort of sounds. These were traditionally compared with the preferences obtained from the subjective tests, getting a “low” correlation of R2 = 0.6633, as shown in Fig. 2. It can be observed that there is some dispersion and that sometimes some sounds with higher values of dBA have higher preference from the jury, which is not logical. Besides, the correlation obtained with Loudness is higher (R2 = 0.75), and the correlation obtained with the multiple linear regression analysis using different metrics much higher (R2 > 0.95 and often very close to 1), proving the need for psychoacoustic metrics to define more accurately the acoustic perception of people.

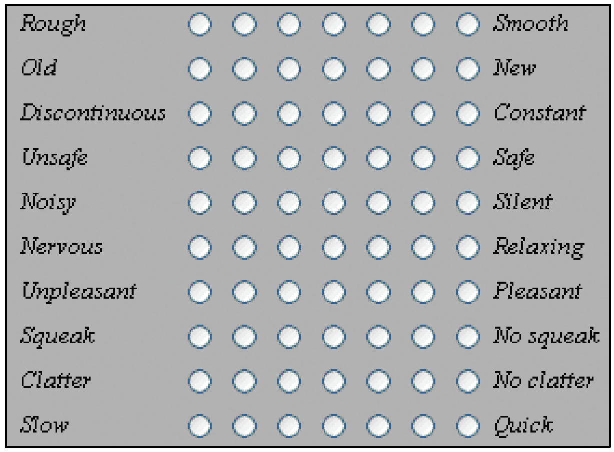
Fig. 2
dBA-preference relation



Once the regression models have been obtained with the Paired Comparison technique, it is advisable to perform a Semantic Differential test in order to find out which sensations jurors have felt when they have classified and ranked the noises of the different lifts. According to Xabier Sagartzazu from Ikerlan, “We want to know more than a simple ranking of lifts, from good to bad, from an acoustic comfort point of view. We want to know in more detail the reasons behind the noises that make lift users judge them as good, medium, bad. This is why we conduct a Semantic Differential analysis.

“The first task”, he continues, “is to define a thorough and clear questionnaire taking into account all important issues, without generating doubts to jurors or forgetting any important detail. Repeating jury tests is quite time-consuming, so we want to do it right first time. Therefore, prior to the real jury test, we make people listen to the lift noises and ask them to write down which words spring to mind when they hear the noises. With the most repeated words and our feedback, we define the final questionnaire with 10 questions, ranked using scores from 1 (bad) to 7 (good)”.

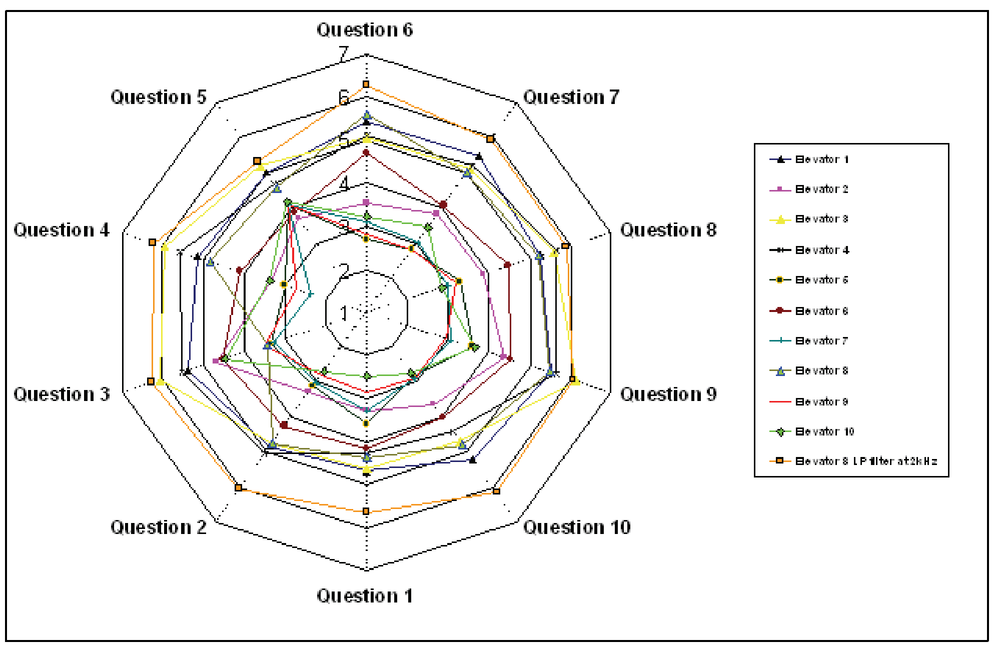
Fig. 3
The questionnaire rankings



All the data obtained during the Semantic Differential tests are introduced and post-processed using Psychoacoustic Test Bench software, and finally, Excel is used to obtain the necessary figures and tables to analyse the results. The type of figure used is called Spiderweb, named that way due to its shape (see Fig. 4). In such a Spiderweb each "circle" with a different colour corresponds to a lift, so "circles" that are in the inner zone around values of 1 to 3 are acoustically bad lifts, and "circles" that are in the outer zone around values of 5 to 7 are acoustically bad lifts.

Evaluating this kind of figure is easy. Having concentric circles means that no question shows up over the others; an outward irregularity in a question means that this question is rated higher by jurors, and an inward irregularity in a question means that this question is rated lower. In this way, knowing which sensations in the lift noises have good and bad ratings from jurors helps to understand why a lift noise is perceived as good or bad, and points the way toward improving such a noise.

Fig. 4
Semantic Differential Analysis: Spiderweb of 10 peaks



Among the conclusions, Xabier says, "Lifts with rattle transmit a feeling of old lifts (even if they are not), and are evaluated as bad lifts from a sound quality point of view. Jurors also think that all lifts, good and bad ones, transmit a sensation of being fast lifts".

The next phase in the sound quality analysis is to compare results obtained with both the Paired Comparison method and the Semantic Differential. "We have concluded that the psychoacoustic model obtained with the Paired Comparison method and the jurors feelings in the Semantic Differential method are quite similar," says Xabier. "Another feature to emphasize is that results from questions in the Semantic Differential test questionnaire that can be considered to be more 'technical' [like fast, rattle and squeak] have a poorer correlation with the results from the Paired Comparison analysis than the rest of the questions. In this sense, removing these three 'technical' questions and building a Spiderweb with seven peaks significantly improves the correlation with the Paired Comparison analysis," he adds.

Conclusions/Future Work

Xabier Sagartzazu says, “The main conclusion is that we now have good psychoacoustic models that accurately evaluate the sound quality behaviour of lifts, and these models have very good correlations with the real feelings of lift users (assessed through jury tests), with regression coefficients R2 over 0.99. These correlations are much better than for the traditionally used A-weighted sound pressure levels, which have shown a much worse correlation of R2 = 0.66”.

He adds, “Besides, using the psychoacoustic models, we have built a ranking according to the acoustical behaviour of all lifts of the same or different types, even including some competitors’ lifts, so that we know which types of lifts are best in class, which ones need to be improved most, and so on”.

After finishing the sound quality study of the constant speed region, the work is now being expanded:

- To cover the area of doors opening and closing – often a transient event due to shocks in the final stage of the cycle
- To develop a catalogue of potential improvements to optimise sound for comfort, finding a relation between the resulting sound quality of the lifts and their construction, so that efforts in design changes of the lifts are focused, for example, improving sound quality. This will also help other projects undertaken to discover noise sources and transmission paths

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