Acoustic study of interior noise of NIM Express driving railcar

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Abstract

This paper discusses acoustic study of NIM Express driving railcar made from extruded aluminum panels. The NIM Express is intended for operation on German tracks with maximal velocity of 189 km/h. Description of several Vibro-acoustic techniques such as SEA / BEM / Hybrid FEM-SEA, used for noise level estimates will be given. Loading conditions and results due to train maximum velocity and estimation of the interior/exterior noise due to active horn will be presented. The unknown acoustic power of the horns will be computed using BEM techniques and further analyzed in system level SEA model. The results of the computations will be presented together with analysis of dominant paths of the acoustic energy propagation. Conclusions about the results and recommendations for future work will be given.

Introduction

Noise limits in rail transportation are not only defined by legislation, but often in these days are defined by more strict expectations of the train service operators. Passengers comfort and resident's satisfaction who live in close proximity is the highest priority. It results in additional acoustic demands on rail cars, which has to be addressed by train manufacturer on top of the standard legislation.

Interior noise level distribution during operating condition, or exterior noise level in parking mode are one of these extra noise situation which has been addressed when developing new NIM EXPRESS train-set.

NIM EXPRESS train

NIM EXPRESS is push-pull type of train set and it is composed from Locomotive 109E3, driver-car, end-car and inserted middle-cars.

Newly developed wagons are semi low floor, double decker construction, where inserted cars are fully passable from one end to another. Driver car with end car are semi passable from one side only. All traction devices are primarily located on locomotive and remaining 6 cars are without the traction. Most of the passenger car devices like HVAC (and others) are located at the end sections of each car, under the train roof. Full train set is produced in Škoda Vagonka and Škoda Transportation.

NIM EXPRESS is high speed train, designed to operate between Nurnberg – Ingolstadt – Munchen and will be operated by Deutsche Bahn. Maximum construction speed is 200km/h. Maximal operating train speed is 189km/h and each car is certified separately.

Driver car

Driver car of the NIM EXPRESS is composed from driver cabin on one side and passenger compartment as shown on (Figure 1). First class compartment is placed in the second floor, where other than nice view, also lower sound pressure levels are expected. Second class is located on the first floor and technical rooms is below the roof, above the elevated part of the train.

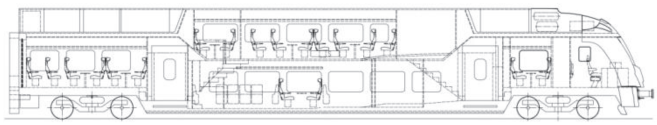


Figure 1: Driver car schematic drawing

Train warning system (horns) are placed above the driver´s cabin. Other noise sources will be discussed later in more detail.

Customer's demands on acoustic

Demands on the acoustic train performance fall into two categories. First is legislative category, related with technical specifications for inter-operability for locomotive [1] and inter-operability for cars [2]. Second category is customer demands, which in many instances are more challenging and requires analyses early in the design stage.

Driver car thus has to satisfy following requirements:

- Overall sound pressure level limits
- Tonal values
- Exterior noise
- Interior noise at passenger area
- Interior noise in drivers cabin

Within this project, different acoustic tasks has been split in between project partners. LogoMotive has been responsible for exterior noise of locomotive. MECAS ESI / VUKV has been responsible for analyses of interior noise distribution and VUKV for the project coordination.

Interior noise solution for driver's car

Primary objective has been set to evaluate interior noise distribution inside the car due to acoustic loading, which may occur during operation. Two loading cases has been nominated as the worst case scenarios. Driving at maximum velocity 189 km/h and noise due to horns when train is in parking mode. Secondary, but not less important, loads has been also used as a base for various sensitivity analyses of influence on different design changes and for energy transfer path analyses to better understand how is energy propagating through the model.

For the desired frequency range of interest 200Hz – 8kHz a full system SEA (Statistical Energy Analyses) model has been created in VA One software (figure 2). Model is discretized into series of panels and cavities, which are connected together via junctions that can transmit the energy. Each panel (cavity) is represented by a series of wave fields, which can propagate, store, or dissipate energy.

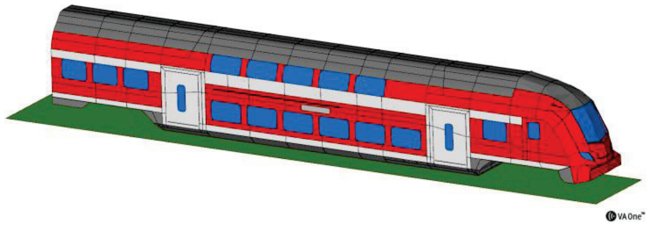


Figure 2: SEA model of Driver's car

VA One model description

Train structure is made from extruded aluminum panels of different profiles as a self-supporting structure. Such panels are quite difficult to model as ordinary uniform shell, where standard analytical flexural wave number description does not apply. An alternative approach is to use Periodic module, which enables to model complex FE cell that repeats itself in two directions to form the complete panel. FE cell could also contain damping layers, or constrained layer damping all described by FE elements, where combined damping will be calculated as one of the Periodic module results.

Whole driver's car contains approximately 30 different complex sections, which has been described by periodic FE cells in term of Modal densities, Radiation efficiencies and combined damping. These results has been re-scaled based on the original SEA panel size and overridden in the full SEA model on panel level and also on junctions level.

For calculation time speed-up purposes, sensitivity analyses on FE cell size has been performed. It turns out that triangle like FE cell gives reasonable results compared to bigger FE cell size, where mainly TL and modal densities has been compared between the cases. Speed-up of factor 4 has been observed.

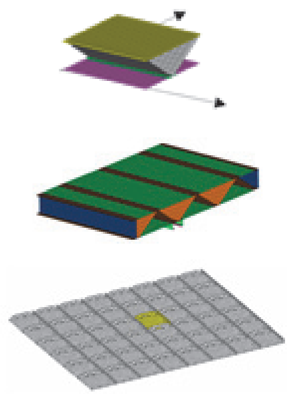


Figure 2: Periodic FE cell

Modeling of the interior trim panels and floor

Interior trim panels are composed from various sandwich panels. One of them was sandwich with honeycomb core made from Nomex paper. Also for this case Periodic module has been used to calculate TL and use that as a base for equivalent SEA sandwich property estimates.

Another major component in the train is the floating floor, which is mounted on flexible supports. In early design stage, acoustic performance of several types of floating floor of various thicknesses have been compared against each other. In this case, Transmission Loss (TL) was not the major indicator, since most of the vibrational energy was transmitted structurally through the supports. For such scenario bending stiffness and damping are the most important factors. Performance has been evaluated using worst case scenarios. Unit type loading, standard practice, will not give right indications.

At this stage of the model also acoustic-fire protection has been installed between the base structure and Trim panels and between base structure and the floating floor.

Seats and internal doors

In driver's car there are four types of seats: fixed and convertible second class seats, first class seats and driver's seat as shown on (figure 4).

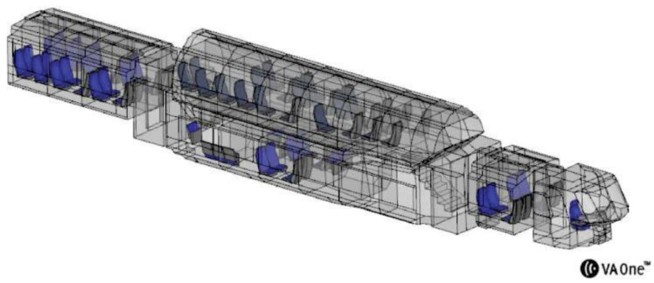


Figure 4: Seats arrangements in Driver's car

Second class seats and driver's seats have textile finish and first class seats are made from leather. Acoustic properties of seats composition, has been measured in impedance tube (figure 5). Interior sectors are connected via interior doors, which includes also ventilation grill to allow air flow, so the noise flow between different sectors.

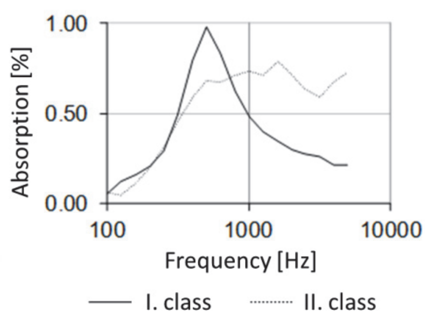


Figure 5: Measured sets absorption

External field around the car has been also modeled, to allow energy partially distribute around the structure.

Acoustic loads

As mentioned earlier, two operational modes has been considered as the most critical.

First scenario is related with the noise generated at train maximum operating velocity 189km/h (Figure 6). At higher train velocities a wheel/rail noise becoming one of the most dominant noise sources. This noise has been described as power spectra introduced into the SEA bogie cavities (figure 6). It has been calculated in different project.

Second important noise source is related with air flow around the car body structure, which is also called Turbulent Boundary Layer (TBL). Such acoustic load is applied on each individual external body panel including windows.

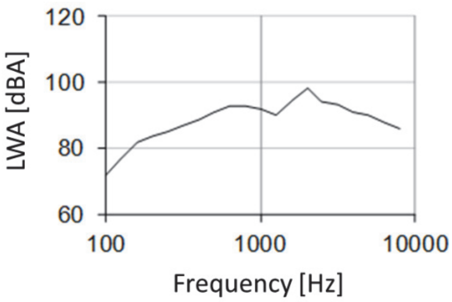


Figure 6: Acoustic power spectra used as Wheel/Rail

Second scenario is related with horn noise simulation, where train is in parking mode and train horns are ON (warning systems test). Horns has to fulfill prescribed noise level at 25m from the tip of the train (as specified in EN 15153-2 [6], Figure 7) and on the other hand interior nose level inside the driver cabin should not exceed noise limits. Unfortunately measured acoustic power radiated by the horns was not available and basic back calculation based on SPL was leading to unrealistic power estimates.

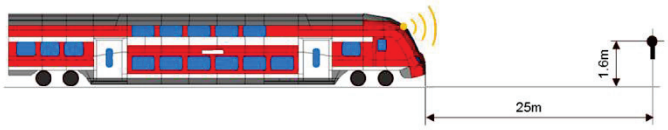


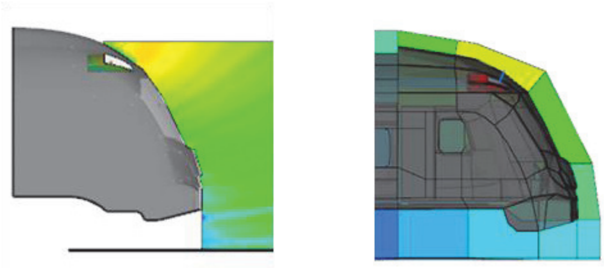
Figure 7: Schematic description of horn noise

Acoustic power of highly directive noise source was necessary to back calculate using deterministic method. For this purpose, Boundary Element Method (BEM) has been chosen. Portion of the train noise geometry has been model to ensure correct diffraction around the cabin as well as detailed geometry of both horns with horn pockets. Model has been finalized with the semi reflective ground. Acoustic monopole of certain strength has been placed inside the horn and tuned to match 25m noise level.

Once the noise levels at 25m from the train satisfied condition of (105 dBA), horn power has been estimated and placed as Power spectra inside SEA model.

Figure 8: Noise level distribution up to 25m

Comparison between BEM and SEA near field are shown on (figure 9), where both use the same contour scale limits.



a b

Figure 9: Near field noise distribution (a) SEA vs. (b) BEM

Analyses and Results

It is important to mention that all conclusions are model dependent and cannot be generalized to all train car bodies. Results are strongly related to input data and train body construction including assumed leakage between different parts and compartments.

Interior noise distribution at 160km/h

Interior noise level has been solved for train moving with constant velocity, for which wheel/rail noise generated at v=160km/h was available at a time. Model has been also loaded with TBL on each exterior panel. Final interior sound pressure distribution is indicated on (Figure 10).

The highest noise level has been estimated at entrance areas, followed by driver cabin and then by noise in first floor. Noise levels did not exceed required noise limits by customer. Noise levels has been also compared to measured values from the train of similar construction, what shows very similar noise distribution.

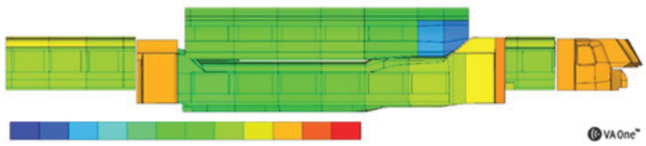


Figure 10: Interior Sound Pressure level distribution at 160 km/h, range of scale: 12dB

Interior noise distribution due to horn noise

SEA model has been loaded by estimated power radiated from the horns as described earlier in this paper. Final Noise levels distribution are shown on (Figure 11).

The highest noise level, as expected, has been estimated in driver's cabin.

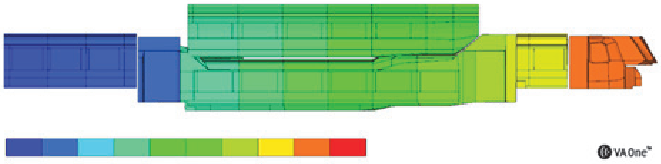


Figure 11: Interior Sound Pressure level distribution due to horn noise, range of scale: 50dB

Sensitivity analyses

On top of the above simulations, several sensitivity analyses has been performed.

One of them has been related with expected increase of the interior noise level due to increase of train velocity from 160km/h to 189km/h. Based on this analyses it has been estimated 4dB noise level increase in the second floor, where noise levels are more effected by TBL flow rather than wheel/rail noise.

Another sensitivity analyses was related with influence of the sprayable damping layer on train body, which may add 1-4 dB depending on extruded panel type. By changing the stiffness of damping layer, it is possible to improve Transmission Loss of the panel.

It has been estimated that by improving the windows, it may be observed improvement up to 2dB in the ideal case, when windows are assumed ideally rigid -> no energy transmission at all.

Energy transfer path analyses

In **lower frequencies** around 500Hz – 700Hz:

- most of the energy entering the interior is related with windows mass law transmission. In entrance area, door construction contributes the most on noise levels.

In **mid frequencies** around 1000Hz, the primary mechanism of the energy transfer:

- **area above the bogies**, is related with bogie noise, which cause vibration of the main body. Then from there it goes through flexible floating floor supports into the floating floor. After then energy is radiated into the interior. Same mechanism of transmission has been evaluated also is in entrance door area.
- **Noise in train middle section** is influenced by the noise of close by cavities directly connected with entrance door area by the corridor doors.

In **higher frequencies** above 2000Hz:

- the mechanism in first floor is similar to middle frequencies, but in the second floor (first class compartment) radiation of the trim panels becoming more dominant above all. Thus structural connections of Trim panels to base structure are important energy path.

Future plans

Results of this study will be compared with measurement, which will be performed on full train-set

Acknowledge

This work was published with kind agreement of Škoda Vagónka.

This work was supported by the project TE01020038 „Rail car competence center“ from a program of Technology agency of Czech Republic.

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