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Evolution of pantograph noise directivity at increasing speeds

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ABSTRACT

In February-March 2018 a set of tests were undertaken to confirm the acoustic performance of high speed rolling stock fleets. These tests were carried out on behalf of HS2 on the ADIF high speed network near the village of Las Inviernas (Guadalajara, Spain). The test site was chosen so that three conditions would be fulfilled. First, maximum speed up to 350 km/h ought to be reachable during tests in dedicated mode. Second, a complete catenary arch ought to be present in the site so that it could be used as a support for installation of a number of microphones. Third, a flat and almost levelled terrain with almost semi-anechoic characteristics should be found in the surroundings of the track. Among other tests, the evolution of pantograph noise emission with respect to speed was studied, for the same unit of a dedicated Siemens Velaro E running at different speeds from 250 km/h to 350 km/h. This paper shows the evolution observed in the directivity emission pattern as observed by the microphones installed in the catenary portal. A theoretical discussion about the physical aero-acoustic phenomena justifying the observed evolution is presented together with the experimental results.

Keywords: Noise, Environment, Annoyance
I-INCE Classification of Subject Number: 13

1. INTRODUCTION

Environmental noise from train operations has been and remains a key consideration in the design of the new HS2 railway and its trains. The maximum operating speed of 360 km/h would otherwise result in comparatively high aerodynamic noise emission levels. This is especially relevant taking into account that many of the most relevant aerodynamic noise sources are placed at a high level in the trainsets, which makes them more difficult to mitigate by means of noise barriers. Being particularly intense at high speed, aerodynamic noise coming from pantograph has drawn the interest of technical community [8-10].

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2. BACKGROUND

2.1 Railway aerodynamic noise

With the development of high-speed rail transportation, systematic research on this noise type has been carried out since the early 1990s, mainly within the framework of German-French cooperation [5]. This research, mainly based on microphone array investigations and also wind tunnel studies combined with numerical simulations, has provided a better understanding of the characteristics of this noise type [5-17]. The most important aerodynamic noise sources in a high speed railway were found to be scattered fluid sound around the bogies, vortex shedding from the pantograph and wake eddies at the train rear. Turbulence noise radiated from the inter-coach areas of a train also played a role, but comparatively smaller. During the European project *Harmonoise*, a preliminary directivity estimation for various aerodynamic sources was proposed [5]. While pantograph was being treated separately, all aerodynamic noise sub-sources were assigned a typical directivity pattern according to the following expression:

$$5 \cdot \ln[\sin(\phi + \pi / 2)] \quad Eq. 1$$

where the horizontal angle, φ, is defined as shown in Fig. 2.1.1.

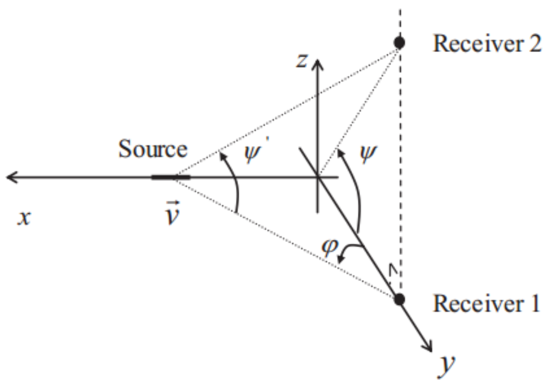


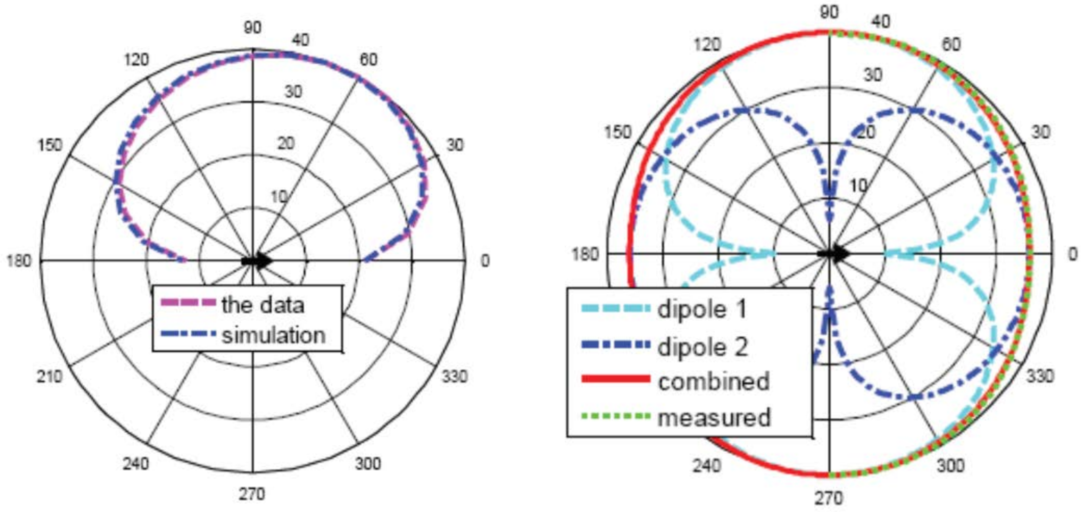
Fig. 2.1.1. The definition of angles: φ is a horizontal angle in the x-y plane and relative to the y-axis; ψ is a vertical angle in the y-z plane; ψ' is a vertical angle in a vertical plane containing the receiver and the source (or the centre of the source line)

2.2 Pantograph noise

First estimations of pantograph noise directivity carried out in the frame of the European project *Harmonoise* were expressed as a set of directivity data of pantograph noise is provided in tabular values. These data showed a dipole directivity character in the horizontal direction (also proved by X.Zhang in [1]) and a slightly directional nature in the vertical direction, whose emissions were estimated to be 4 dB higher than in the lateral direction.

Zhang in [1] presents a discussion of the physics behind the phenomenon. Pantograph noise would be mainly caused by the vortex-induced vibration (VIV) which under certain conditions can cause Aeolian sound if the frequency of vortex shedding matches the resonance frequency of the structure [14]. Since Aeolian sound is a dipole source [15] with an orientation transverse to the flow and the sliding bow, the VIV sound would be also a dipole source of vertical orientation. To explain observed characteristics of horizontal directivity, Zhang assumes the presence of an additional dipole source with lateral orientation. Actual orientation of this second dipole source is assumed by Zhang to be perpendicular to the dipole source of the first VIV sound, thus configuring a Perpendicular Dipole Pair aerodynamic noise source (PDP). The origin of the second dipole source perpendicular to the main vertical VIV dipole remains unclear; a possible interaction between the air flow and the two end parts of the sliding bow is suggested by Zhang [1]. This interaction would induce a lateral vibration, compared with the lift force on the middle part of the sliding bow where the first VIV sound is induced. Another possible explanation would be that the total VIV contains comparable vertical and lateral components due to the shape of the sliding bow of a pantograph.

The Perpendicular Dipole Pair (PDP) theory for pantograph noise seems to be consistent with experimental measurements to date [1]. By assuming that the vertical component of the VIV sound is about 4 dB stronger than the lateral component, the vertical longitudinal directivity can be re-produced as shown in Fig. 2.2.1(b), with a good agreement with test data.



(a) (b)

Fig 2.2.1: (a) The measured horizontal directivity of pantograph noise [16] compared with the simulation directivity function as formulated by Zhang in [1]. (b) The measured vertical (longitudinal) directivity of pantograph noise compared with the simulation of a Perpendicular Dipole Pair of which the dipole with lateral orientation is 4 dB weaker.

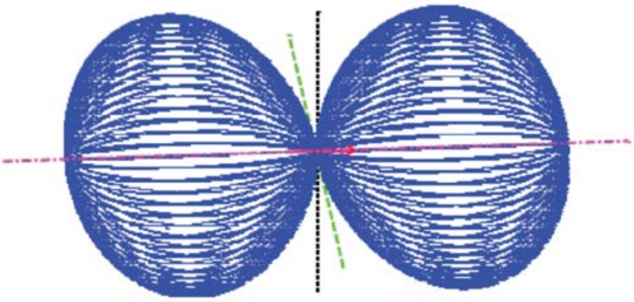


Fig 2.2.2: 3D directivity shape of a free dipole (taken from Zhang [1]).

Concerning turbulent boundary layer noise, experimental data in literature [5] confirms that its importance is lower compared with other aerodynamic noise components. However, it is worth noting that the analytical solution of this component has long ago been found by Tam [13]. From this solution, reference [3] shows that the directivity of turbulent boundary layer noise in a plane perpendicular to the flow can be estimated by the following expression:

$$\Delta L^{P}(\varphi) = 10\log[0.001 + 0.75 \cdot cos(\varphi) + (0.25 - 0.001) \cdot cos^{2}(\varphi)] \quad Eq. 2$$

This directivity function describes a sound source which is slightly less directional than a dipole. Zhang in [1] notes the numerical coincidence of Eq.2 with the *Harmonoise* proposal for the directivity of aerodynamic sources other than pantograph noise (Eq.1), drawing the conclusion that the generic Harmonoise proposal for the directivity of aerodynamic noise would be in fact for that of turbulent boundary layer noise.

3. TEST SETUP

In order to gain deeper knowledge of the characteristics of noise emissions from rolling stock operating at speeds up to 360 km/h (maximal commercial speed foreseen in the new HS2 line), a test was organized and carried out by the Spanish engineering company SENER on behalf of HS2 in the Spanish ADIF high speed network. Maximal speed during the tests was limited to 350 km/h because of railway certification issues. This speed was considered as close enough to the target (360 km/h) so that conclusions drawn could be fully applicable to HS2 case.

3.1 Setup

Test site was placed in the nearby of chainage PK117.10 in the high speed line Madrid-Zaragoza-Barcelona-French Frontier, in the surroundings of Las Inviernas (Guadalajara, Spain). The test site was chosen so that the following three conditions were fulfilled:

1. Maximal speed up to 350 km/h ought to be attainable during tests in dedicated mode.
2. An arch ought to be present in the site to serve as support for installation of a number of microphones above and around the train. Microphones above the train will benefit from the barrier effect of the carbody in front of other noise emissions at a lower lever (rolling noise, etc.). A pre-existing catenary arch used as support for these microphones is a very practical choice and minimizes acoustical interaction (reflections) with the phaenomenon observed. Possible use of a bridge for a similar purpose was

ruled out in order to avoid the effect of bridge surfaces on the results because of acoustical reflections.

3. A flat and almost levelled terrain with almost semi-anechoic characteristics should be found in the surroundings of the track, so that role of acoustic cross reflections could be neglected.

Measurements were split in two phases:

- Measurement of commercial traffic during daytime: in this phase, commercial units of the model Siemens-Velaro series 103, Talgo series 102/112 and Alstom TGV (all of them at pass-by speed around 300 km/h) and also units CAF Alvia series 120/121 at a pass-by speed of approximately 250 km/h.
- Measurement of a Siemens Velaro series 103 unit set up for testing during a possession at night when no commercial services operate

Complete setup used in the test campaign included up to 16 different microphones and accelerometers; its complete details are described in reference [4] (to be presented in the forthcoming IRWN13 congress, together with the different analysis that have been carried out based on the different recordings). Figure 3.1.1 shows the part of the test setup which is placed closer to the source. Approximate assessment of pantograph directivity has been carried out combining measurements from microphones MIC1 to MIC4 in the setup, as further explained in the next section.

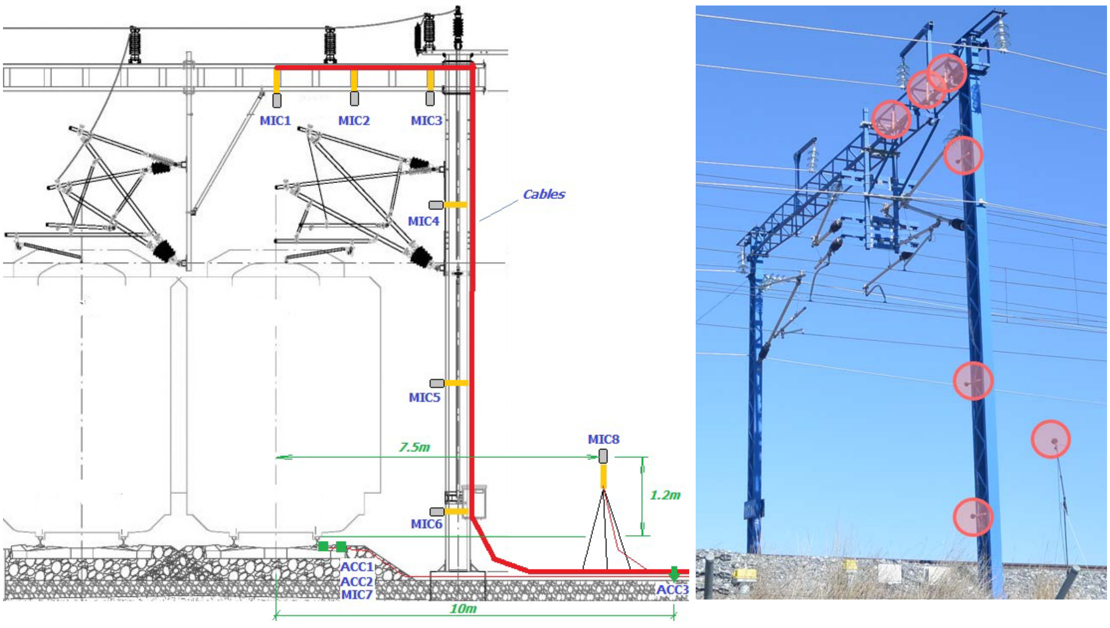


Figure 3.1.1: Scheme and view of the near field sensors installed in the catenary portal.

Figure 3.1.2: Pass-by of a RENFE series 103 under the instrumented catenary portal.

3.2 Post-process

Post process strategy for estimating pantograph directivity was defined after looking at the temporal recordings observed in the upper microphone MIC1. These recordings allowed to distinguish very neatly the pantograph peak from other peaks that could be attributed to other aerodynamic noise sources (see figure 3.2.1). As already mentioned, contribution of non-aerodynamic noise sources such as rolling noise to the levels represented in figure 3.2.1 is small thanks to the barrier effect provided by the own car-body of the high speed unit.

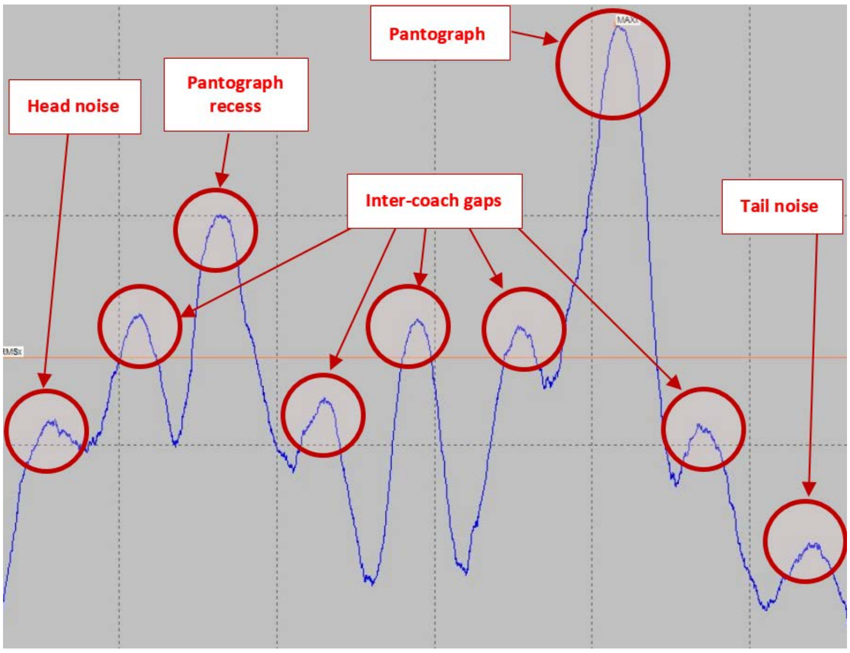


Figure 3.2.1: Identification of different high level aerodynamic noise sources in the MIC1 recordings (case of a Siemens-Velaro RENFE series 103).

However, one quite interesting additional outcome from the results was the observation that noise from aerodynamic features in upper parts of the train could be clearly distinguished not only in MIC1, but also in microphones MIC2, MIC3 and MIC4. These microphones are placed at different but similar distances from the noise source, and at different angles. Figure 3.2.2 shows temporal RMS noise values observed in MIC1 to MIC4 for a single pantograph pass-by. It can be noticed in signals MIC3 and MIC4 that despite these microphones have a direct line of sight with respect to lower noise sources (rolling noise, turbulence, etc.), upper noise (coming in this case from the pantograph and train roof) is clearly dominant, thus masking noise coming from lower parts of the train.

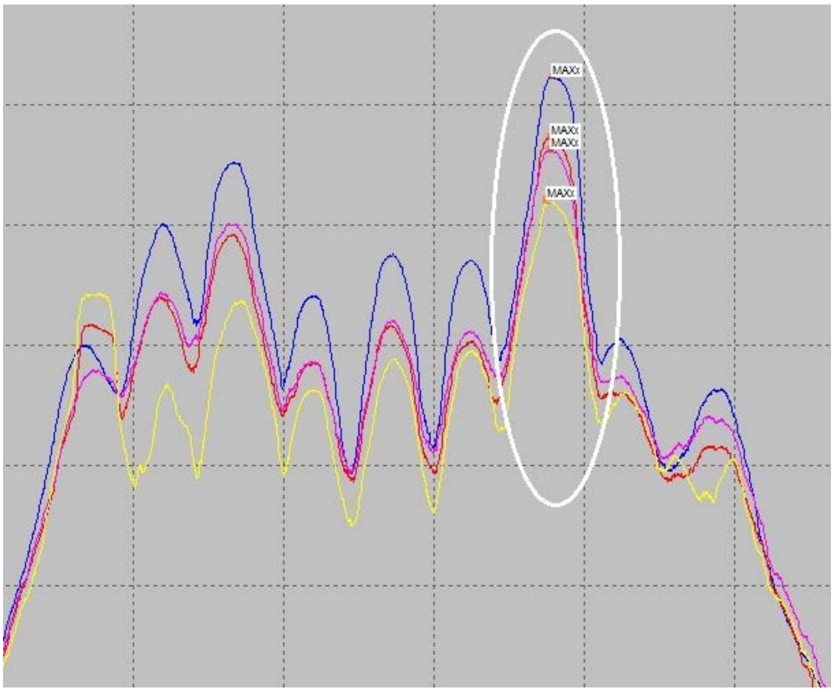


Figure 3.2.2: Comparison of noise recorded in positions MIC1 (blue), MIC2 (magenta), MIC3 (red) and MIC4 (yellow) at pantograph pass-by (time segment corresponding approximately to the white ellipse in the figure).

From the anterior observation it was considered that some indication of pantograph noise directivity could be roughly estimated from peak values observed in signals MIC1 to MIC4. For that, the following assumptions have been made:

• Lower noise in microphones MIC3 and MIC4 is around 9 dBA lower than peak level attributable to pantograph and thus can be disregarded (see figure 5.7.1).

• Noise is assumed to be generated by a cloud of vortices whose approximate centre is placed 50cm below the contact between pantograph and catenary (this is a significant simplification since noise can come from pantograph contact, pantograph arm and pantograph recess). Geometrical distance corrections between source and positions MIC1 to MIC4 have been calculated according to this assumption.

• Upper noise reflections in car body have been assumed to be comparatively small.

• Pantograph noise emission is assumed to be symmetrical with respect to horizontal plane in catenary and also with respect to vertical plane passing through track midpoint.

Impact of Doppler effect on the measures has been minimized by using the highest possible frequency sampling rate provided by the test equipment (52000 samples/second) and carefully selecting a reduced time lapse corresponding to the passing of the pantograph below the microphones (during this small time, relative velocity of the noise source with respect to the microphone in the direction that unites them is very small).

4. RESULTS

Figures 4.1 to 4.3 show comparisons between different polar emission patterns corresponding to same train unit (Siemens Velaro RENFE series 103) at different speeds, ranging from 250 km/h to 350 km/h. All figures show vertical transversal directivity, that is, orthogonal to train advance direction. Values at angles different to those observed have been interpolated with splines. Progressive transition from a low directivity pattern at 250 km/h to a quite marked dipole behavior at 350 km/h can be observed.

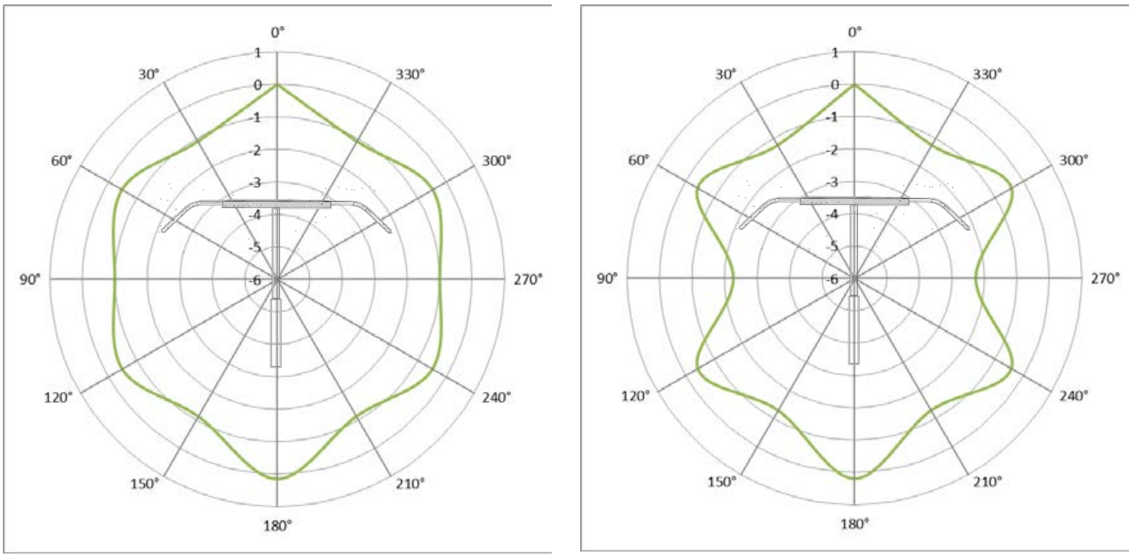


Figure 4.1: Comparison of estimated polar patterns (vertical transversal directivity) for pantograph noise emission from Velaro units at 250 km/h (left) and at 280 km/h (right).

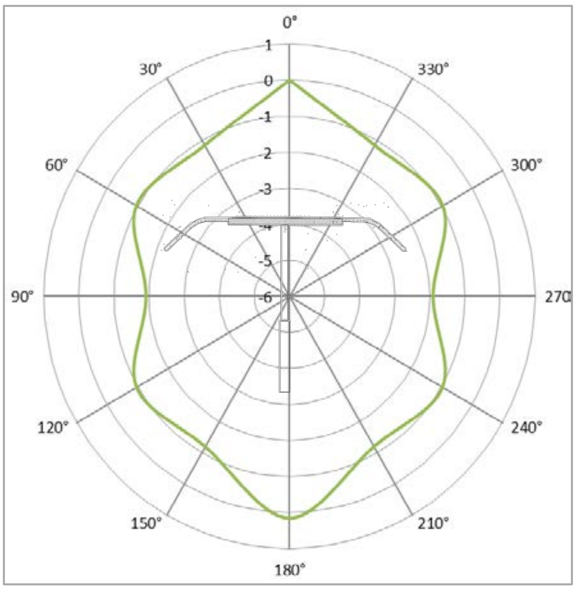


Figure 4.2: Estimated polar pattern for pantograph noise emission (vertical transversal directivity) from a Velaro unit at 300 km/h.

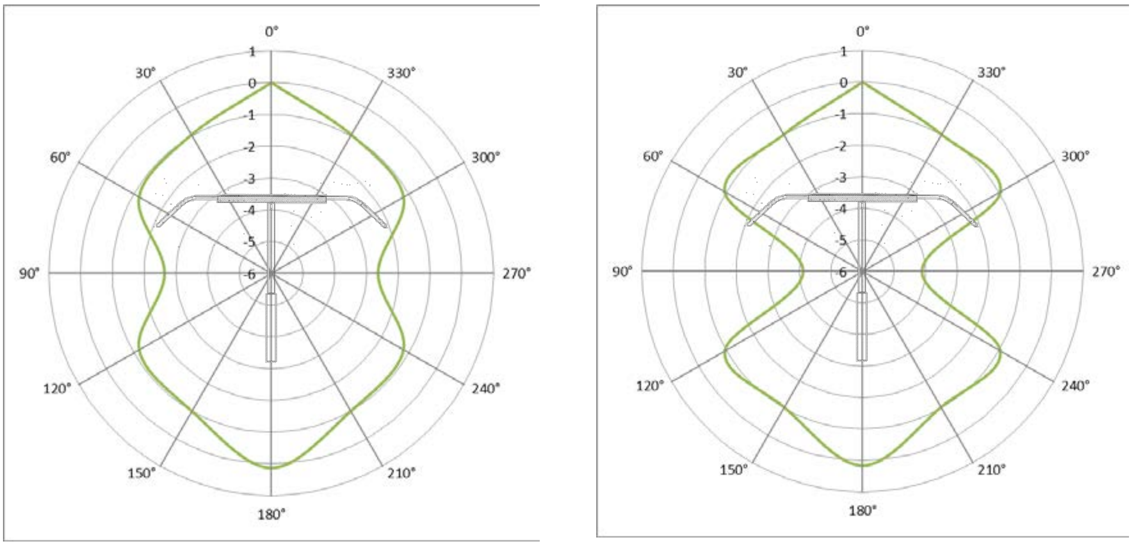


Figure 4.3: Comparison of estimated polar patterns (vertical transversal directivity) for pantograph noise emission from a Velaro unit at 320 km/h (left) and at 350 km/h (right).

5. CONCLUSIONS

A comparative of pantograph noise emission at different speeds and according to different directions has been carried out. This comparison is based on tests on the same unit and in the same point, thus eliminating these factors from the comparison. Albeit approximate (taking into account the methodology), the results show a definite and progressive evolution in the directivity of pantograph emissions, clearly increasing with the speed. The already reported combined dipole nature of aerodynamic pantograph emissions is confirmed by the results observed, together with an increase of directivity with respect to the speed.

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