Assessment of Interior Noise of Rail Vehicles due to the Electrical Traction System - Simulations and Full Scale Tests -

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Introduction

The design of rail vehicles is driven by a number of functional requirements. One of these is the internal acoustic comfort in the vehicle. In this paper, the focus is on the noise emitted by the components of the traction system, as it happened to be the object of complaints in some cases.

Based on previous studies [1], the objective of this work was, in a first step, to understand the traction noise generation mechanisms. In a second step, the aim was to try to find the technically possible changes that are relevant regarding the acoustic comfort, by means of an available software code [2] enabling simulations and parameter variations.

Traction Noise

For electrically driven trains, together with fan noise, the noise emitted and radiated by the components of the traction system is the dominant noise at low speed of the train, and especially during starting and breaking. The converter-fed traction motor and the gearbox contribute to the traction noise. The alternating current creates magnetic forces that excite the motor's structure and make it vibrate. These might even excite the bogie frame. The converter is responsible for the creation of harmonics in the current signal, which produces additional magnetic forces. A brief summary of traction noise generation mechanisms is given in [3].

Figure 1 shows a typical example of the audible tones (fundamental tones and their harmonics) as function of the motor's stator frequency. Table 1 gives the symbols used. A double-stage gearbox is considered. The coefficients k_1 and k_2 depend on the number of teeth per gearwheel. The switching frequency is the frequency at which the switches[1] inside the converter are turning on and off.

Table 1: Symbols used in Figure 1

f_{sw} : *Switching frequency*	k : *Number of the harmonic*
f_s : *Stator frequency*	p : *Motor pole pair number*
f_{motor} : *Motor frequency*	$f_s = p \cdot f_{motor}$

Normally, one can notice two distinct phases for the noise radiated by the motor: the asynchronous phase with constant tones, and the synchronous phase with tones that are proportional to the stator frequency. This is related to the operating program of the converter.

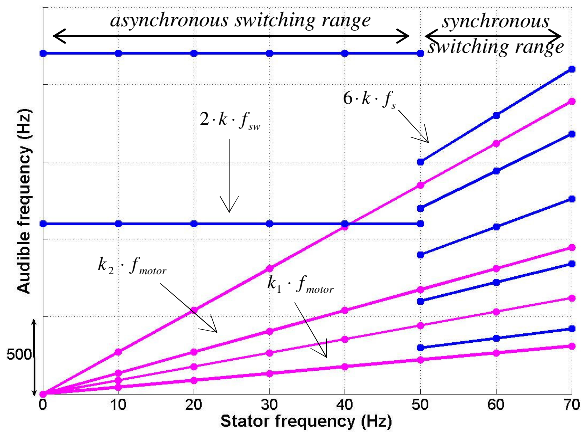

Figure 1: Example of the audible tones created by the traction system at starting of the vehicle (■ tones due to the motor, ● tones due to the gearbox)

Simulation Tool

A Matlab-code called Metroklang [2] was used to carry out this work. This program provides the simulation and auralization of starting and braking noise of electrical rail vehicles. Figure 2 shows the relevant input parameters. The traction noise components and binaural room response are synthesized while recorded rolling noise and transfer functions comprising mechanical and room resonances are used.

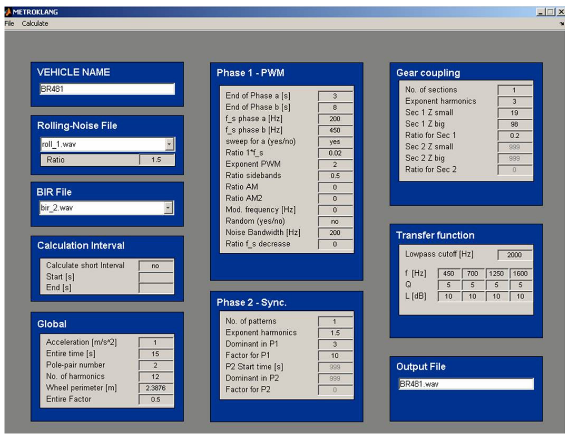

Figure 2: Metroklang's interface showing the input parameters

In order to analyze the traction noise of various vehicles, a measurement campaign was carried out.

[1] e.g. IGBT (Insulated Gate Bipolar Transistor) or GTO (Gate Turn-off Thyristor)

Finally, two vehicles, equipped with converters having two different kinds of semi-conductor were selected. On the one hand, recordings of the noise at starting of those vehicles were carried out; on the other hand, using the relevant data, starting noise was simulated with Metroklang. The two were then compared. Figure 3 shows an example of traction noise reproduction at starting of a commuter train using a GTO converter.

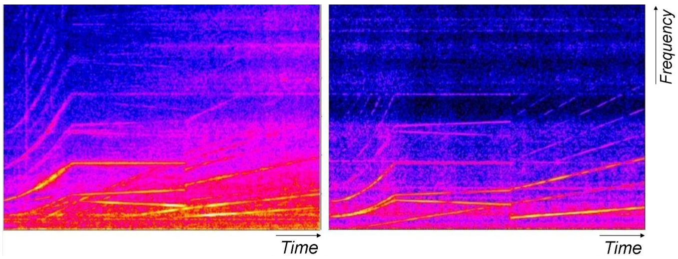

Figure 3: FFT vs. time of the recorded signal (left) and the reproduced signal (right)

Parametric Studies

The characterization of noise alone by its A-weighted sound pressure level has got limitations. Contrary to what is commonly believed, and what often drives work done for acoustical improvement, a quieter sound is not automatically the best solution. Regarding traction noise, the point of interest is the frequency content of the noise rather than its sound pressure level. Some psychoacoustic metrics were used for sound quality assessment, such as loudness, tonality and roughness.

Parametric studies were done and compared to recordings obtained from full-scale tests. In particular, the influence of a randomized modulation of the switching frequency, in the asynchronous phase, was investigated. The effect on psychoacoustic metrics was compared and investigated, using eight different modulation bandwidths.

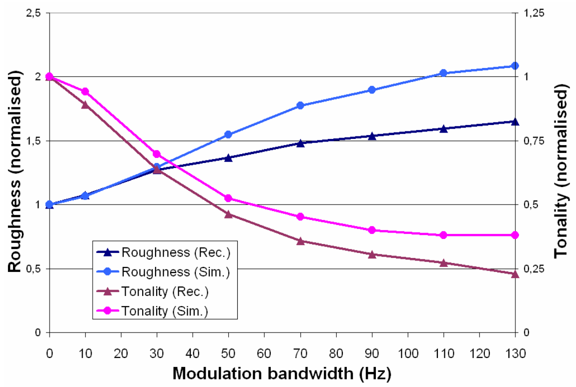

Figure 4: Effect of a randomized modulation of the switching frequency in asynchronous range on tonality and roughness

Figure 4 shows the results of this parametric study on tonality and roughness. Reproduced (●) and recorded (▲) samples follow the same tendency. A decrease of tonality and an increase of roughness as bandwidth increases is observed. This is explained by the fact that as the bandwidth widens, the energy is spread on a larger frequency interval. Tones are then less audible, thus a decrease of tonality. On the other hand, due to this same distribution of energy, modulations in the noise can be perceived, which increases the roughness. For this specific noise, when submitted to listening tests, it is observed that a higher roughness is preferred compared to high tonality [1], [4].

Conclusions

Metroklang simulations give satisfactory relative agreement to measurements. Hence, it is a useful tool to auralize interior acceleration noise of electric rail vehicles early in a project. A limited and easily accessible number of input parameters are required. It is an easy way to compare different design alternatives while avoiding extensive parameter studies on real vehicles or drive-system test rigs**,** and can give support in decision making.

It is yet to be noticed, that the absolute agreement between simulation and reality is relatively poor. The obtained results remain qualitative and not quantitative. Some limitations come from the fact that, to create a model, experience and empirical data are still needed. Also, some improvements are still to be done on the code.

What is retained for the improvement of traction noise sound quality is to choose a higher mean frequency, and a randomized modulation (e.g. 10%) of the converter switching frequency in the asynchronous range. Also, asynchronous switching should be used for a wide stator frequency range before turning to synchronous switching. However, the range of possible frequencies is narrowed by other boundary conditions such as the thermal capacity of the semi-conductors, electro-magnetic compatibility, costs.

The eventual aim of this work was also to improve the communication between the various engineering disciplines when designing the traction system of a train. It was shown that sound quality can be considerably optimized by simple changes when acoustical know-how among other disciplines is applied from the very early phases of a vehicle's traction design process.

By the change of technology from GTO to IGBT semiconductors and higher capacity of modern IGBT, which make higher switching frequencies even possible for medium or high power applications, most of the above recommendations can be taken into account.

References

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