SQUEAK AND RATTLE SPECIFICATION METHODOLOGY FOR PASSENGERS SEAT IN HIGH SPEED TRAINS.

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Passenger acoustic perception is one of the main factors in order to evaluate the comfort in a HST. Squeak and rattle noises are typically the type of noises that influence the perceived comfort inside a train. The consequence is challenging requirements from train operators regarding zero squeak and rattle noises for train interiors.

The scope of this current study is to obtain a robust specification methodology for seats in order to anticipate new types of acoustic comfort requirements for new projects.

A seat system of a high speed train has been instrumented with accelerometers on its two attachment points on the floor and the panel and also on its structure. First, we have conducted modal analysis of the seat in static condition and also acceleration measurements in dynamic condition at very high speed. Second, a specific bench has been designed in order to install the seat system on a Multi-Axial Simulation Table within a semi-anechoic room. The modal behavior of the global system has been compared to the one identified in the train. Third, the excitation of the table has been tuned in order to obtain the same dynamic response of the seat system as if it was in the train rolling at very high speed. And finally, vibro-acoustic measurements thanks to accelerometers and acoustic head device have been conducted. Noises from passengers’ typical handling of seat devices such as the shelf, footrest, armrest have been also recorded thanks to head acoustic device.

The deep analysis of these vibro-acoustic measurements allow us to define a methodology for vibro-acoustic allocations for seat system regarding squeak and rattle noises.

1. Introduction

Passenger acoustic perception is one of the most important factors in order to evaluate the comfort in a High Speed Train. Squeak and Rattle (SR) noises are typically the type of noises that influence the perceived comfort inside a train. In recent years, for ensuring good comfort quality to customers, challenging requirements are starting to be requested by train operators regarding zero SR noises for train interiors.

In the automotive industry, the research and application on reduction and elimination of SR noises have significantly increased after the mid 1990’s due to the fact that repair of vehicles with SR problems costs to the industry hundreds of millions of dollars per year in warranty. Therefore, SR noises have been largely studied and methodologies for specification and prediction have been developed and in particular for seat systems.

For the railway sector, regarding rolling stocks, SR noises have not been really studied in design phase. Several studies have been done to characterize acoustic interior environment as an overall perception issue.
Seats systems are known to be a major contributor to interior SR noises due to their mechanical complexity and multi-functionalities. They include many components and subassemblies such as retractable trays, pivoting footrests, electro-pneumatic device for seat tilting, all integrated in a tight packaging space. The challenges to design seat system free of SR noises lie on:

- Constant-increasing demands for weight reduction.
- Lack of analytical tools that directly allocate SR targets.
- Correlation between test results at component/subsystem level and full-train level.

This paper presents the SR noises methodology for specification of a seat system installed on a multi-axial vibration table in a semi-anechoic room using binaural recordings and psycho-acoustics analysis in order to set targets to seat suppliers.

2. Static and dynamic characterizations of the seat in the train

First part of the study is focused on evaluation of the seat system on a running train.

2.1 The seat-system

A test campaign has been conducted in a high speed train in dynamic condition. A first class double seat system has been instrumented with accelerometer sensors (Fig. 1).

![First class double seat system](image1)

Fig. 1. Seat system and its instrumentation for static and dynamic testings.

Seat systems are fixed to train structure by one vertical attachment to the floor and one lateral attachment to the side panel. These attachment points as well as several parts of the seat system have been instrumented with accelerometers. Microphones have been also installed in the compartment in order to estimate the Sound Pressure Level (SPL) at several positions along the corridor.

2.2 Static tests

Accelerance and FRF measurements with hammer impact have been conducted. These measurements will be considered as reference for the test bench structure validation. Example of an accelerance level at one attachment point of the seat system on the structure is presented in Fig. 2. This accelerance has been obtained with hammer impact on the attachment point.
2.3 Dynamic tests
Vibration levels for the same measurements points have been recorded during acceleration phase of the train and also during constant speed. Fig. 3 shows samples of time signals recorded.

Sound pressure levels have been also measured in the same compartment along the corridor. On Fig. 4, an example of SPL versus 1/3rd octave frequency:

2.4 Evaluation of SR events in the tested train through a subjective approach
During the test campaign in the considered train, no SR noises have been detected in instrumented seat system. It must be noted that the instrumented seat was not equipped with retractable trays at the rear because it was at the extremity of the compartment. Moreover, the average SPL in the compartment at very high speed may have masked eventual SR noises. However during the evaluation campaign, other seat systems in other compartments had SR noises.

3. Test Bench Definition
Second part of the study is focused on test bench design.
3.1 Semi-anechoic room and vibration table

In Fig. 5, an image of the semi-anechoic room is shown (L 6 m / W 4 m / H 4 m) with the central vibration table (L 1 m / W 1.5 m).

Fig. 5. Semi-anechoic room with the multi-axial vibration table.

3.2 The background noise improvement

The background noise level of the semi-anechoic room without any device in operation was about 19 dBA. But when the hydraulic system of the vibration table was powered on, SPL increased to 62 dBA, which could cover most of SR noise occurrence and increase complexity of SR noises analysis.

That is why improvement of background noise with hydraulic system operating has been studied. An encapsulation made of wood and acoustic material has been placed around and over the table to shield noise from the hydraulic system.

Before encapsulation 62 dBA / after 34 dBA

Fig. 6. background noise mitigation thanks to encapsulation

Thanks to this modification, background noise level in the semi-anechoic room has been decreased from 62 to 34 dBA (see Fig. 6).

4. Design of receiving structure and validation of the test bench

In order to install the seat system on the vibration table, it has been necessary to design and manufacture a receiving structure. This structure was optimized to have the same dynamic properties than real train attachment structure. A validation was performed to ensure that receiving structure had same receiving stiffness than train attachments. The validation of the global system was performed by correlating static and dynamic measurements done in the train with the ones obtained on the test bench.
4.1 Static Validation of the seat system on the test bench

Reference accelerances and FRFs measured at same location in the train and on the test bench have been compared. Design of the receiving structure was then modified in a loop process to have the same receiving dynamic stiffness than the train attachment.

![Image of seat system and vibration table]

Before bench modification / After / Reference accelerance in train

**Fig. 7.** a) Receiving structure on the table and b) Accelerance validation of vertical attachment point

On Fig. 7 in the left is shown the receiving structure and the seat system installed on the vibration table. On Fig. 7 in the right is shown the accelerance measurement done with impact hammer at the vertical attachment point of the seat system. Measurement before and after design modification is shown, as well as reference accelerance measured in the train. The stiffness at the vertical attachment point of receiving structure has similar trend than observed in the train.

4.2 Dynamic Validation of the seat system on the test bench

The multi-axial vibration table parameters have been tuned in order to reproduce as much as possible the same levels of vibrations measured on the seat system in real train at very high speed. This has been achieved through an iterative process as illustrated in Fig. 8.

![Image of iterative process]

**Fig. 8.** Iterative process in order to reproduce train excitation

Fig. 9 shows examples of vibration levels at 2 locations obtained after several iterations. The levels measured on the bench reach similar levels than in the train. The gap between 2 measurements is in average less than 10 dB.
5. **SR analysis of binaural recordings and psychoacoustics analysis**

Final part of the study is focused on binaural recording and listening and target setting for the seat system.

### 5.1 Introduction

A design of experiment has been conducted in order to evaluate the impact of different parameters on the SR. Different configuration have been tested, each corresponding to the combination of 3 parameters:

- The first parameter is the position of the seat that can move from up position to middle and low position.
- The second parameter is the presence or not of a dummy body seated on one of the 2 seats.
- The third parameter is the position of the retractable tray, out or in.

For each configuration, 5 binaural recordings have been done at 5 different positions of the recording device (acoustic head): on the 2 seats, in the front, on the side and at the rear of the seat system.

### 5.2 Evaluation of SR events by a subjective approach

Table 1 gives the summary of a subjective listening done with the playback of binaural recordings. Each recording lasts 30 seconds for each configuration and position. The subjective listening has been performed by only one acoustic expert.
Table 1. Table of subjective evaluation

As noticed in the train, the Table 1 shows that no SR events could be detected for the reference configuration C1 of the seat system. SR events could be heard only when both seats were in low position, i.e. in configuration C3 at position P2 (left seat) and position P6 (at the rear). We also noticed SR events in configuration C5 at position P6 when a dummy body was placed on one of the seats.

When SR noise occurs, an important thing to add is that the noise is continuous and not intermittent, even for the base line excitation level (referred as x1 in Table 1).

When input excitation is multiplied by a gain of 2 (referred as x2 in Table 1), SR events are detected in the rear position for all configurations. When both seats are in low positions or when a dummy body is placed on one of the seats, SR events could be detected in all positions.

The origin of the SR events for all cases detected seems to be rattle noise generated by the rear trays. The physical explanation is the rattling of the tray on its contact points with the seat structure. After analysis, the frequency range of this rattle noise is between octave 1000 Hz and 4000 Hz.

We noticed in additional tests that other rattle noises generated by the seat structure itself occurred when input excitation level was multiplied by a gain of 5 or 10.

5.3 Psychoacoustics analysis

As the rattle noise comes from the rear trays, psychoacoustics analysis has been conducted for position P6 in configuration C3. Psychoacoustics metrics have been estimated for baseline input excitation level (x1) and also for input excitation level multiplied by gains of 2 (x2), 5 (x5) and 10 (x10).
Table 2. Psychoacoustics metrics estimation at position P6

From the data analysed in Table 2, it can be concluded that for the seat studied, fluctuation strength and tonality are not relevant. Other parameters like Loudness, Sharpness or Roughness could be representative of SR noises for this seat system but in order to simplify the analysis, the dB(A) is set as a reference for specification methodology.

6. Conclusions and Outlooks

From the measurements and analysis done, a methodology for the specification of acceptance to seat suppliers is proposed consisting in:
- Test of the seat in a semi-anechoic room with a 6 dof vibration table. Background noise should be lower than 35 dBA.
- Application of a typical vibration energy coming from measurements in a similar product with a multiplication factor that has been chosen from present analysis.
- Microphone measurements around the seat in several seat configurations.
- Maximum acceptance level that has been also set thanks to present analysis.

However and in order to complete the work done, one must continue the study with the following actions:
- A stronger subjective evaluation with a wider panel of users should be considered to obtain a robust model for specification.
- Different types of seats should be evaluated with this method to find the best compromise between the acoustic parameters to set the targets.

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REFERENCES