EXPERIMENTAL CHARACTERISATION OF A NEW AEROACOUSTIC SOURCE ON HIGH SPEED TRAINS

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ABSTRACT

For many years, SNCF has been concerned with the improvement of the passenger's acoustic comfort. A research program has been defined to study the acoustic phenomena responsible of noise into the high-speed train coaches.
A pure tone in the sound spectrum into the coaches evolves with the sleeper spacing and the train speed. This parametric excitation has been already studied as a mechanical phenomenon but the "Couette" flow between the train and the track may generate noise too.
The paper presents the test bed set up in the laboratory to reproduce the flow between the coach and the track. The flow characteristics are measured. In some conditions, a pure tone appears in the wall pressure spectrum.

INTRODUCTION

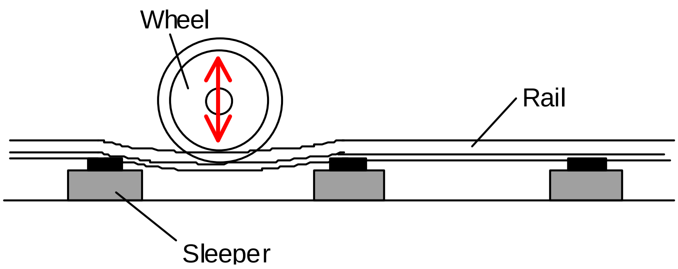
The two major aspects of the comfort studies carried out at the French railway company are given as follow :
- On a commercial side, the company tries to satisfy the customer need of comfort,
- On a technical side, improvements must be done to compensate the annoyance due to the increase of train's speed.

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 acoustics phenomena responsible of noise [POI02].
In this context, vibratory sources have been characterised, a transfer path analysis has been conducted and the acoustic characteristics of the room measured. Then, a prediction model, based on the statistical energy analysis (SEA) approach, has been build. The acoustic spectrum in third octave band within a TGV coach can be predicted for different speeds, in normal operating conditions and in tunnels.
This paper focuses on a particular source called "the parametric excitation". A mechanical approach has been already developed to study this source. The phenomenon is briefly

presented in the first part. The second part describes the experimental set up developed to reproduce the aerodynamic aspect of the phenomenon. The flow characteristics between the coach and the track are discussed in the last part.

1- THE PARAMETRIC EXCITATION

The parametric excitation [NOR98] [HEC95] 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 (see figure 1).



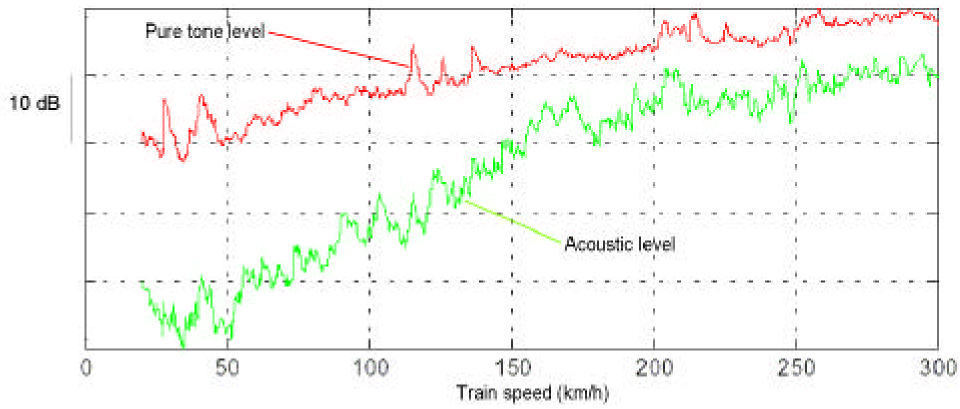
- Figure 1 : the parametric excitation phenomenon -

The frequency F_{PE} of the vertical displacement can be easily linked to the train speed V and the sleepers spacing d :

$$F_{PE} = V / d \ .$$

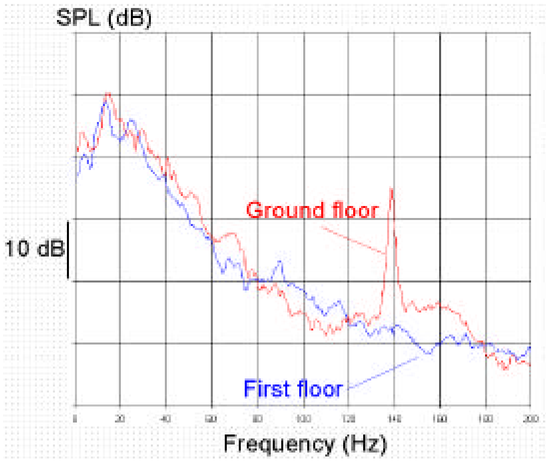
For a TGV in normal operating conditions (300 km/h, high-speed track), the parametric excitation frequency is 139 Hz.

The level of the pure tone is more difficult to predict. A measurement campaign with a TGV shows that the pure tone level evolves with the train speed but this evolution can not be simply fitted. In particular, the level depends on the microphone location in the coach. An example of the level evolution of the pure tone according to the train speed is presented in figure 2. Signal is recorded in the middle of the coach.



- Figure 2 : evolution of the level of the parametric excitation according to the speed -

The parametric excitation generates a pure tone in the sound pressure spectrum at the frequency F_{PE}. For example, the spectrum of the sound pressure into the coach of the TGV Duplex is presented figure 3. A psychoacoustic study [POI00] has shown that passengers may be annoyed by pure tones in the low frequency band even if the emergence contributes very few to the A weighted sound pressure level.

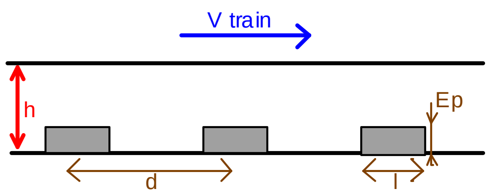


- Figure 3 : the pure tone of the parametric excitation emerges of the sound pressure spectrum in the ground floor of the TGV Duplex running at 300 km/h -

Measurements confirm the mechanical explanation of the phenomenon : the pure tone exists in the vertical acceleration of the axle boxes. Nevertheless, an aerodynamic source may appear due to the flow between the coach and the track.

2- THE EXPERIMENTAL SET UP

To detect an aerodynamic origin of the sleeper passage phenomenon, an experimental set-up has been design, realised and installed in the acoustic laboratory of “Ecole Centrale de Lyon”. This set-up try to simulate the flow between the track and the coach. With a 2-D assumption the main characteristics of the configuration are the train’s speed, V, the track-coach distance, h, sleeper wide and thickness, l and E, and the space periodicity, d (see figure 4).



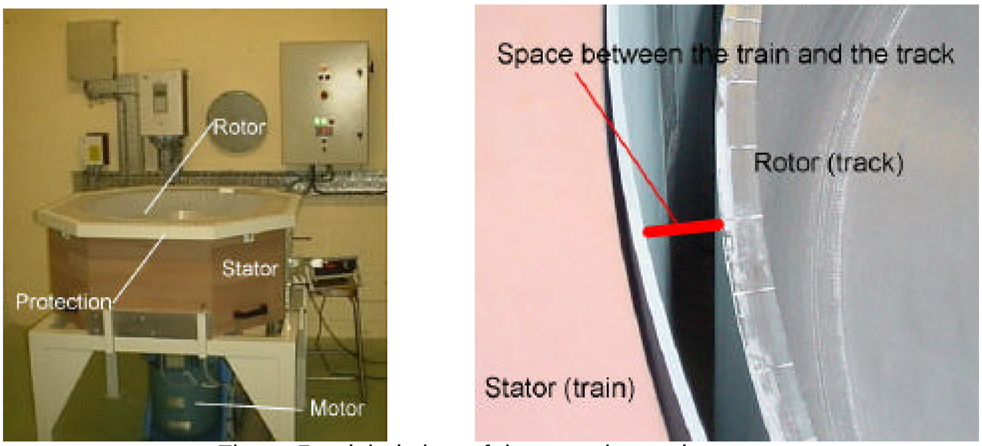
- Figure 4 : geometrical characteristics of the system -

Typical values of real operating conditions are presented in table 1.

Reynolds number Rh	d/h	l/h	E_p/h
$2.5\ 10^6$	1.5	0.72	0.1

- Table 1 : parameters in normal operating conditions (300 km/h) -

The typical flow between two mobile plates is a Couette Flow. In this case, we have a Couette flow with periodic boundary conditions. The Reynolds number is very high. OTTAVY [OTT97] shows that a conveyor belt is not sufficient to reach it. Then, a cylindrical experimental set up is preferred, assuming that the curvature radius of the system is large according to h. Two coaxial cylinders are used : the stator corresponds to the coach and the rotor to the track (figures 5). Irregularities glued on the rotor represent the sleepers (figure 6).



- Figure 5 : global view of the experimental set up -

- Figure 6 : rotor with the “sleepers” -

It seems to be difficult to preserve the Reynolds similarity in the air. Then, a maximum value of 10^5 is chosen even if 10^4 is sufficient to obtain a turbulent flow [OTT97]. Assuming the Reynolds similarity, dimensions of the experimental set up are given in table 2.

Rh	h (cm)	d (cm)	l (cm)	E_p(cm)	Rotor diameter (cm)	Linear rotor speed U_1 (m/s)
10^5	2.5$^{(*)}$	4.5	2.2	0.3	70	50$^{(*)}$

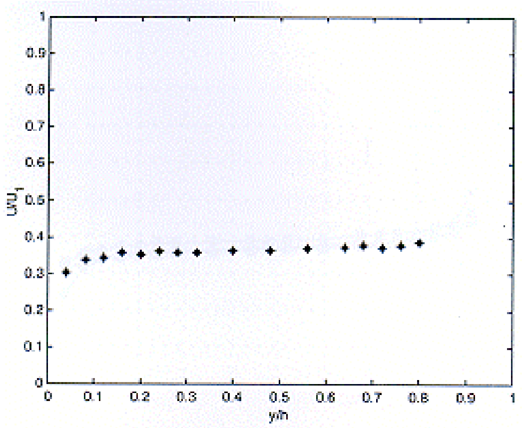
(* : adjustable, h=2.5cm corresponds to the Duplex TGV)

- Table 2 : dimensions of the experimental set up -

3- THE FLOW CHARACTERISTICS

3-1 SMOOTH ROTOR

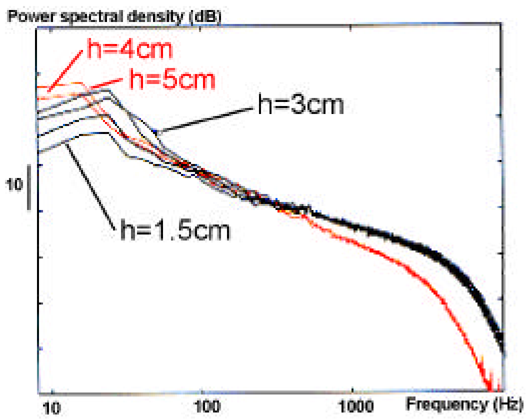
First, a smooth rotor is used to characterise the flow. The speed field is measured with a hot wire probe. 15 configurations are tested for 5 <U_1 (m/s) < 50 and 1.5 < h (cm) < 5. An example of the mean speed U is presented figure 7.



- Figure 7 : mean speed profile (U_1=50m/s, h=2.5cm) -

In all the cases, the mean speed profile levels off around the middle of the space between the planes which characterises a turbulent Couette flow. If the mean speed and the speed fluctuation are normalised by the speed of the moving plate U_1 and the distance between the plans h, the shape of the speed profiles is invariant. Nevertheless, the level of the plateau evolves with h (0.37 U_1 for h<3 and 0.2 U_1 for h>4) which means that two rates of flow exist.

The wall pressure is measured on the stator with 5 microphones 1/8" (B&K4138) arranged crosswise. The wall pressure field is characteristic of a turbulent flow and can be represented by a Corcos model. The spectrum is wide band and its level evolves with the cube of the speed. Its variation according to h is presented in figure 8. A critical value h* seems to separate two rates of flow which confirms the previous result.

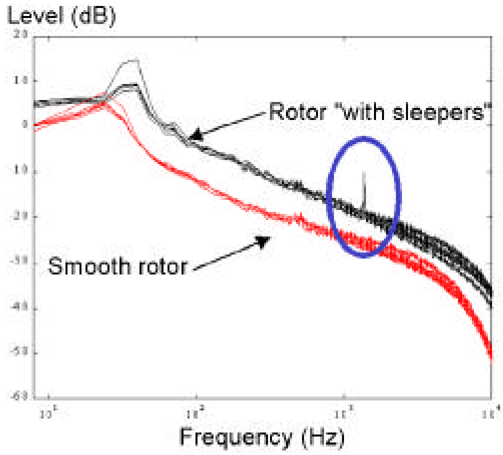


- Figure 8 : wall pressure spectral density (U_1=50m/s) -

Measurements show that the coherence length falls steady when the frequency grows and falls suddenly in very low frequencies. In the middle frequency, the coherence length is of the order of h. In the other hands, the study of the convection speed confirms that the wall pressure field is influenced by the flow and that both planes are coupled.

3-1 ROTOR WITH "SLEEPERS"

The same experiments are conducted with the rotor presented figure 6. Mean speed profiles remain the same. The level of the plateau depends on h too but is higher (0.54 U_1) than with the smooth rotor. The fluid is better drive by the irregularities. The wall pressure can be represented by a Corcos model too. The spectrum level grows of 10 dB and a pure tone appears (see figure 9). Like the parametric excitation, the pure tone frequency depends on the rotor speed U_1 and the distance d ($F_{PE} = U_1 / d$).



- Figure 9 : wall pressure spectrum -

The pure tone level depends on the distance h. The emergence level reaches 18 dB when h is small (h~1.5cm) and decreases with the exponential of h.

When h is representative of the TGV Duplex, the pure tone emerges. It does not in a case of the TGV Atlantique. This result agrees with the normal operating conditions. The pure tone corresponding to the sleeper passage phenomenon does not emerge in the sound pressure spectrum within a TGV Atlantique coach for which the distance between the floor and the track is higher than for the TGV Duplex.

CONCLUSION

The experimental set up built to investigate an aerodynamic origin of the sleeper passage phenomenon seems to be very efficient. Using two coaxial cylinders, high Reynolds number are reached and a turbulent Couette flow established. Measurements show that the displacement of a smooth plane over a plane with periodic irregularities induces a pure tone in the spectrum of the wall pressure. Its frequency depends on the speed of the moving plane and the distance between irregularities. Its level is linked to the distance between the planes. This result agrees with measurement in normal operating conditions of the TGV Duplex and Atlantique.

Now, investigations concern the theoretical approach of the phenomena. Nevertheless, some special cases like bi-block sleepers will be tested on the experimental set up. If the existence of an aerodynamic origin to the sleeper passage phenomenon is validated, it will be interesting to separate the contributions of the mechanical and aerodynamic sources.

BIBLIOGRAPHY

[HEC95] M. A. HECKL, "Railway noise – Can random sleeper spacings help?", Acustica, vol. 81, p. 559-564, 1995.

[OTT97] G. OTTAVY, Ph. D thesis, 1997.

[MZA02] M. MZALI, "Perception de l'ambiance sonore et évaluation du confort acoustique dans les trains", Ph. D thesis, Université de Paris VI, 2002.

[NOR98] A. NORDBORG, "Vertical rail vibrations : parametric excitation", Acta Acustica, vol.84, p. 289-300, 1998.

[POI00] F. POISSON, F. LETOURNEAUX, S. GUERRAND "Assessment of the acoustical comfort in high speed trains at the SNCF : integration of subjective parameters." Journal of sound and vibration, p. 839-846.

[POI02] F. POISSON, F. LETOURNEAUX, N. VINCENT, "Inside noise in high speed train coaches", Forum Acusticum, Sevilla, september 2002.