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QUANTIFICATION OF THE PASS-BY NOISE EMISSION OF TRAIN WHEELS USING A MICROPHONE ARRAY TECHNIQUE

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ABSTRACT
Reduction of pass-by noise caused by trains is a main environmental target. Many sources contribute to the noise emmision of trains, but the wheels are a dominant factor in many situations. Standard measurements are often not capable to separate the different sources, especially when a train is passing at a very high speed. In those cases a microphone array technique can be applied. This technique can allow a better separation of different sound sources and in particular of train wheels. The proposed technique corrects for the Doppler-shifts and focusses on individual wheels. This paper presents the results of the application by LMS Engineering of the phased microphone array technique for the quantification of the considerable noise reduction of Lucchini prototype wheels mounted on a high-speed ETR470 Pendolino train.

1 - INTRODUCTION
In recent years, the introduction of low noise solutions as well as new legislation gives rise to the need for improved measurement methods for railway noise. These methods need to be accurate enough for quantifying the effect of individual noise control measures like the use of silent wheels. The microphone array technique has been established as a valuable method for sound-source localisation and quantification, especially for railway vehicles. Specific components of a moving train can be tracked as potential sound-sources and their noise emission can be quantified.
In this paper the focal point is the interaction of different train wheels (standard or silent) with an identical part of the F.S. railway track test-site at Renacci (Italy). The advantages and effectiveness of using this array technique when compared to standard measurements, like SPL meters or single microphone measurements, are presented. It is shown that this technique allows comparison of noise emission of rolling train wheels even during pass-by at high speeds.

2 - MEASUREMENT TEST-SETUP
An ETR470 Pendolino train from FIAT Ferroviaria is equipped with special damped prototype wheels made by Lucchini. This train is running on the high-speed railway line between Firenze and Arezzo and passes-by the test-site at various constant speeds between 50 kph and 220 kph.
For all pass-by tests, a linear microphone array is used. An array of 21 microphones is positioned at 3.30m from the nearest railway track, at the same height as the contact zone between the train wheels and track. The spacing in between the microphones is constant and equals 0.08m, thus the total length of the array is 1.60m. Vibration levels on the track are monitored at the centre line, and a far field microphone is positioned at 7.50m from the nearest railway track, at a height of 1.20m. An optical barrier is placed along the track in order to detect the exact speed of the train, and points in time at which the individual wheels and bogies are passing by the microphone array. On the train, at the train driver position, a calibrated mid-frequency volume velocity sound source is installed, which emits a pure

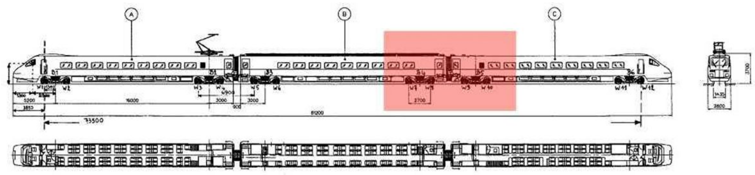

Figure 1: ETR470 Pendolino, location of the prototype silent "Syope" train wheels is indicated.

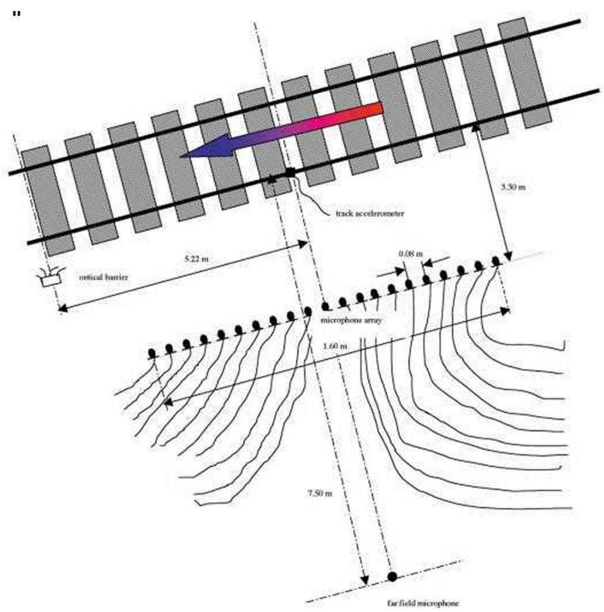

Figure 2: Sketch of the test-site and sensor locations.

sine tone at 2kHz (height above track equals 2.6m). This signal will be used to check the resolution of the microphone array technique.

At a speed of 140kph, the light-barrier signal, lateral track acceleration, first, centre and last microphone in array and far-field microphone are presented in the time domain. One can clearly recognise the pass-by of the bogies in figure 3, by observing the increased vibration and noise. Note also the dynamic pressure field created by the train entering and leaving the array. (Fig. 3, left sided curves)

3 - ANALYSIS OF PASS-BY NOISE DATA

Conventional analysis of the data was done by applying a gated spectral analysis, existing in calculating an autopower spectrum corresponding to the points of time during which the individual bogies are passing by. However, application of this technique gave no correct frequency information and individual wheels could not be tracked.

Another analysis technique consists in performing a short FFT Time/Frequency analysis on the data. The first colormap, fig. 4 on the left side, shows the pass-by noise as received by the central microphone in the array during pass-by at 140 kph. One can observe four phenomena, corresponding to four wheelgroups. It is also clear that the noise level of the third wheelgroup (Syope wheels) is lower when compared to the second wheelgroup (standard wheels), especially above 1500 Hz. Note the presence of the sine tone at 2 kHz as the train is arriving. This signal has a clear Doppler effect, as the nearing frequency is 2256 Hz and the leaving frequency dropped to 1796 Hz. The second harmonic of this sine tone is also present. One can conclude that the separation in time of individual wheels remains impossible, and that there is still no correct frequency content information available for potential noise sources like bogies or train wheels.

In order to separate and quantify individual train wheels as potential noise sources during pass-by, a more complex data processing needs to be applied, called the phased microphone array technique. This technique consists of two steps:

- A time delay correction of all array microphone arrays for the delay between noise emmission on the moving object and its arrival at the array microphone. This first step in the analysis eliminates

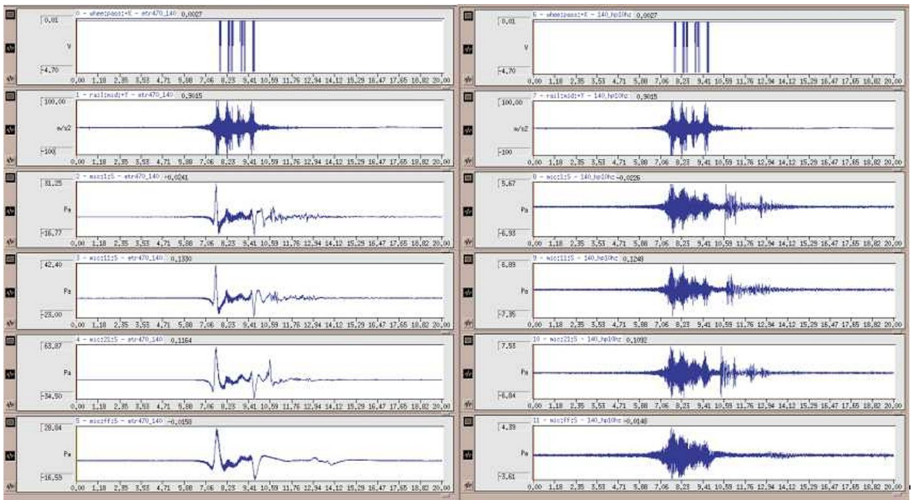

Figure 3: Recorded time signals, from the optical barrier, far field microphone and four array microphones; right curves, after high pass filtering of the array microphones.

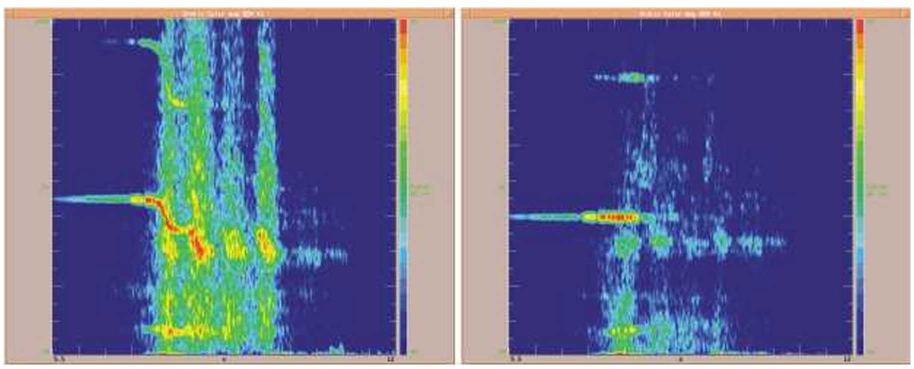

Figure 4: Time/frequency analysis colormaps; left side, individual microphone; right side after time delay correction, for the 2 KHz source location, and averaging all array microphones.

delay relative to one point on the train, and eliminates the Doppler effect.

- Linear averaging of all corrected array microphone time signals. This second step reduces the noise coming from sources on the train outside the target point for which the delay correction was made. The noise from the train away from the target point will not align in time, and will therefore be reduced in level.

The array size and spacing is chosen to obtain a data-set allowing optimal post-processing in the frequency range of interest, knowing that the first eigenmode of the train wheels used is situated around 300 Hz, and that the noise generated by the wheels is supposed to be important (when compared to other potential sources) from 1kHz on. The horizontal array analysis considers only the separation of potential noise sources in the horizontal direction.

Tracking the sine source on the train is done as a validation of the procedure and to correct position information. The result for the sine source is shown in the right side of figure 4. The signal is clearly de-Dopplerized (pure sine tone at 2kHz) and spectra are strongly reduced for all sources other than the target 2KHz sine source. In addition it is verified that the procedure and software used work well, as energy level decrease is minimal when comparing the original microphone signal to the phased microphone array signal (only 0.5 dB(A) decrease in this case of the pure sine source).

However, the microphone array signals can also be corrected for potential source positions like the train wheel-track contact zones. This was done by defining the distance in horizontal plane of the target sound source to a reference position, which is chosen here to be the first wheel passing-by. The reduction of the non-targeted sources can be seen clearly in the colormaps of fig. 5. These results also shows the difference between the standard and special silent wheels, and the remainder of the 2KHz sine which is not totally suppressed.

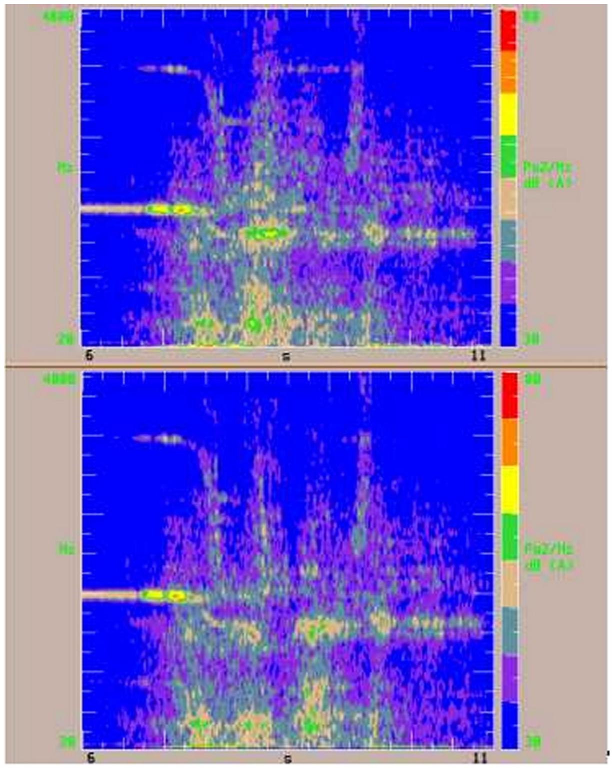

Figure 5: Time/frequency analysis colormaps; top chart, targeting standard wheel number 3 and bottom chart targeting silent wheel number 7.

A very comprehensive way to represent the result data is to calculate, out of the time-delayed and averaged microphone data, an OA-level representation.
On the standard microphone signal (highest curve) no clear separation of individual wheels can be seen. All other curves show a more focused picture on the tracked virtual sound source.
The Syope wheel (wheel 7) is the most silent of all at 80.5 dB(A). When compared to a standard wheel at 84.5 dB(A) (wheel 3) a reduction of 4 dB(A) can be observed for a train pass-by at 140 kph. This is a clear improvement in pass-by noise emission. Differences within each of these wheelgroups can be explained by the near presence of auxiliary equipment or other sound sources on the train.

4 - CONCLUSIONS

The presented microphone array technique gives a correct indication on the frequency content of the noise emitted by the train wheels, and is also able to separate much better the individual wheels as sound sources. It is also concluded from the analysis results that with the Lucchini Syope wheels a reduction of 4dB(A) in OA-level is obtained when the ETR470 passes-by at 140 kph. This is a clearly audible result. It should also be mentioned that the noise reduction around 1600 Hz is most important.

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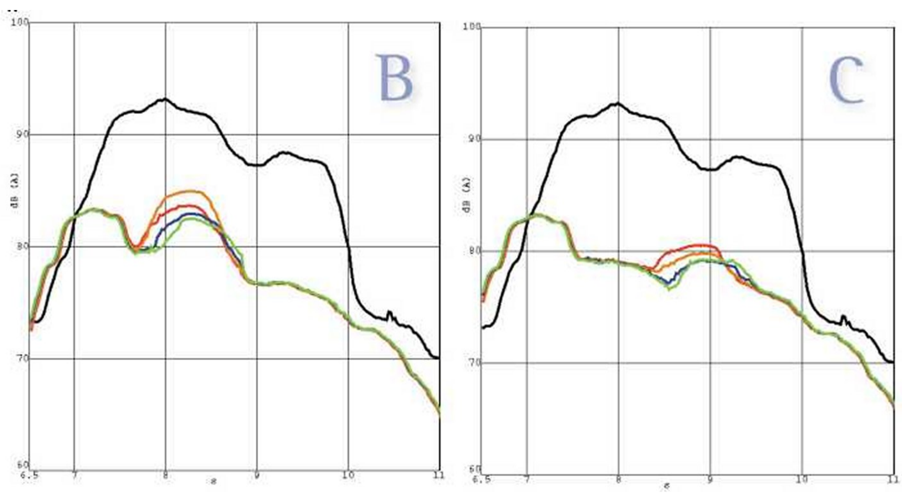

Figure 6: OA level versus position on the train; the black curves represent the uncorrected non-averaged signal; the colored curves focus on individual wheels; left side, B, when targetting on individual standard wheels; right side, C, when targeting individual silent wheels.