Pass-by noise assessment of high speed units by means of acoustic measurements in a perimeter close to the train

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Abstract. Characterization of rolling stock from the perspective of exterior noise emission is typically carried out by following the technical procedures detailed in the international standard ISO 3095. Whilst this standard can be considered adequate for conventional rolling stock, the advent of very high speed railway transport has introduced a number of challenges in terms of the characterization of noise emission. The most relevant one is the multiplication of noise sources, with the substantial increase in aerodynamic noise emissions from particular zones in the train including: pantograph, pantograph recess, inter-coach gaps, front of train, connection cables, low-level turbulences, high level noise, etc. For example, high level noise has a major influence on the effectiveness of mitigation measures such as noise barriers becoming a contributor to the environmental impact of the train at very high speed. Therefore it is desirable to differentiate between noise sources in order to inform whole-system design and ISO 3095 does not currently provide an appropriate method for addressing this issue. This paper proposes an improved methodology for acoustic characterization that although more difficult than the procedures described in the standard ISO 3095, is not as difficult as acoustical analysis based on microphone arrays.

Keywords: High Speed Railway Noise, Rolling Stock, Measurements.

1 Introduction

1.1 Formulation of the problem

In comparison with the other mode of transports, railway is considered the most environmental friendly. One of the few concerns still associated with the development of a previously existing and/or an entirely new scheme is the social criticisms related to the fears of ambient noise impact.

The European Technical Specification for Interoperability (TSI) [1] provides limits for the acoustics characterization of rolling stock units and track systems, but promoters of schemes (such as HS2) or infrastructure companies need to provide further noise reduction in order to comply with regional noise policies. This is achieved either through specification that delivers a betterment over TSI, or through additional mitigation measures.

One example of this approach can be found in the development of the new high speed railway line High Speed 2 (HS2). The HS2 rolling stock procurement has specified pass-by noise to be as low as possible, establishing an incentivisation regime. This is seeking to achieve the noise predictions in the HS2 Hybrid Bill based on performance of both train and track, which is 3 dB lower than 2008 TSI at 360 km/h [2].

Very high speed railway transport has introduced a number of challenges in terms of characterization of noise emission. The most relevant one is the multiplication of noise sources, with the substantial increase in aerodynamic noise emissions from particular zones including: pantograph, pantograph recess, inter-coach gaps, front of train, connection cables, low-level turbulences, overall roof unevenness, etc.

Two important consequences related with the aerodynamic noise emission are: (i) the aerodynamics of the train’s body that influence the pass-by noise and (ii) the aerodynamics of the upper parts of the train have a major influence on the effectiveness of mitigation measures such as noise barriers.

Evaluation of rolling stock from the perspective of exterior noise emission is typically carried out by measurements according to the procedures detailed in the international standard ISO 3095 [3]. This standard adequately measures the overall noise produced by a trainset but does not allow to evaluate separately the noise coming from the different sources. The latter is important for the whole-system design i.e. mitigation measures can be designed that appropriately address the source emissions.

The absence of standard methodologies for evaluating noise sources at very high speed makes very challenging to setup specific requirement and/or acceptance criteria on aerodynamic noise sources which can be verified with field test.

This paper propose an improved methodology for acoustic characterization that although more difficult than the procedures described in the standard ISO 3095, is not as difficult as acoustical approaches already presented in literature.

1.2 State of the art

In order to design the proposed measurement methodology, several test approaches have been analyzed and summarized in table 1 below, with some pros and cons in terms of being used for the evaluation of noise sources at very high speed.

Table 1. Comparison of the different test approaches

Test Approach	Advantages	Disadvantages
1) Close measurement onboard the train	Concept is easy to understand. Quite objective and not prone to raise objections. Repeatable in different places.	Few precedents [4] [5] Difficult to get permissions from infrastructure manager (IM) and train operator (TO).
2) Close array measurements	Precedents available [6] [7] [8] Provides comparatively more information than others. Quite repeatable in different places.	Requires an elevated number of microphones. Requires complex processing. No standard way to process the data.

		Not so intuitively understandable. Difficult to get permissions from IM.
3) Far field measurements behind a noise barrier	Concept is easy to understand. The barrier will screen the noise coming from the lower part of the train making possible to capture the noise contribution from the higher part. No permission is actually necessary from IM (although it is recommended).	No precedents. Difficult to exactly repeat the test in another place. Easy to understand but potentially objectionable because of specific barrier characteristics and secondary noise captured (diffracted, transmitted).
4) Far field measurements with directional microphones	Concept is relatively easy to understand. No permission is actually necessary from IM (although it is recommended). Comparatively easier to repeat the test (effect of barrier particularities is considerably rejected).	Few precedents [9]. Some detailed calculation required to achieve accurate results (although approximate results are quite straightforward to achieve).

A method easy to understand, repeatable in different places and able to produce results without complex processing would be ideal for the characterization of high speed noise sources. Among the methods in table 1 “close in” approaches seem to assure higher repeatability due to their proximity to the source. Within this category method number 1 could satisfy also the other requirements but it involves the need to get permissions from both IM and TO. Method number 2 might be less onerous in terms of getting permission but it is difficult to understand and requires an extensive data processing and microphones. Due to the issue highlighted from both method number 1 and 2 a novel “close in” measurement approach, more difficult than the procedures described in the standard ISO 3095, has been developed.

2 Methodology

2.1 The requirements

In order to achieve the aims discussed in section 1.2 and in addition to the requirements described in the international standard ISO 3095, this proposed methodology has the following requirements:

- The placement of a number of microphones in a perimeter close to the train. Taking into account safety issues, an existing catenary portal has been proposed for the installation of 6 microphones, as shown in Fig.1 (MIC1 to MIC6). Compared to other possible pre-existing structures (bridges, buildings, etc.) a catenary portal has the advantage of having a small acoustic cross section. This helps in minimizing acoustic reflections that could contaminate the measurements.

- The placement of accelerometers on the rail (see ACC1 and ACC2 in Fig. 1) in order to discriminate rolling noise emissions from the microphone at short distance from the lower part of the train (MIC6 in Fig. 1).
- The complementary use of a low-profile aerodynamic microphone installed in the sleeper (See MIC7 in Fig. 1).

An additional requirement to the methodology is:

- The placement of different microphones to measure noise propagation in the far field up to 300m from the track center, in a free field test site having acoustic conditions comparable to semi-anechoic. Both near and far field measurement sensors are fully time synchronized.

3 Results

3.1 Test site and setup

A suitable test site with a catenary portal frame and free field propagation conditions was found on the Spanish high speed network managed by ADIF, close to the small town of Las Inviernas (Guadalajara, Spain). Commercial traffic at speeds between 250 km/h and 300 km/h was measured over 4 days, covering 4 different types of high speed rolling stock (Alstom TGV, Siemens Velaro E, Talgo 350 and CAF Alvia/ATPRD). Outside of commercial hours, a single dedicated Siemens Velaro E was studied at increasing speeds from 250 km/h to 350 km/h, both with the pantograph raised and lowered. Fig. 1 shows the scheme and view of the sensors installed in the catenary portal and its surroundings, up to 300m, as described in section 2.2.

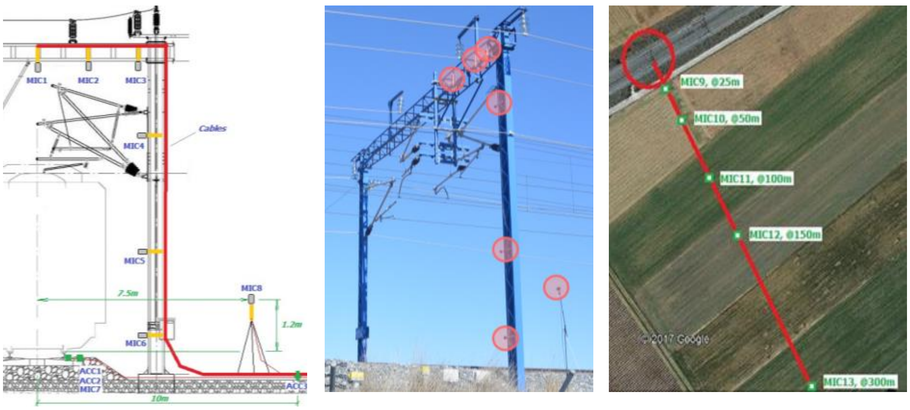

Fig. 1. Scheme and view of the main elements of the test setup.

3.2 Pass-by Measurements

Measurements at pass-by were carried out at different distances according to setup shown in figure 1. Reference measurement points at 7.5m and 25m as specified in European TSI were included. It was observed that for all speeds and rolling stock, noise levels were well below European TSI limits (see Fig. 2). From the results obtained, extrapolation at speeds up to 350 km/h using a logarithm law $50 \cdot log(V/V_{ref})$ has been shown to be reasonable. This extrapolation law (with V_{ref} = 250 km/h) is suggested by European TSI for speeds ranging from 250 km/h to 320 km/h; results obtained in the test show this law can be reliably extended to 350 km/h.

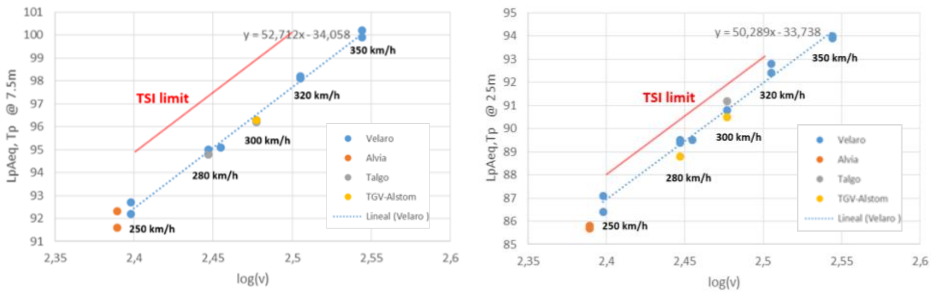

Fig. 2. Pass-by noise results at different speeds compared to TSI, as observed at 7.5m of distance from track center and 1.2m height (left) and 25m from track center and 4m height (right).

3.3 Measurements in the catenary portal

Preliminary results for the measurements in the catenary portal showed a much cleaner definition of the high level noise sources, compared to pass-by measurements. This was observed in all microphones placed above 3m higher than the rolling plane, but was particularly clear in the case of the microphone installed just above the train (MIC1 in figure 1). Fig. 3 (left) shows the increase in noise source discrimination in with respect to usual measurement points at 7.5m and 25m. In the right of Fig. 3, distinct noise signatures and pantograph peak identification for different rolling stock are shown. Fig. 4 (left) shows that the increase in discrimination allows a quite clear identification of high level noise sources. Accurate quantification of pantograph emission was achieved with the pantograph drop-off tests, as shown in Fig. 4 (right).

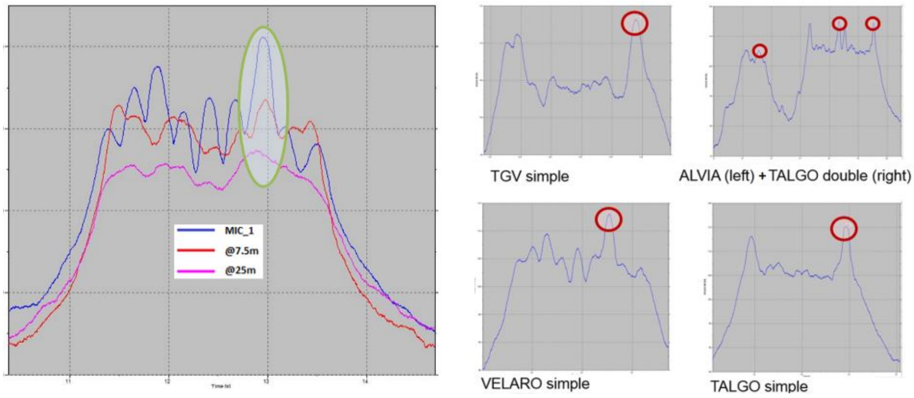

Fig. 3. Left: increase in noise source discrimination in MIC1, compared to usual measurement points at 7.5m and 25m (ISO 3095 / Technical Specification for Interoperability in EU). Right: distinct noise signatures and pantograph peak identification for different rolling stock.

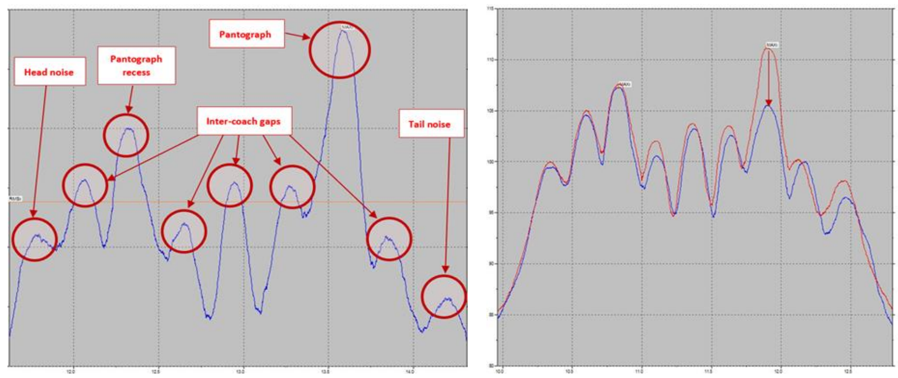

Fig. 4. Left, identification of high level noise sources in a Siemens Velaro E from noise lecture in catenary portal above the train. Right, effect of pantograph drop-off in a Siemens Velaro E running at 350 km/h.

4 Estimation of pantograph noise directivity

From the readings in microphones MIC1 to MIC4 it has been possible to estimate approximate polar patters of noise emission directivity for the pantograph, in the plane perpendicular to the track (see Fig. 5). While being just approximations, they can be used to compare the behavior of different pantograph models at different speeds, and also can be used to estimate differences of noise emission in the directions that are of relevance for each acoustic study. Reference [10] shows details of the methodology followed to estimate these polar patterns.

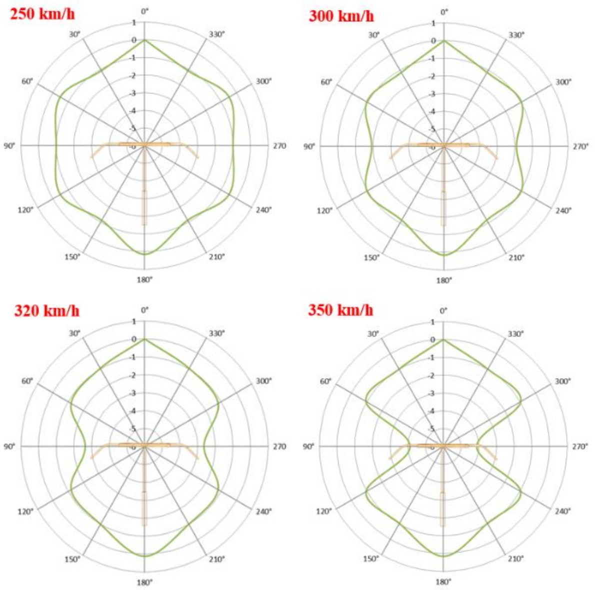

Fig. 5. Evolution of pantograph directivity with speed (Velaro E). Approximate curves obtained from readings in the microphones installed in the portal (see [10]).

5 Conclusions and further work

A new experimental methodology for characterization of high speed rolling stock has been presented. This methodology aims at achieving a more detailed acoustical characterization of high speed trains, without resorting to the use of sophisticated technologies with complicated post-processing (e.g. acoustic holography or beamforming). Preliminary results show promise, being possible to achieve (with a relatively simple setup) a level of noise source discrimination that had only been reached previously by using far more complex approaches. It is considered that with some further development, a consistent and repeatable characterization methodology can be developed from this experience.

Further results are expected from all the data gathered during the test. Particularly, it is expected to combine readings from the accelerometers installed in the rail together with readings in the aerodynamic microphone installed in the sleeper and also readings in the microphone installed in the lower part of the catenary portal (MIC6), in order to discriminate between rolling noise and aerodynamic noise in the lowest parts of the train. Also, the high number of spatial positions where noise recordings have been taken at each pass-by is expected to be used in order to improve acoustical models, in terms of transmission and directivity of the different noise sources involved.

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