26th INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
7-11 July 2019, Montreal

AN INNOVATIVE NUMERICAL APPROACH FOR TRAIN PASS-BY NOISE FORECASTING

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This paper deals with an engineering method for the prediction of vehicle pass-by noise based on a FEM/ BEM exterior acoustic calculation in the frequency domain.

The researchers simulate, in a virtual environment, the experimental outdoor pass-by noise measurement. The simulated pass-by noise campaign is synthesized from multiple acoustic transfer functions between a line of virtual microphones located 7.5m on the side of the vehicle and each noise source. A numerical FEM/BEM train bogie acoustic model has been created within the MSC ACTRAN commercial softwares. Wheel-rail rolling noise, engine and powertrain noise acoustic source have been implemented and positioned inside the FEM and BEM model to demonstrate the validity of the proposed methods. The contribution from noise sources, expressed both in terms of sound pressure level and overall value, to the pass-by noise were evaluated up to 5 kHz. The virtual pass-by-noise assessment has been then validated by experimental measurement of the complete four coach's train with respect to different speed regimes.

Keywords: Railway vehicle noise, Wheel-rail interaction, Vibro-acoustic simulation, FE Modeling

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1. Introduction and overview of the approach

Railway operational noise originates from several sources, such as: rolling (wheel-rail interaction), traction (engine, fans and gears), aerodynamic effects (pantograph, body turbulence) and so on. The dominant contributor, over the widest speed range (from around 50km/h to around 180km/h) are wheel-rail rolling noise, engine and powertrain noise. In order to reduce the different noise sources and study the noise propagation around the trains, the manufacturing companies and their suppliers have to come up with innovative solutions to predict the emitted noise level.

The train pass-by-noise regulation aims to characterize the overall acoustic signature of a vehicle and it requires experimental measurement in its operational condition – as it passes over stationary microphones. In the development process of novel trains, the pass-by-noise tests represent one of the most important step in the commissioning process; at this stage, not-compliance or critical issues would represent a dramatic aspect. That is the reason, why the development of forecasting numerical methods and models represent a fundamental tool to be used during the design route.

The present work is part of a research project aimed at the improvement of noise performances of modern train vehicle and rolling noise systems. The first part of the paper mainly concern with the objective to investigate a method for the determination and characterization of the "rolling noise" phenomenon. The key issue is the estimation of the acoustic radiated power given by the wheel-rail contact, on which the European Union is focusing its attention in order to reduce the environmental impact of such class of transport system. Many numerical model have in the past been developed by the authors and other scientist, also taking into account the roughness profile of the rails that must fulfil the requirements of the ISO 3095 test procedure reference norm. Significant noise level is also generally associated at the electrical engine. This source can become a very annoying source because of the typical spectra that many times present pure tones or harmonic components.

2. Noise sources definition

Two different noise sources have been taken into account during the modelling process: the wheel/rail interaction and the electrical engine.

First noise source has been studied through a full numerical approach based upon previous studied conducted by the authors as well as other notable authors. For the second noise source, an experimental approach has been preferred because of the lack of information related to the specific functionality and construction characteristics of the engine.

2.1 Wheel-rail interaction noise source

The most important sound radiating parts of a tracked transit system are the steel wheels of the rail vehicles. Small-scale unevenness on the wheel and rail contact surfaces, referred to as roughness, induces high frequency dynamic interaction between the wheel and rail when a train runs on the track. As a result, the wheel and rail are excited, vibrate and radiate noise. It is important to know the wheel/rail interaction force for predicting track and wheel vibration, railway noise radiation as well as the formation of wheel and rail corrugation or truck damage. The combined roughness form a relative displacement input between the wheel and rail, and thus the wheel-rail interaction force depends on the dynamic properties of the wheel and rail (including the contact zone) at the contact position. The rationale of the approach include a preliminary FE modelling of the wheel and the rail with extraction of the relative normal modes. Next figure show first mode shape for both the elements.

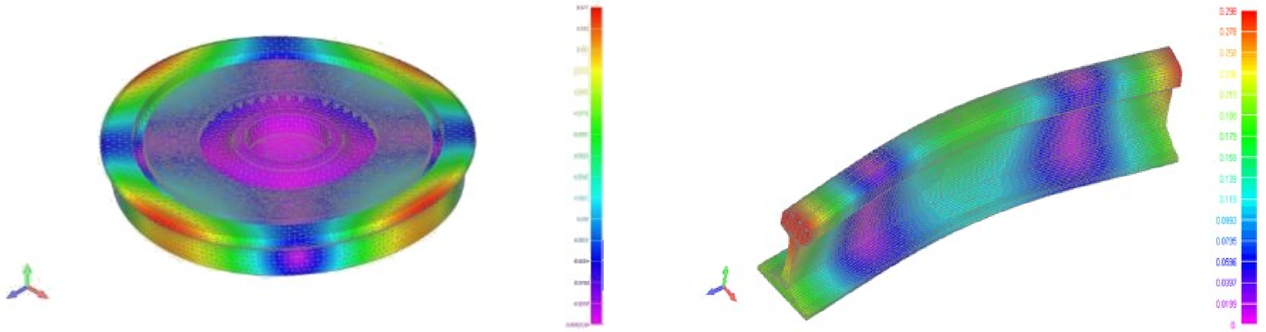
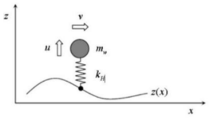


Figure 1: First mode shapes for wheel and rail

On the basis of specific characteristics of the train (mass, primary and secondary dampers stiffness, speed) and of the rail roughness profile, the equivalent point force has then been computed. In compliance with EU 2015/996 regulations, and on the basis of the standard roughness profiles, a MATLAB® routine has so been developed which allows for estimating the operative wheel-rail interaction force on a real train.

This force has been imposed both at the wheel and rail and the relative dynamic response and vibro-acoustic response has been computed by the use of the MSC ACTRAN and also Ansol Coustyx code.



$$\check{F}(s,t) = \frac{\check{z}(s,t) - \dfrac{m_w v_0}{m_w s^2 + k_s}}{\dfrac{1}{K_H} + \dfrac{1}{m_w s^2 + k_s} + \dfrac{1}{8EIk_0^3}} \qquad \check{z}(s,t) = \sqrt{\frac{u(t)}{2R}\frac{v}{s}}\left(1 - e^{-\sqrt{2Ru(t)\frac{s}{v}}}\right)$$

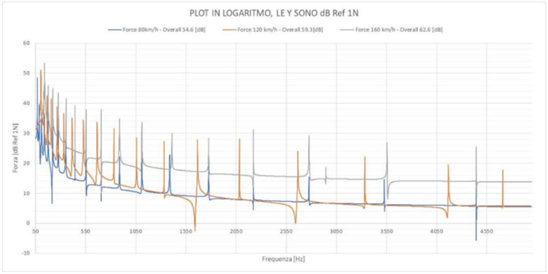


Figure 2: Mathematical model for the force computation

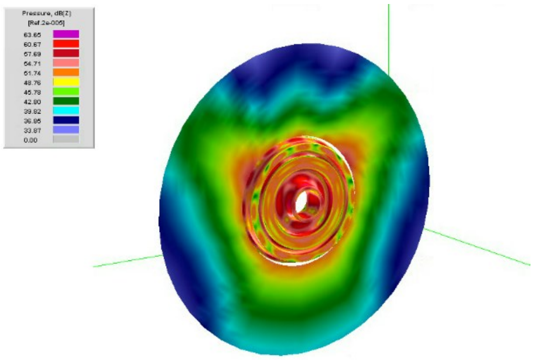
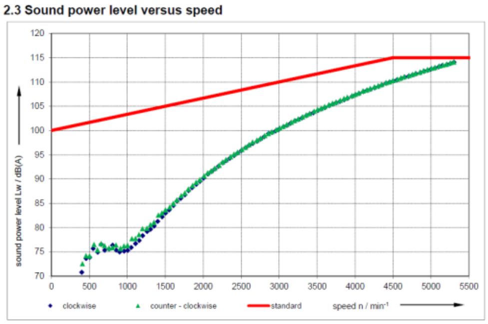


Figure 3: An example of acoustic pressure distribution around the wheel by Ansol Coustyx

2.2 Characterization of engine acoustic power

As previously introduced, the characterization of the electrical engine has been assessed on experimental basis.

The engine, installed in a dedicated anechoic environment, has been driven in a the whole operative frequency range and relative acoustic signature has been acquired. During this test campaign, both microphones and sound intensity probe has been used for a better evaluation of the sound power and sound directivity of the source.



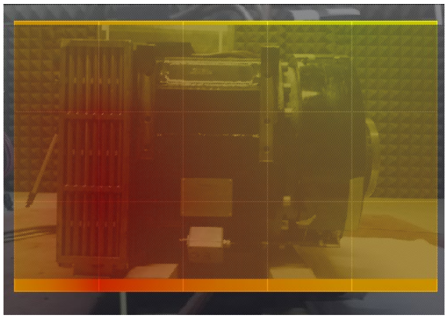


Figure 4: Engine installation (left) and sound power level versus speed (right)

Next picture show the spectral distribution of the noise at different rotational conditions.

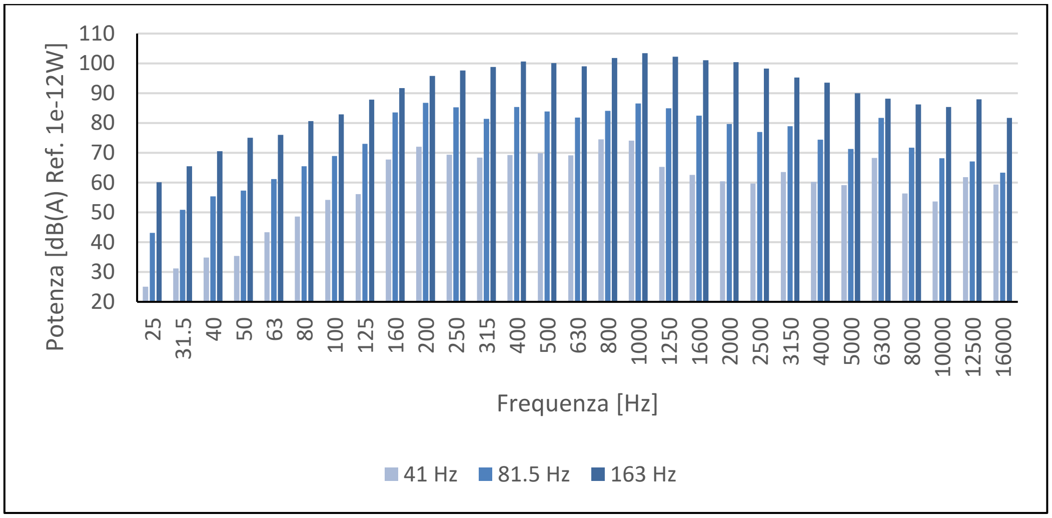


Figure 5: Noise spectra at different rotational conditions

3. Implementation of noise sources at boogie level

Once the single noise sources have been characterized in terms of noise power level and relative spectra and directivity patterns, the same have been implemented at boogie level. In the specific two different boogies have been simulated. The so-called "*motored boogie*", presenting four wheels (with relative rail portion) and two engines, and the "*trailed boogie*" where only the wheel (and rail) are present.

Vibro-acosutic response has been so computed whose an example is reported in next figure 6, while relative spectra are compared in the next figure 7.

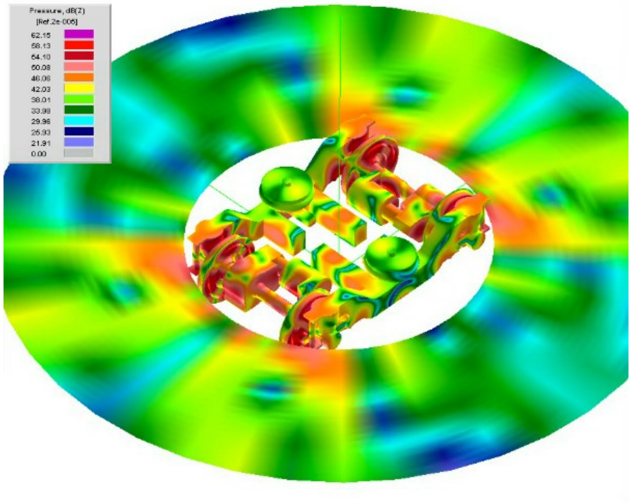


Figure 6: Acoustic Pressure Distribution Around the Boogie by Ansol Coustyx

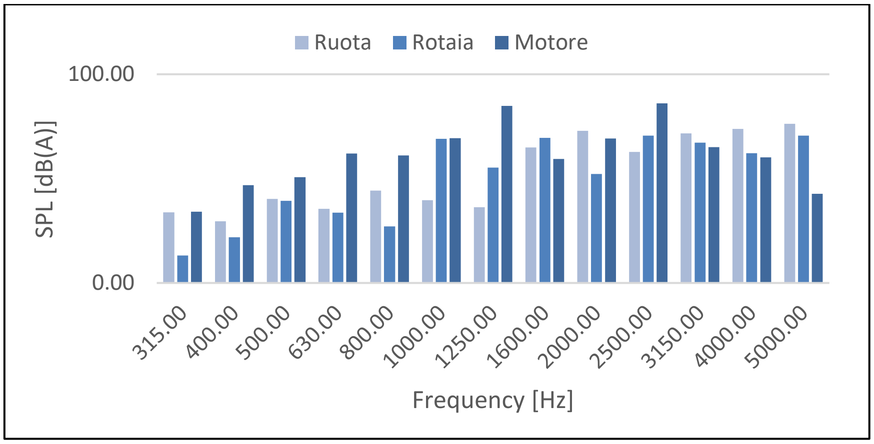


Figure 7: SPL spectra of different sources

4. Evaluation of the pass-by noise

External noise evaluation generally realized in accordance with EN ISO 3095, require the SPL measurement at 7,5 mt from the center of the rail, in correspondence of the train passage

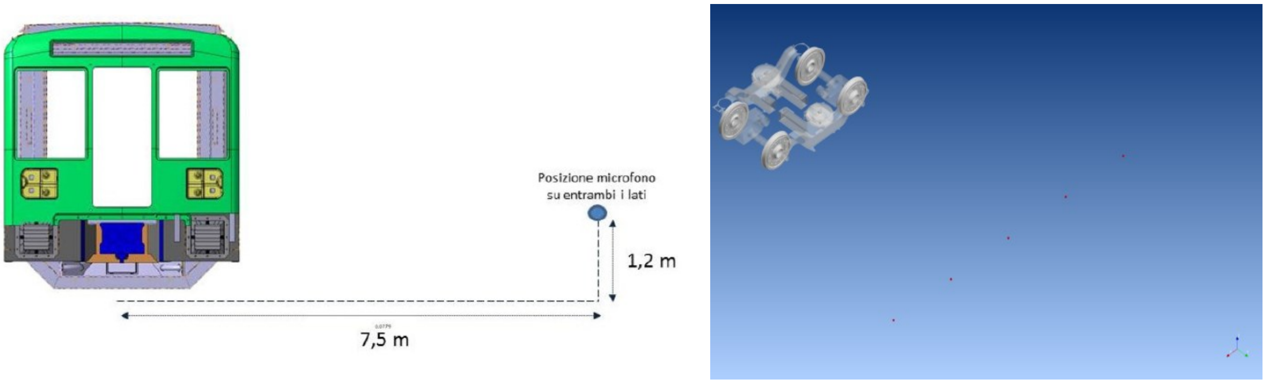


Figure 8: Pass By Noise - EN ISO 3095 reference (left) – Simulated microphone's line (right)

Specific noise level have so been computed for a line of microphones simulated at this distance along the train moving direction.
Next figure show the difference related to the trailed and motored boogie passage.

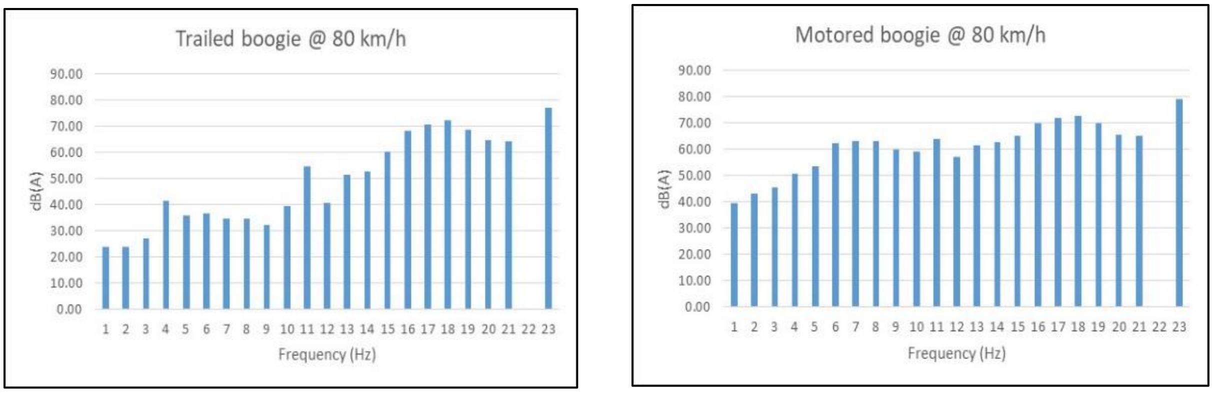


Figure 9: Pass By Noise - EN ISO 3095

The space computed noise level, have than be post-processed on a time basis approach, to fulfil the normative requirement that require the evaluation of the Equivalent Noise Level measurement, referred to the train pass-by time.

$$Leq_{dB} = 10\, Log_{10} \left[\frac{\sum t_i \left(\frac{P_i}{P_0}\right)^2}{t_f} \right] \qquad (1)$$

The result of the computational process is summarized in the next picture where the classical shape of train pass-by noise can be recognized.

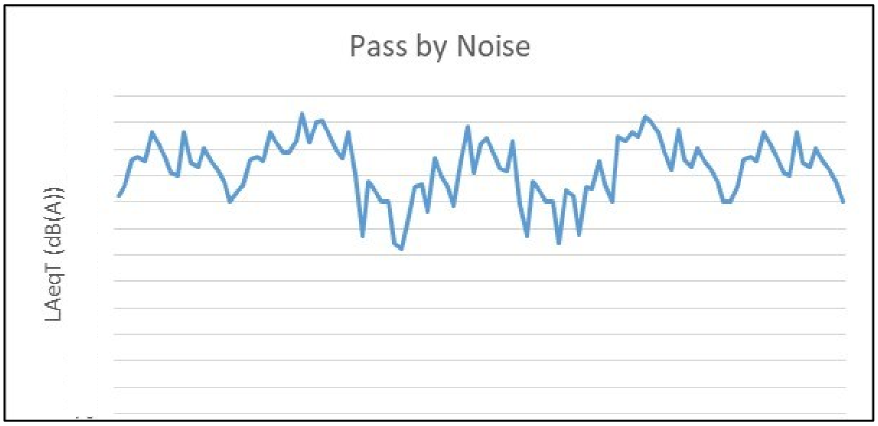


Figure 10: Pass by noise computation (noise level has been voluntarily hidden)

5. Conclusion

The paper presented a computational approach to forecast the pass by noise of train vehicles according to the reference normative. The proposed methodology started form the characterization of the main noise sources (wheel/rail interaction and electrical engines), performed on the basis of both numerical and experimental approaches. Single sources have then been simulated into an integrated boogie environment to evaluate their effect and relative interaction with the boogie structure. Overall noise has been estimated both in the near field that at the far field and specifically in the location prescribed by the reference normative. The space state domain has finally been post processed to compute the pass-by noise at time domain.

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