

Using Statistical Energy Analysis to support Interior Noise Reduction for a Metro Rail Vehicle

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Problem statement

Subways play significant role in city's life. Lots of people spend time in metro trains on their way to work or home. Recently, as a fact of rising living standards, the number of people's complaints about the noise level are increasing. Thus, reducing railway noise is necessary in order to improve rail transportation and by that improve passenger's comfort and sustainability.

Railways, especially subways, will never be silent, although, it is nonetheless of great significance to reduce their noise and vibration as much as reasonably achievable. It is well-known, that in a subway from time to time passengers are exposed to extremely high noise levels, sufficient to prevent conversation of any kind, during trip through the tunnels. The primary purpose of reducing vehicle noise is to produce a reasonably pleasant environment for passengers, allow conversation with normal vocal effort, and reduce overall passengers and driver noise exposure.



Figure 1: Metro in Saint-Petersburg

Preliminary measurements

The key point is to identify the main noise generators during vehicle operation:

- Noise coming from vehicle equipment (motor, compressor, ventilation, etc...)
- Rolling noise (wheel/rail noise that has a broadband frequency spectrum, often with a broad peak between 250 and 2000 Hz)
- Aerodynamic noise (not significant at 60km/h)
- Structure-borne excitation from the bogie

On the preliminary trials it was not possible to separate Rolling noise and Aerodynamic noise. Individual measurements of devices generating the noise in controlled environment were not available.

The only option was to switch on/off different vehicle equipment's in various combinations during the interior Sound Pressure Level (SPL) measurement. As shown on [Figure 2](#), interior noise level has not been changing by greater amount, where Projects 047 and 048 represents all wagon equipment is ON and Project 058 represents all wagon equipment is OFF.

Different operating modes did not help to identify any critical equipment which may contribute to high noise levels. Thus rolling noise has been assumed as the main interior noise contributor.

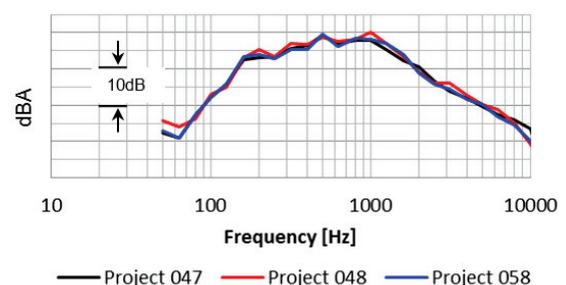


Figure 2. Measured Sound Pressure level based on different operating modes

SEA modeling

The objective of the study was to create a model which covers Frequency range from 100Hz to 8kHz and is suitable for Sound Pressure levels estimates based on Air-borne excitations.

Structural part: As discussed in the measurement section it was difficult to establish how the energy gets into the interior, since the noise in the tunnel is well diffused around the car body and may get through in any location. From this view, it was necessary to model whole car body not to miss weak spots. During SEA model creation it was decided to include also main frame of the structure, modeled with SEA beams as shown in [Figure 3](#). The frames can transmit significant structure-borne noise within the vehicle.

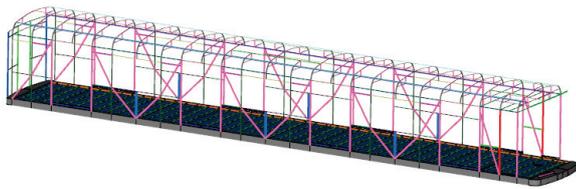


Figure 3: Main frame structure

Usually floor is often the most critical component in rail vehicles, since it is in direct contact with the noisiest areas around the bogie compared to other panels. For the rail vehicle operating in the tunnel noise becomes more uniformly distributed around the car body and situation is slightly different. Floating floor (shown on Figure 4) made from plywood sits on rubber glued on the cross-members which are welded with the corrugated floor covered with acoustic treatment.

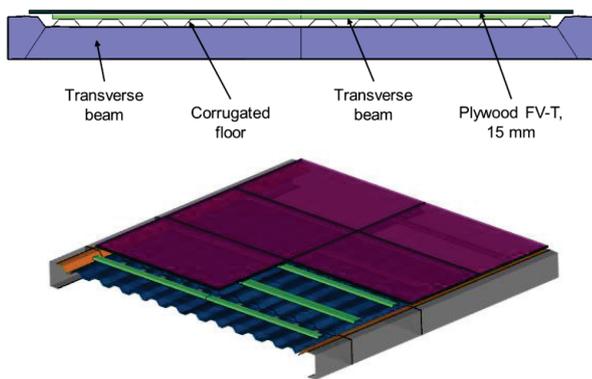


Figure 4: Floating floor arrangement

External panels are made from Aluminum and had been modeled using Sandwich properties (soft core between thin skin material), where core material properties have been evaluated using FE cell and periodic boundary conditions (using Periodic module).



Figure 5: External Aluminum profile panels

Further Interior panels and seats have been added to complement structural part of the model. Typically seats are not structurally connected with the main frame and their vibrations levels are out of interest, but they may increase interior absorption. Model also contains leaks around the doors and some additional leakage inside the interior.

Tunnel: When modeling car exterior, it was necessary to model tunnel cavities in which acoustic energy can freely

propagate around the car body and form diffuse acoustic field. For these purpose different sets of cavities have been created. First set represents near field in close proximity to the structure, second sets represents mid-field and finally connections with Semi Infinite Fluids (SIFs), which represents energy sinks or in other words infinite tunnel.

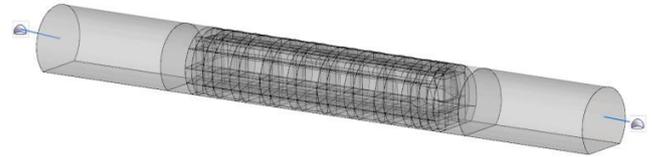


Figure 6: Tunnel modeling

Loading condition

The aim of the study was to investigate sound pressure level (SPL) at 60km/h and perform acoustic optimization based on real SPL envelope and levels. Simulation assumed 3 acoustic loads:

- Rolling noise / exterior noise
- Ventilation noise in driver cabin
- Ventilation noise in passengers saloon

Ventilation noise has been calculated from the measured SPL at 0km/h with ventilation on and off. SEA model has been constrained at several locations with measured Pressure and required Power input (Pin) has been evaluated. The difference between the Pin of 2 modes has been assumed to be acoustic power coming from the ventilation.

For the exterior noise, the idea was to back calculate required Acoustic Power in bogie cavities to match measured interior SPL with ventilation on. Finally use all back calculated acoustic power as the loading for all other consequent analyses.

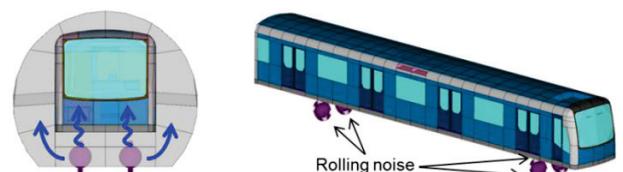


Figure 7: Rolling noise modeling

Figure 8 shows comparisons between measured and calculated interior SPL in the saloon. It can be seen from the measured data, that noise right above the bogie is approx. 2dB higher then noise in the middle of the saloon. Same trend has been captured via simulation.

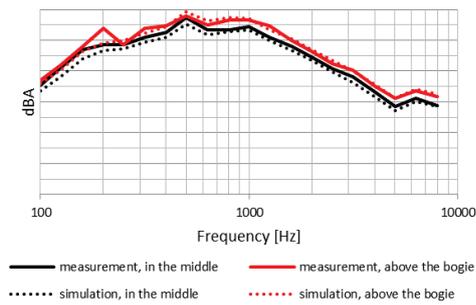


Figure 8: Saloon Sound Pressure level at v=60kmph

Figure 9 displays the comparison of the SPL in the driver cabin, where both Simulation and Measurement shows stronger influence of the ventilation above 1kHz. At this stage, noise coming from the ventilation has not been assumed as critical.

In general, Sound Pressure Levels prediction in Saloon and Cabin showed reasonably good agreement and has been assumed as qualitative enough for further optimization.

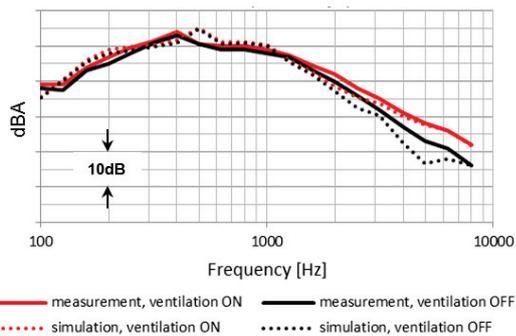


Figure 9: Cabin Sound Pressure level v=60kmph

Sensitivity analyses

Initially focus has been done on sliding door sealing, which has been expected as design change already in the model building phase. From technical point of view, sealing of the sliding doors, represents demanding challenge for designer.

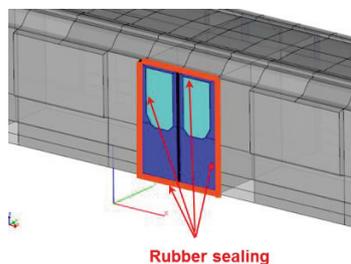


Figure 10: Entry door sealing

Noise in the saloon has been reduced by introduction of the rubber sealing around the doors, which covers the leakage between the doors and car body.

The second most obvious modification was to change windows properties since they occupy fairly big area. One of the options if such modification will lead to an improvement is to fully block the energy through the windows (numerical masking). This could be done by simple disabling the area junctions related with all windows and estimate theoretical limit.

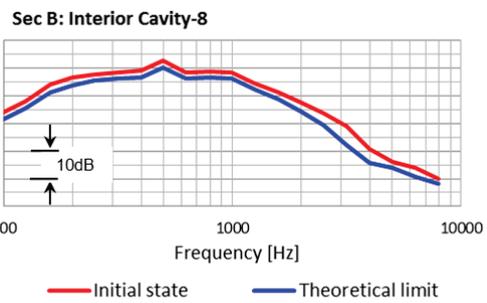
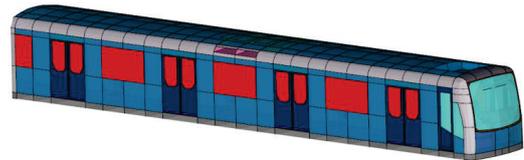


Figure 11: Windows influence on overall levels

It turns out that such modification can bring up to 2.5dB improvement in Overall Levels, so new windows had been chosen to fulfil cost / mass / TL requirements.

Next positive improvement has been done by changing acoustic insulation of the external skin from inside, where PUR Foam with closed porous has been substituted with Insulation made from fiber layer and thin Aluminum foil.

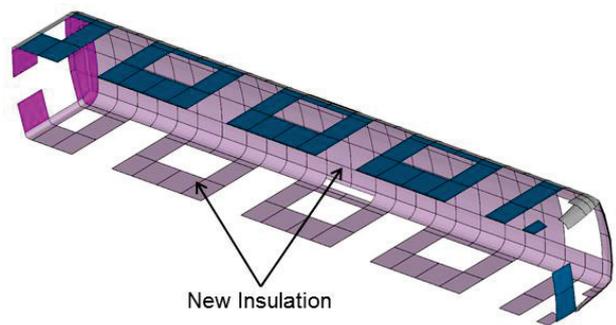


Figure 12: Position of the acoustic Insulation

Additional Improvement has been achieved by addition of heavy layer into new acoustic insulation, which helps to improve Insertion Loss (IL) of the trim, but also it improves damping of the base panels.

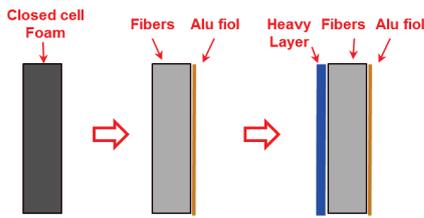


Figure 13: Acoustic Insulation development

Though **Driver cabin** is separated from the saloon cavities by the door and wall, all above design changes also affected the noise in driver cabin. Unfortunately noise reduction has not been as good as was in saloon. As shown on Figure 14 most of the noise in the cabin comes from the exterior noise (black line) through the windshield, where Total represents sound pressure level in the cabin. During the optimization, SPL has been decreased to certain level and then noise coming from the ventilation becomes to have more influence on cabin interior noise.

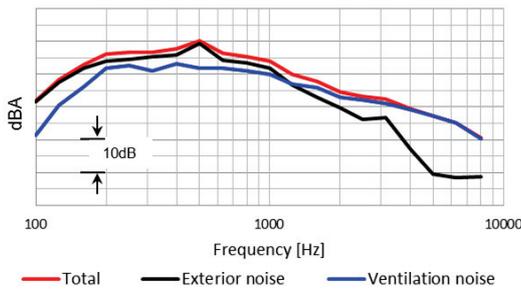


Figure 14: Influence of loading on Cabin Sound Pressure level

Sound pressure level evolution summary

Metro car body has been split into several sectors for better orientation. Noise levels have been primarily estimated in the widows/seating area and driver cabin has been kept as one big cavity.

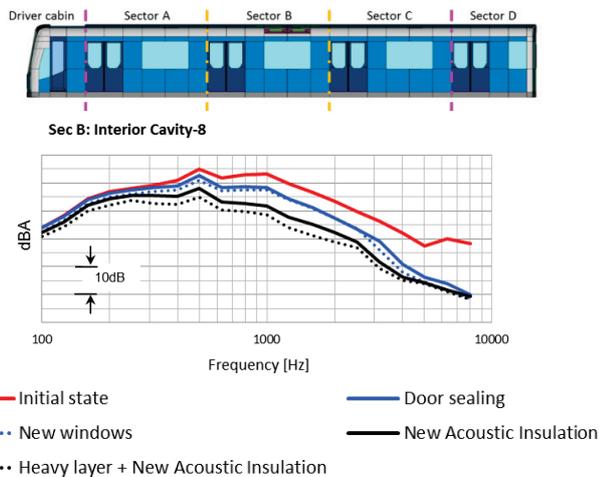


Figure 15: Sound Pressure level evolution

Table 1: Results summary

Interior Noise improvements	Leq [dB(A)]				
	Reference (initial state)				
Reference (initial state)	x	x	x	x	x
New Door sealing		x	x	x	x
New Windows			x	x	x
New Acoustic Insulation				x	
Heavy layer + New Acoustic Insulation					x
Cabin	ref.	-0.4	-1.7	-2.9	-3.3
Sec A: Interior Cavity-7	ref.	-3.0	-4.4	-7.2	-10.1
Sec B: Interior Cavity-8	ref.	-2.9	-4.2	-7.0	-9.7
Sec C: Interior Cavity-8	ref.	-2.3	-3.9	-6.4	-9.2

As shown in table above noise level in the saloon is possible to reduce approx. by 9-10dB in overall levels based on the position in the car.

Conclusion and future plans

SEA model has been developed based on the metro vehicle construction and measurement data. The primary model was adapted to represent the current situation with the interior noise level. Then, step by step, almost every part of the body shell was improved from noise insulation/absorption point of view, taking into consideration cost, weight, practicality, and safety. Finally, the significant 10dB reduction of interior noise was achieved.

The vehicle construction which would incorporate all the body shell changes gained by the final SEA model has not been produced yet. Although, solutions mentioned above are planned to apply in the foreseeable future in order to increase passengers' comfort.

References

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