Characterization of wheel noise during train pass-by at Fiat Ferroviaria

LMS®
ENGINEERING INNOVATION

Reducing the pass-by noise of trains is an important issue and innovative companies, such as Lucchini of Italy, are developing a range of new low noise wheels to address the problem. But how can the contribution of a new set of wheels to the overall pass-by noise levels be assessed - given the multiple sources contributing to overall noise levels, the couple of seconds it takes for a train to flash by at 220kph, and the very noticeable Doppler shifts that distort everything? In a recent case history LMS Engineering Services were called upon to do just that. Even more challenging, only two bogies in the high-speed train were fitted with the new wheels, the rest were conventional.

Standard measurements using a single microphone are not capable of separating the noise generated by different sources, especially when these are passing by at very high speeds, so a microphone array technique is required to isolate and quantify the noise emission.

An ETR470 Pendolino train from FIAT Ferroviaria was equipped with the special Lucchini damped prototype wheels, known as “Syope” and ran at various constant speeds between 50kph and 220kph on the test-site of F.S. (Ferrovie dello Stato) at Renacci, on the high-speed railway line between Florence and Arezzo. A linear array of 21 microphones was positioned at 3.30m from the track, at track level. An accelerometer measured the rail vibration, and a far field microphone was positioned at 7.50m from the nearest railway track, at a height of 1.20m.

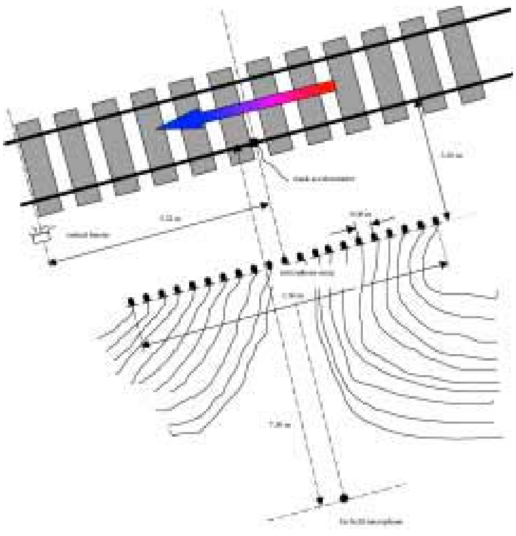
An optical barrier was used to trigger the 12kHz data acquisition and to derive the exact speed of the train and the position of each wheel for every time sample. On the train, a mid-frequency volume velocity source emitted a pure sine tone at 2kHz in order to check the validity of the technique.

Typical results during pass-by are shown below. One can clearly observe the pass-by of the bogies, the increased vibration levels on the track and the sound levels. Notice also the dynamic pressure field created by the train entering and leaving the array: after high-pass-filtering to remove these shockwaves, the data now correspond to normal pass-by noise levels.

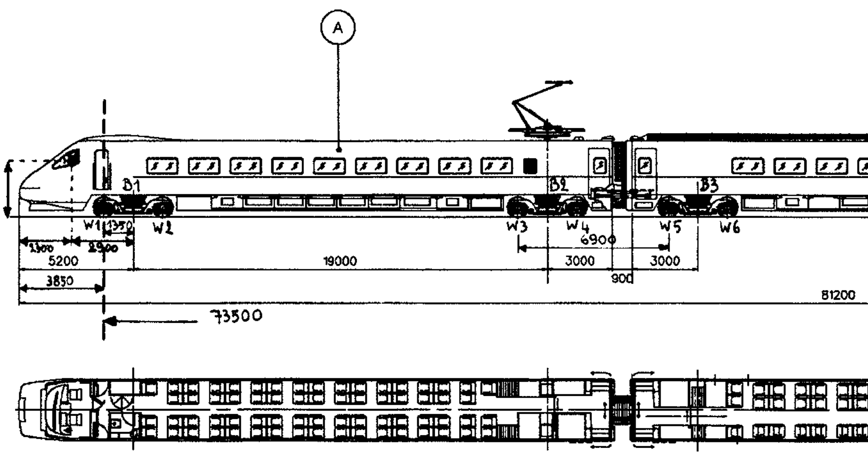
Conventional Data Analysis

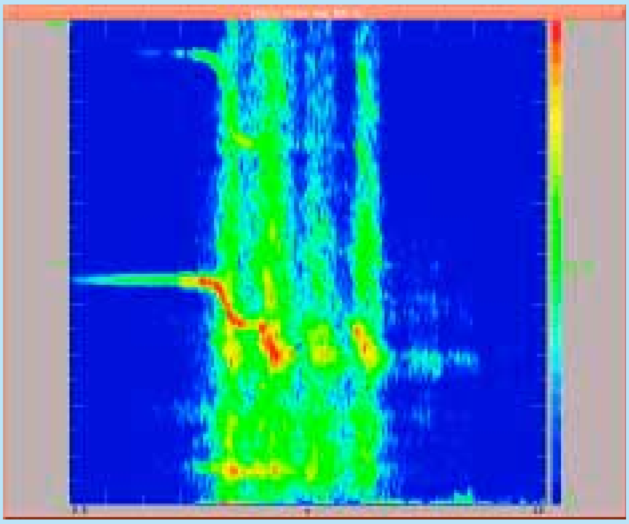
The first way of analyzing the data was to calculate an autopower spectrum corresponding to the points of time during which the individual wheelsets (or bogies) are passing by. In this way it was possible to quantify the emitted noise of four groups (considering different wheels together).

When a time/frequency analysis was performed, one can clearly observe four phenomena, corresponding to the four groups as defined earlier. It is also clear that the noise levels of the third group are lower when compared to the second group, especially at higher frequencies (above 1500Hz). Note the clear presence of the sine tone at 2kHz as the train was arriving. This signal has a clear Doppler effect, as the nearing frequency was 2256Hz and the leaving frequency dropped to 1796Hz. The second harmonic of this sine tone was also present. One can conclude that the separation in time of individual wheels remains impossible, and that there was still no correct frequency content information available for potential sources like bogies.

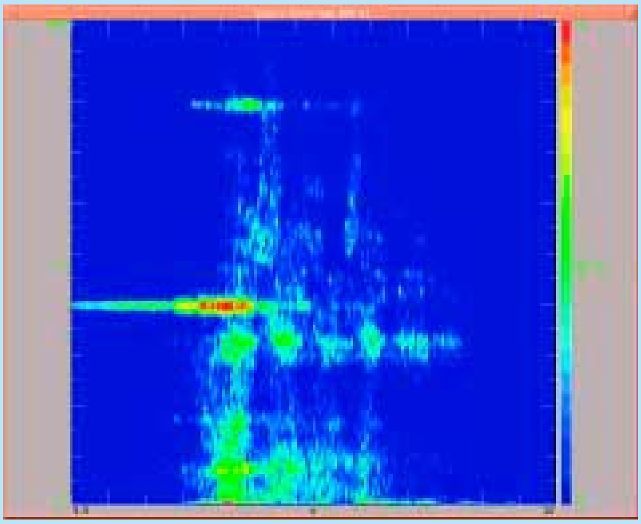


A linear array of 21 microphones was positioned at 3.30m from the track, at track level.





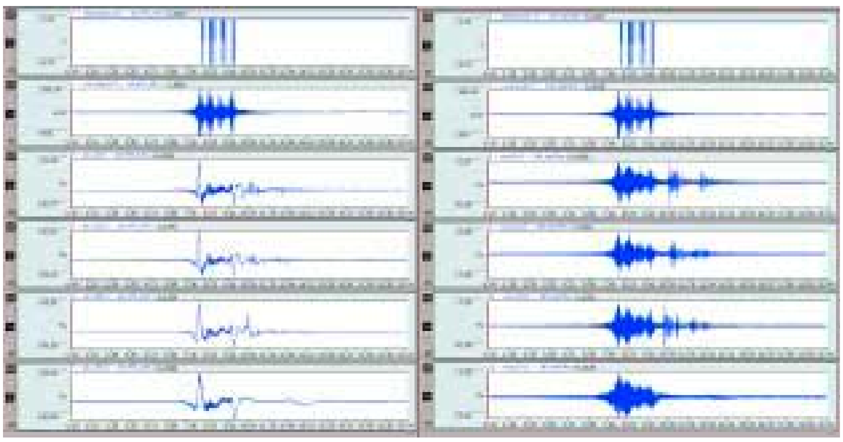
Short Time FFT waterfall of 140kph pass-by noise. The four wheelsets can be identified, but, apart from a large Doppler shift of the 2kHz tone, little else of significance.



Validation of the phased array process: the signal is De-Dopplerized and the time averaged signals tend to zero.

Phased array analysis

Intuitively, when we listen to a sound we use both ears to locate the nominal source, and move our head to track its movement. A microphone array approach uses the same principle, in this case 21 widely spaced microphones achieve far superior results than two. Of course, it would be impractical to turn such a large array to track a source on the train, so it is moved electronically instead, in an approach sometimes referred to as a 'phased array'. The microphones do not physically move, but use progressively varying time delays between the microphones to 'point' the array centerline to a 'virtual' location (assuming monotonic signal). In general, off-center sources tend to interfere and cancel each other out, while the coherent source is time averaged and enhanced. By varying the delays between the microphones for each time sample the array can be steered and pointed at the nominal target as it moves down the track. It is then just a matter of repeating the analysis for each of the wheels, and for each frequency in the bandwidth of interest. Also note that the Doppler effect would be removed by an adaptive resampling technique prior to this phased array analysis, so correct frequency information would be obtained. Altogether, a massive amount of non-trivial digital signal processing was involved.



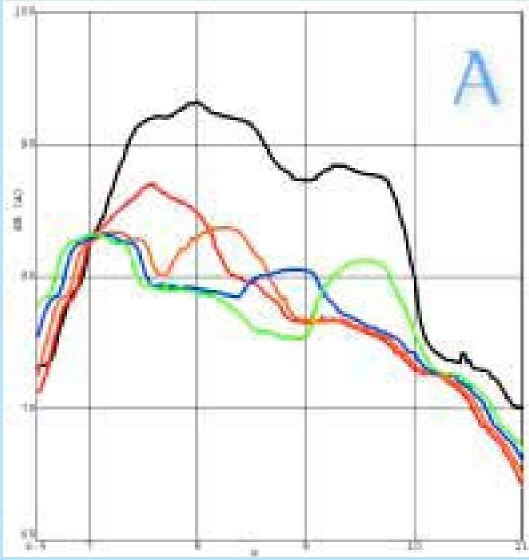
Example of original pass-by data at 140kph(left) , high-pass filtered at 10Hz to remove the shock-waves (right). From the top: light barrier, track vibration, first, center and last microphones in array, and far field microphone.

The analysis was carried out in a batch mode using a User Program specifically developed by LMS Engineering Services. In this case, the microphone time signals were delayed for 12 individual wheels, corresponding to the contact zones between the 12 wheels and the railway track. In addition, the six bogies were also tracked, as well as the sine-tone source on the train. The latter serves as a reference to correct the position information and to check the validity of the procedure: it was verified that the procedure and software works well, as energy level decrease of the tone was minimal (0.5dB).

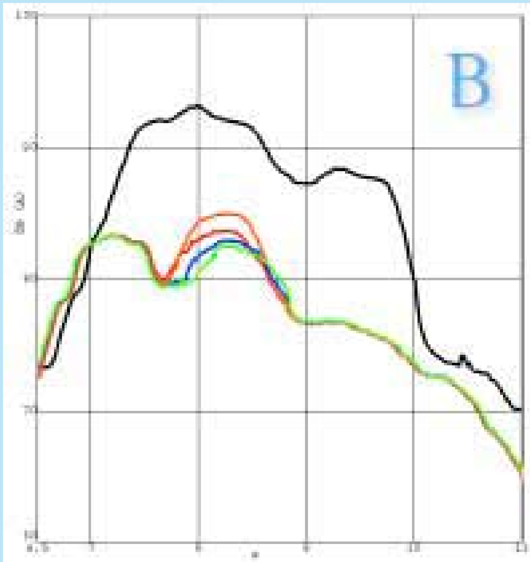
Figure A shows the OA level of the central microphone signal compared to the first wheel in every wheel group, i.e. wheel 1, 3, 7 and 11. On the black curve no clear separation of the individual wheels can be seen. All other curves clearly show a more focused picture on the tracked virtual sound source. The Syope wheel (gray curve) is the most silent of all at 80.5 dB(A), and when compared to a standard wheel (green curve) a reduction of 4dB(A) in OA-level can be observed, which is a clear improvement on pass-by noise emission.

Figure B shows the results in OA-level for all standard wheels in the 2nd wheelgroup, i.e. wheels 3,4,5 and 6.

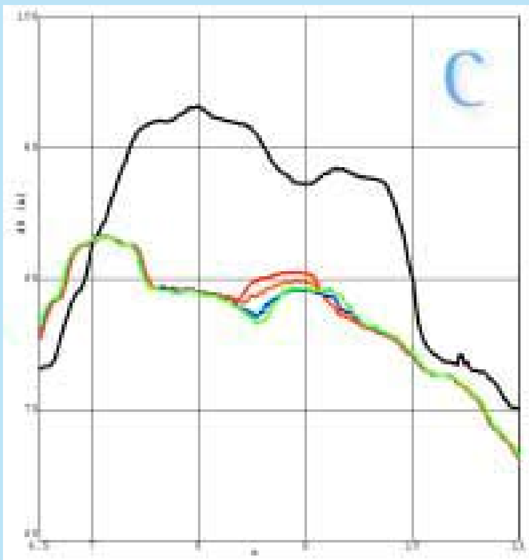
Finally Figure C shows the same data but now for the 3rd wheel group containing the Syope wheels. Difference in between each of these wheels can be explained by the near presence of auxiliary equipment or other sound sources on the train.. ■



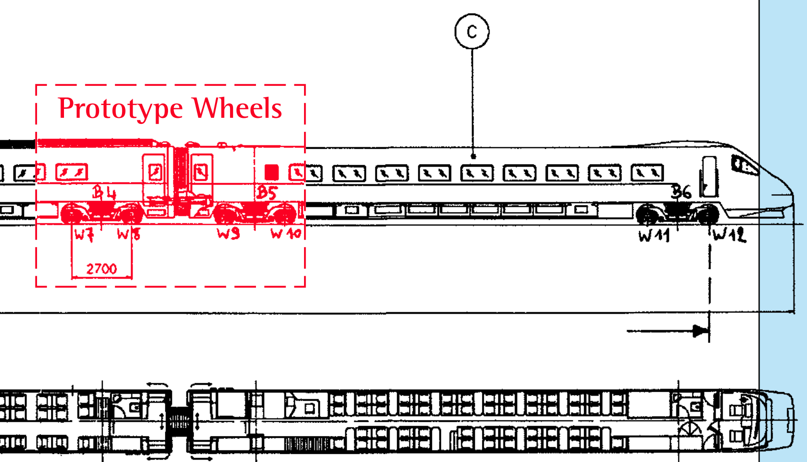
OA levels for the front wheels of the four wheel groups



OA levels for standard wheels



OA levels for Syope wheels



LMS INTERNATIONAL
Researchpark Z1, Interleuvenlaan 68
B-3001 Leuven [Belgium]
T +32 16 384 200 | F +32 16 384 350
info@lmsintl.com | www.lmsintl.com

Worldwide For the address of your local representative, please visit www.lmsintl.com/lmsworldwide

LMS is an engineering innovation partner for companies in the automotive, aerospace and other advanced manufacturing industries. LMS enables its customers to get better products faster to market, and to turn superior process efficiency to their strategic competitive advantage. LMS offers a unique combination of virtual simulation software, testing systems and engineering services.

LMS is focused on the mission critical performance attributes in key manufacturing industries, including structural integrity, system dynamics, handling, safety, reliability, comfort and sound quality. Through our technology, people and over 25 years of experience, LMS has become the partner of choice for most of the leading discrete manufacturing companies worldwide.

LMS is certified to ISO9001:2000 quality standards and operates through a network of subsidiaries and representatives in key locations around the world.

LMS®
ENGINEERING INNOVATION