INSIDE NOISE OF HIGH SPEED TRAIN COACHES

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ABSTRACT

For many years, SNCF has been concerned with the improvement of the passengers acoustic comfort. A research program was defined to find relevant auditory comfort criteria and to study the acoustic phenomena responsible of noise into the high speed train coaches.
The paper presents the vibroacoustic part of this study. Measurement campaigns and data processing are set up to evaluate the contributions of the main acoustic and vibratory sources to the sound pressure level inside coaches. Multiple Input Multiple Output (MIMO) systems are studied to characterise the transfer paths of the energy. In the same time, a model of the coach, based on the "Statistical Energy Analysis" approach is built. After validation with experimental data, the model is used to perform parametric studies to improve the acoustic comfort.

INTRODUCTION

The two major aspects of the comfort studies carried out at the French railway company are given as follow :
- On a commercial side, the company tries to satisfy the customer need of comfort,
- On a technical side, improvements must be done to compensate the annoyance due to the increase of train's speed.

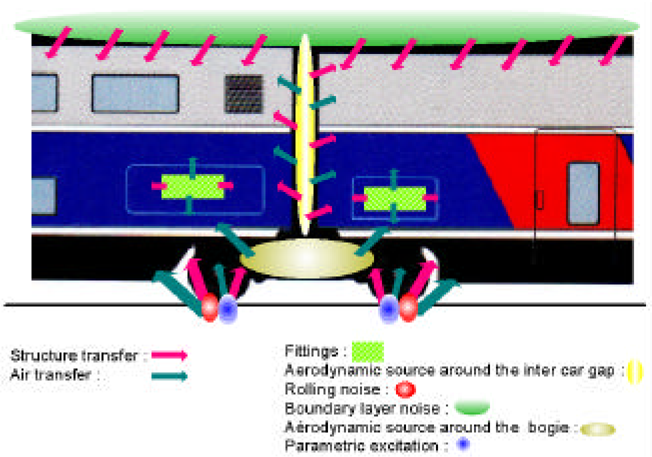
The importance of the first task has led SNCF to investigate in order to qualify the customer need of comfort according to physical parameters. Concerning the acoustic aspect, a research program has been conducted during four years to develop acoustic comfort indicators [MZA02] and investigate acoustic phenomena responsible of noise into the TGV coaches, especially in the low frequency band [0-1000 Hz].
This paper focuses on the vibroacoustic aspect. Main sources and transfer paths are listed in the first part. Methodologies set up to characterise sources and transfer paths are presented respectively in the second and third part. The prediction model based on the previous investigations is discussed in the last part.

1- MAIN SOURCES

Vibratory and acoustic sources which contribute to the sound pressure level inside a TGV coach running in normal operating conditions are numerous and can be sort according to the origin of the phenomenon :

- “technical equipment”. This group corresponds to the technical equipment of the coach like air conditioner, ventilation, electric converter, generator…
- “aerodynamic source around the inter-car gap ”. This source concerns the aerodynamic phenomena which can be created in the inter-car gap.
- “aerodynamic source around the bogie” is the noise created by the bogie in the air flow.
- “boundary layer noise” due to the air flow on the roof, floor and sides of the coach.
- “rolling noise” due to the wheel / rail contact.
- “parametric excitation” which corresponds to a periodic vertical displacement of the rail wheel system. This displacement is due to the track stiffness variation during the rolling of the wheel on the rail. An aerodynamic origin may exist too.

Noise and vibrations generated by these sources contribute more or less to the sound pressure level into the coach depending on the frequency band. For each source the energy is transferred either through the air or/and the structure. Main transfers are sum up figure 1.



- Figure 1 : main sources and transfers which contribute to the sound pressure level inside a TGV coach -

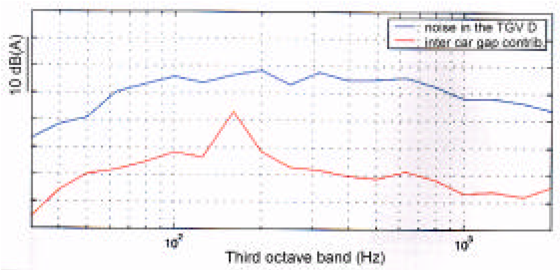
2- SOURCE CHARACTERISATION

2-1 TECHNICAL EQUIPMENT

For the TGV Atlantique (1 floor) and TGV Duplex (2 floors), technical equipment is located respectively underneath passengers and at the end of the coach. In both cases, equipments are mounted on elastic dampers which reduce efficiently the structure borne sound. The acoustic contribution of technical equipment is taken into account in the train specifications. A maximum sound pressure level is admitted in the TGV coach in stationary conditions with the air conditioner. This level is 12 dB(A) less than the sound pressure level measured in operating conditions at 300 km/h. Even if the sound pressure spectrum contains some pure tones, noise of technical equipment does not emerge in running conditions and can be neglected.

2-2 AERODYNAMIC SOURCE AROUND THE INTER-CAR GAP

Aeroacoustic phenomena generated by the inter-car gap are not yet identified. Contribution of this acoustic source is assessed by measurements in normal operating conditions. Sound pressure spectra measured by microphones located in the inter-car gap of a TGV show that acoustic modes appear around 200 Hz in some places. Some of them are not dependent on the train speed. The “Coherent Output Power” method is used to estimate the contribution of this source to the noise spectrum in the coach. Figure 2 shows that the contribution of the inter-car gap noise to the noise in the TGV coach can be neglected.



- Figure 2 : contribution on the inter-car gap to the sound pressure level into a TGV coach -

2-3 BOUNDARY LAYER NOISE

The boundary layer noise is due to the air flow around the coach and may be different on the roof, the floor and the faces. According to [ROB84], the Corcos model is well suited to describe the phenomenon. A measurement campaign is performed to identify the parameters of the model using 7 wall pressure microphones arranged crosswise on each side of the coach (see figure 3).

- Figure 3 : 7 wall pressure microphones arranged crosswise on the face of the TGV -

The Corcos parameters will be used later to predict the contribution of the boundary layer noise for each train speed.

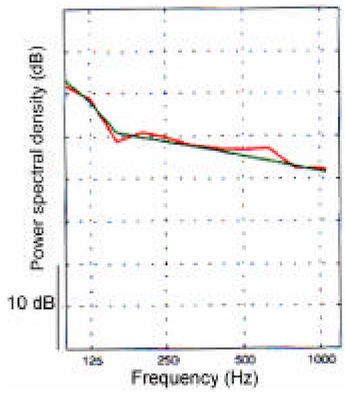
2-4 ROLLING NOISE

Rolling noise is one of the most important source of the railway system. The rolling of the roughness of the wheel on the roughness of the rail causes the vibratory source. The acoustic energy is radiated by the wheel and the track and vibrations reach the structure of the coach through the bogie.

An hybrid approach based both on measurement and simulation is used to estimate this source. In running operating condition, the rolling noise can be evaluated with a microphone located in a bogie and/or by a pass-by measurement if the train speed is assumed to be small enough to neglect the aerodynamic noise. These measurements are used to tuned the model developed using the Track Wheel Interaction Noise Software (TWINS) [THO96]. Then, the acoustic source of the rolling noise is computed using TWINS for each train speed and track and wheel roughness.

2-5 AERODYNAMIC SOURCE AROUND THE BOGIE

Conversely the rolling noise, the aerodynamic noise of the bogie can be estimate by a pass-by measurement if the train speed is assumed to be large enough to consider that the aerodynamic noise of the bogie is the main source, especially in the low frequency band. Then, the aerodynamic source around the bogie is characterised during a measurement campaign at 350 km/h. The acoustic power of the source is computed from the sound pressure spectrum assuming some hypotheses about the directivity pattern of the source (see figure 4).



- Figure 4 : acoustic power of the aerodynamic source around the bogie -

The shape of the power spectral density is considered to be independent of the train speed. Then, the acoustic power of the bogie P_{aero} can be computed for each train speed V, using the approximation presented figure 4 and the formula :

$$P_{aero} \approx 60\log_{10}(V).$$

2-6 PARAMETRIC EXCITATION

The parametric excitation generates a pure tone in the sound pressure spectrum in the TGV coach. It corresponds to a periodic vertical displacement of the rail wheel system [NOR98]. This displacement is due to the track stiffness variation during the rolling of the wheel on the rail.

The frequency of the vertical displacement can be easily linked to the train speed and the sleepers spacing but the level depends on too much parameters to be simulated. Then, the parametric excitation is introduced in the model presented in paragraph 4 using measured data. On this subject, an aerodynamic phenomenon caused by the flow between the track and the coach may appear as shown in [POI02].

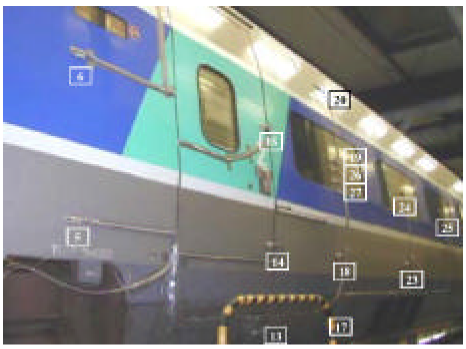
3- TRANSFER PATH ANALYSIS (TPA)

Energy is transferred through the air or/and the structure for each source (see figure 1).

- For the boundary layer noise, roof, faces and floor are directly excited by the pressure field. The coupling is computed using the Statistical Energy Analysis approach (see paragraph 4).
- For the aerodynamic source around the bogie, acoustic energy is transferred by the air and through the panels within the coach. Then, transfer functions and transmission loss/sound insulation of the panels must be assessed
- Rolling noise is transferred within the coach by the air and by the structure too. Then, a transfer path analysis of the bogie is performed.

3-1 CHARACTERISATION OF TRANSFER FUNCTIONS

Transfer functions are assumed to be independent of the train speed. If the speed is very low (<20 km/h), the rolling noise is the main source and pressure microphones are not disturbed by the air flow. Then, transfer functions between the source (rolling noise computed using TWINS) and the faces is measured with microphones showed on the surface of the coach (see figure 5).



- Figure 5 : microphones showed on the surface of the coach -

3-2 TRANSFER PATH ANALYSIS OF THE BOGIE

In the TGV, a coach is supported by the other coach itself supported by the bogie like a semi trailer. Then, the links between the bogie and the coaches are numerous. Some assumptions (links are symmetrical on each side) are done to simplify the identification of transfer functions.

The ratio *acoustic pressure / force*, P/F_i , is measured in stationary conditions for each input point of the structure of the coach. The forces $F_i^{'}$ are identified in normal operating condition with an inverse method based on the measurement of accelerations on these point. The contribution of the vibratory source P_{vib} to the sound pressure spectrum in the coach is computed by (for each degree of freedom of the link i) :

$$P_{vib} = \sum_i \left(\frac{P}{F_i} \right) F_i^{'} .$$

4- PREDICTION OF INSIDE NOISE

4-1 THE MODEL

The prediction model of noise in a TGV coach combines several approaches to take into account vibratory and acoustic sources, aerial and solid transfers. The SEA approach is used to estimate the contributions to the pressure spectrum in the TGV coach of :

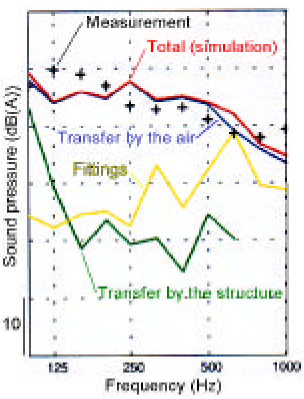
- the boundary layer noise,
- the part of rolling noise transferred by the air and including the parametric excitation source,
- the aerodynamic noise around the bogie (air-borne noise).

A complete model of the coach is set up with the “AutoSEA” software. The passenger room is split into 6 cavities, connected by insertion loss in order to take into account spatial dissimilarities. Absorption coefficients of the panels and sound pressure spectra in the intercommunications are measured data. The SEA assumes that the modal density of each subsystem is large enough to exchange energy between subsystems. For this model, the low frequency limit is around 250 Hz.

The contribution of the rolling noise transferred through the bogie is evaluated according to the methodology presented in paragraph 3.2.

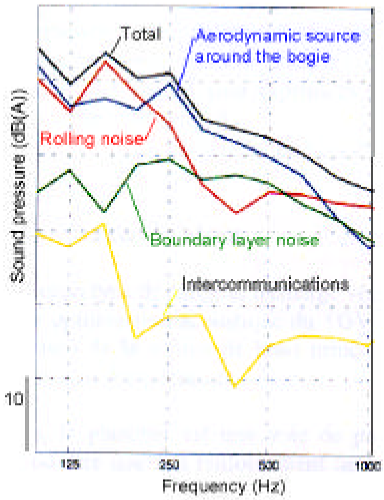
4-2 RESULTS

The model presented in the previous section is able to predict the sound pressure level and spectrum in third octave band for different locations in the TGV coach. At the beginning of the project, investigations were limited to the low frequency band (<1KHz) but the approach is efficient in high frequency band too (<5000Hz). The comparison between the computed sound pressure level and the measured one for different train speeds and locations in the coach show a good agreement : a difference of less than 3 dB(A) for 4 speeds and 4 microphone locations is achieved. Up to 700 Hz the computations always underestimate the levels. Spectra are presented figure 6. The agreement between computed and measured spectra is around +/- 3dB(A) for each third octave band level.



- Figure 6 : sound pressure spectrum in the TGV coach (300 km/h) -

The model can be used to estimate the contribution of each transfer path (figure 6) or source (figure 7).



- Figure 7 : contribution of each source to the sound pressure spectrum in the TGV coach -

The particular case of running in the tunnels is simulated to estimate the new contribution of each source.

CONCLUSION

The model built to estimate the sound pressure level and spectrum into the TGV coach is operational. This model uses a simplified SEA model of the coach and a database of transfer functions in the air. The methodology is now validated. The database should be completed especially to predict the spectrum from 250 Hz to 5000 Hz.

Parametric studies can be achieved using the model, to test some mitigation measures : source reductions and/or transfer path modifications.

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