Pantograph noise measurements in Madrid-Sevilla high speed train (AVE)

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ABSTRACT: Ten years ago, the first Spanish high speed line which traveled from Madrid to Sevilla at an average speed of 250 km/h was inaugurated. At this speed pantograph noise, which is of an aerodynamic nature, is thought to have rather influence in the passengers zone. However, pantograph contribution is often omitted since main noise sources are expected to come from wheels and devices placed under the floor (motors, engines, compressors, etc). According to this, special anti-noise treatments are designed for floor structures achieving high noise insulation levels. Then, not expected noise contributions from the pantograph become significant.

This paper is aimed at evaluating whether is necessary to apply anti-noise measures on the roof structure or not, by using the vibro-acoustical description of all car's elements, and the measured pantograph sound power level as the inputs of a SEA model. Firstly, two microphone arrays had been used for the measurement, one of them having optimum microphone spacing to achieve best resolution at low frequency octave bands, and the other one to get best performance at high frequency octave bands, covering a global range of frequencies between 500 Hz and 4000 Hz. And finally, SEA model revealed the need of reinforcing roof insulation.

1. INTRODUCTION

Although pantographs are often disregarded as noise sources in the railway sector, they might become of importance while traveling at speeds about 300 km/h. Moreover, a weak roof structure may lead to significant levels of annoyance in the passenger's zone. To decide whether this structure should be reinforced or not is the aim of the measurements and calculations expounded in this paper.
First of all, a measuring session, in which two microphone arrays were used, was carried out in order to isolate pantograph noise contribution from the noise contribution of all other train elements. It's important to empathize that locating each of the train noisy components was not the goal, but only to determine pantograph contribution. It means that, as no other source exists at the pantograph height, the purpose was vertical source location and so a linear placement of the array's microphones was enough.

2. PANTHOGRAPH NOISE MEASUREMENTS

Noise measurements were carried out in Madrid-Sevilla high speed train line in order to evaluate the pantograph sound pressure level for a new range of vehicles. Figure 1 (a) shows this new train units and figure 1 (b) shows a detailed view of its pantograph.

Figure1 (a): *Measured AVE units.* (b) *Detailed view of the pantograph*

Measurements were made using two microphone arrays, one of them having optimum microphone spacing to achieve best resolution at low frequency octave bands, and the other one was conceived to get best performance at high frequency octave bands, so frequencies ranging from 500 Hz to 4000 KHz were covered. Post processing applied to the acquired data is based in a double Fourier transform to calculate the wave-number frequency spectrum of the field, which provides information about wave direction of propagation.

2.1 Experimental setup

Evaluate pantograph contribution is the same as evaluate the sound pressure level from the waves propagating from its position. As there is no other noise focus at this height of the train, azimuth angle of incidence is the defining coordinate of pantograph noise so a one-dimensional array is enough to isolate it. Two eight microphones sparse arrays are used. Sparse arrays are those laid out on an underlying regular gird (a set of points separated by a fundamental spacing d), but all locations of the equiespaced gird are not available: sensors are placed in the gird locations that ensure that the separation distances (the distance between each pair of sensors) take on as many different contiguous values as possible. This kind of arrays are preferred because with the same number of microphones the spatial extent (and so the resolution) is greater for a sparse array than for a filled array, which is the one that has microphones in all gird points. Given eight microphones the distribution scheme that provides maximum spatial extent is [0,1,2,11,15,18,21,23].d [1], where the numbers in brackets refer to the microphone positions in the gird. The fundamental spacing for each array is chosen taking into account the maximum frequency of the range in order to avoid spatial aliasing, thus for the array ranging from 500 to 1000 Hz fundamental spacing d equals 0,15m, and for the array ranging from 2000 to 4000 Hz fundamental spacing is d = 0,03 m .Both arrays, whose microphones were merged, were placed 10 meters far from the railway held by a crane as can be seen in the figure below:

Figure 2: *Experimental setup.*

2.2 Processing

Checking the temporal recording, train pass-by interval can be easily identified and isolated [2], as shown in figure 3, to be processed.

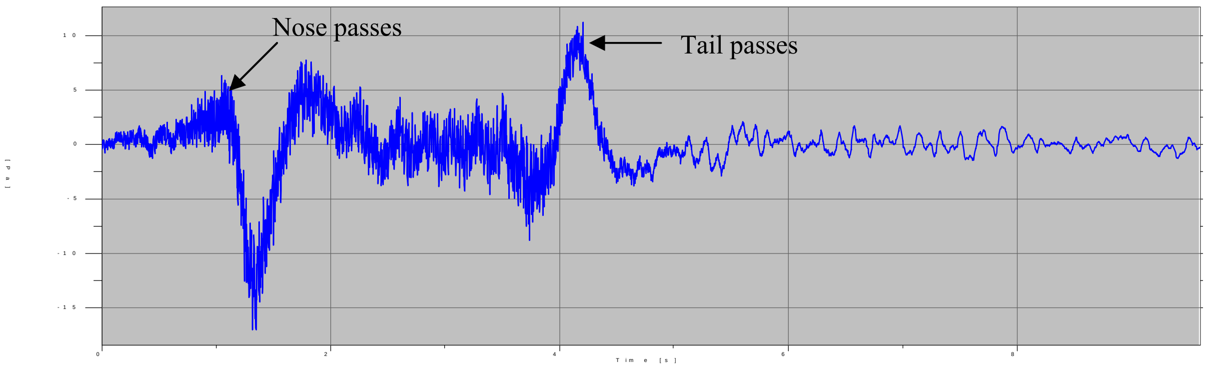

Figure 3: *Passing train pressure history*

Notice that no pantograph shape can be inferred from the temporal history. Thus, further processing is required in order to evaluate its contribution to overall noise.
Firstly, data recorded during the train passing interval has been truncated in blocks of 0,01 seconds, meaning that about 0,7 meters of train length has passed in front of the array.
Secondly, for each of these blocks, a double Fourier transform has been performed in order to obtain the wave number-frequency spectrum of the field [3], which provides information about wave direction of propagation. In figure 4 α represents the incidence angle of the sound wave coming from the pantograph, which impinges on the array. Figure 5 shows how, in a wave number-frequency spectra, every sound wave energy is projected on a straight line through the origin with a slope of tan β, which is related to its direction of propagation.

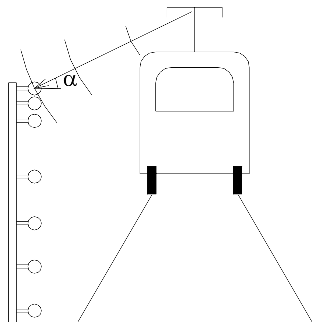

Figure 4: *Incidence angle of a wave impinging on the array*

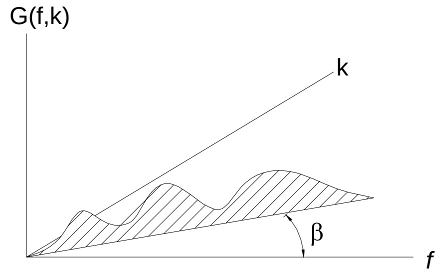

Figure 5: *Wave number-frequency spectrum*

The relation between α (the incidence angle) and β (the slope of the projection) is given by:

$$\tan\beta = \sin\alpha / c \qquad (1)$$

This is due to the relation between the frequency of the signal and the array's estimation of its wave number:

$$k = f \sin\alpha / c \qquad (2)$$

As said before, a double Fourier transform has been applied to the data in order to obtain the acoustical field decomposition according to the direction of propagation of every wave. Known the distance from the array to the railway and the dimensions of the train, it's easy to infer the angular range which the pantograph is found in. This information is need in order to add up all the noise coming from this range of angles and to assign the result of this calculation to the pantograph. Figure 6 shows the angular placement of each source.

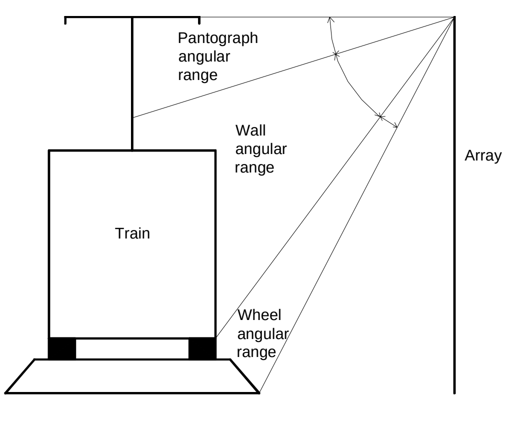

Figure 6: *Angular placement of the train sources.*

Finally, three time histories has been obtained, one for each group of sources: pantograph, wall (including aerodynamic noise generated in the train's frame), and wheel (including all sources placed under the train's floor). They show the individual noise contribution of each source for a train length of 0,7 meters.

3. MEASUREMENT RESULTS

As this paper is focused in pantograph noise, only the results obtained for this source will be discussed. A significant numbers of trains riding at operation conditions has been measured, processed and compared to come to the following conclusions. For instance, figure 7 shows pantograph noise history obtained as described before. The blue line is for a train having the pantograph on the last coach, and the pink one refers to a train which has the pantograph in the front and an extra coach at the end (making this curve longer). It can be noticed that the blue line rapidly decreases after the first peak while the pink one remains; this is because of the presence of the pantograph over the engine for the pink line. In contrast, the blue plot increases abruptly at the end, showing, before the tail passes, a sharp peak that can't be found in the pink line, this is due to the presence of the pantograph in the last coach. Once the pantograph shape has been identified, its sound power level value can be inferred from the maximum pressure level of the peak, assuming that the pantograph acts like an aerial punctual source. Is also assumed that in the moment when the maximum occurs, the pantograph stayed in front of the array, and so the distance between them (r) was the same that existed between the array and the railway. Given the block size used in processing, in the case that this assumption is not verified it will not influence the sound power level estimate, which is about 128 dB.

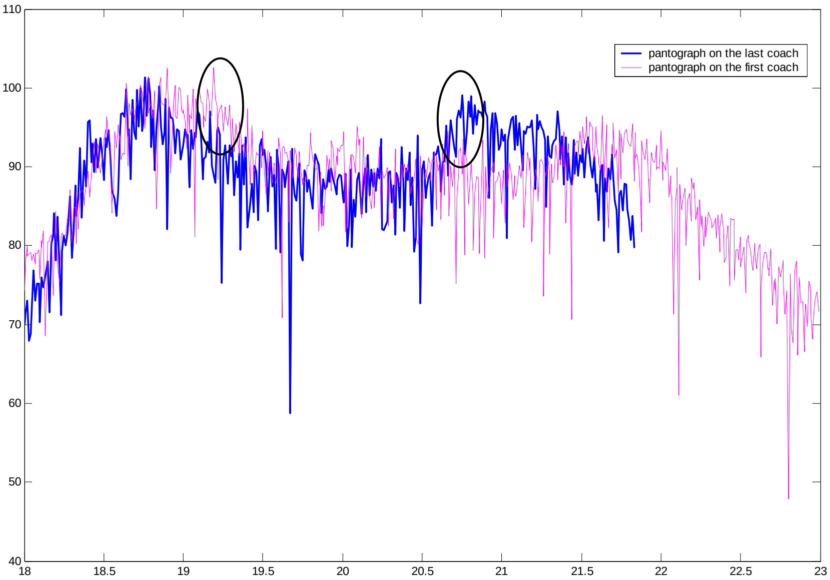

Figure 7: *Pantograph noise level histories*

4. MODELLING RESULTS

Afterwards, the sound power level value has been used as an input for a SEA model which also included vibro-acoustical characterization of the train elements [4]. Figure 8 shows the results of SEA modeling, it reveals that in the passengers zone under the pantograph this become the main source although it is not of the same importance along the rest of the train. As a consequence of the fact that the pantograph becomes the main source on its influence area, it was agreed with the train builder to reinforce the acoustical insulation of the roof with additional barrier/absorbent layers in the surroundings of the pantograph zone, in order to keep the estimated noise levels within specifications in this specific zone.

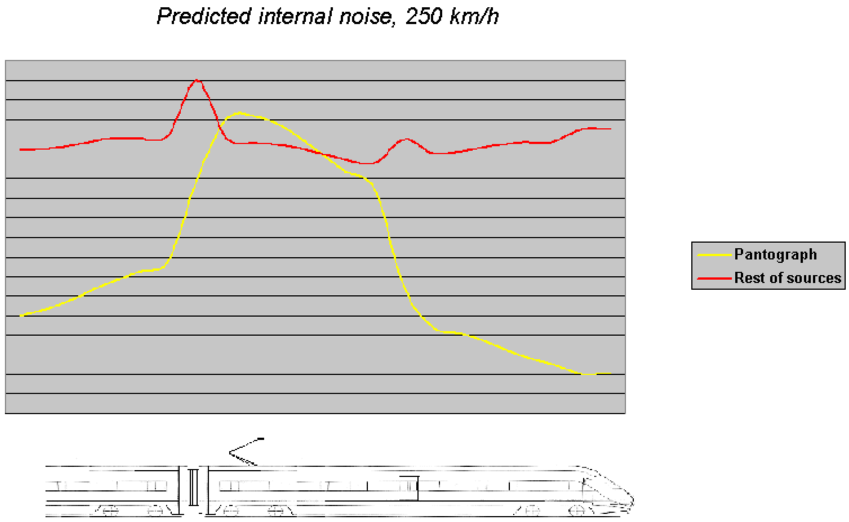

Figure 8: *SEA modeling results*

Several different alternatives to enhance roof insulation were considered. For each of them, new estimations for the improved roof acoustical insulation were introduced in the model and the results obtained were compared with the allowed threshold level. The solution which was finally implemented consisted of roof insulation reinforcement in a reduced area under the pantograph. The dimensions of this area are those that reduce pantograph noise level until it has no influence on the global noise level. The results are showed in the figure 9.

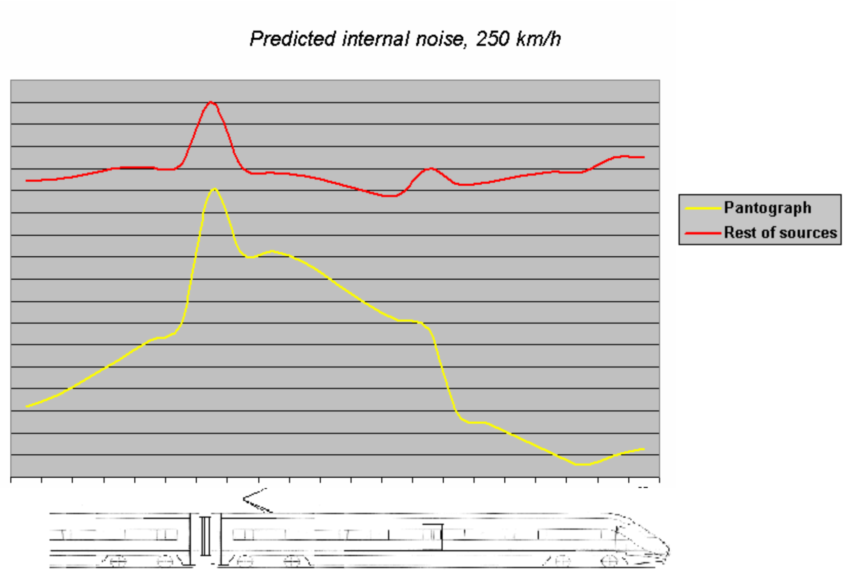

Figure 9: *On the SEA modeling results reinforcing the roof insulation.*

The yellow line shows the evolution of the sound pressure level caused by the pantograph along the train, the red one shows the same for the rest of the sources. Actually, most of the sources of this train are placed under the floor; this is why the red line remains the same after reinforcing the roof insulation. An explanation for such sharp peak in the bellow area, caused by the rest of sources, is that this zone is isolated from the previous and the following coaches by doors which attenuate the sound propagation into the train. Also exterior doors can be identified as a weak point of the train structure. However, pantograph influence is found mainly (fig.8) surrounding the pantograph placement, this is why a local treatment of the roof has been suspected to success.

Figure 9 shows that the pantograph noise level along the coach is significantly reduced applying a roof insulation treatment, except for the bellow zone, where the roof treatment obviously has no influence, and the pantograph contribution remains the same.

5.CONCLUSIONS

At high speed pantograph noise, which is of an aerodynamic nature, is proved affect passengers acoustic comfort, because it became soon evident from the predictions that pantograph noise could have locally a significant impact on the overall noise level in the passengers zone. This was due not only to the acoustic power expected for that source (in fact, its estimated power values were lower than those expected for the rolling noise), but mainly to the acoustical weakness of the roof structure.

Pantograph noise contribution in its nearness can be eradicated by reinforcing the roof insulation, and this has not to be done all along the train but only in a well dimensioned area under this source. By doing this pantograph contribution can be reduced until having no influence in the global noise caused mainly by the sources placed under the floor.

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REFERENCES

[1] Darel A. Linebarger and Ioannis G. Tollis " *Difference bases and sparse sensor arrays*" IEEE Transactions on information theory, VOL.39,Nº 2,March 1993.
[2] Robert A. MacNeil, Samuel Holmes and Harvey s. Lee " *Measurement of the aerodynamic pressures produced by passing trains*" Proceedings of the 2002 ASME/IEEE Joint Rail Conference Washington, DC.
[3] M.M. Boone 1987 Ph.D thesis, Delft University of Technology."*Design and development of a synthetic acoustic antenna for highly directional sound measurements".*
[4] G. Alarcón and J. Palmiola " *An application of the statistical energy analysis (SEA) to the internal noise prediction in trains*" Proceedings of Forum Acusticum, Sevilla 2002.
[5] J.D van der Toorn, H. Hendriks and T.C van den Dool "*Measuring TGV source strength wuth SYNTACAN*" Journal of Sound and vibration (1996) vol (1), 113-121
[6] A.M Mast and M.M Boone "*An experimental microphone antenna array for measuring aircraft noise*"Proceedings of Internoise 2001.
[7] T.C van den Dool and M.M Boone " *Microphone T-array technology for moving noise source measurement*" Proceedings of Internoise 2000.
[8] Don H. Johnson and Dan E. Dudgeon "*Array signal Processing*" Prentice Hall (1993).
[9] Lyon R. H. "*Statistical Energy Analysis of Dynamical Systems: Theory and Applications*". MIT Press, 1975.
[10] Kamisnky C., Unglenieks R." *Statistical Energy Analysis of Noise and vibration from an Automotive Engine*". SAE Paper 971975, 1997.
[11] Parrett A.V., Hicks J., Burton T.E., Hermans L. "*Statistical Energy Analysis of Airborne and Structure-Borne Automobile Interior Noise*". SAE Paper 971970, 1997.
[12] Tsujiuchi N., Koizumi T., Kubomoto I., Ishida E. "*Prediction of Noise Level for Tractor Cabin Using Statistical Energy Analysis*". The 29th International congress and Exhibition on Noise control Engineering, 2000.