Characterizing noise from individual wheels during train pass-by

In what is believed to be one of its first industrial applications, the phased microphone array method was used to separate and measure the noise produced by individual train wheels flashing by at over 220kph. The biggest challenge of assessing the performance of a new low-noise wheel design was distinguishing the contribution of the low-noise wheels from the noise generated by the other wheels as well as the rest of the train. The signal collected from a linear array of 21 microphones was analyzed using progressively varying time delays to point the array centerline to track point sources of noise on the fast-moving train. The analysis eliminated non-wheel noise, corrected for the Doppler shift and separately tracked the noise from each individual wheel and bogey. The results showed that the new wheels were 3dB to 4dB quieter than the standard wheels.

Reducing the pass-by noise caused by trains is becoming a major environmental issue. Lucchini Group, a leading European producer of railway products such as wheels, rims and axles is at the forefront of addressing this issue. Lucchini developed a new wheel design, called Syope, that is intended to substantially reduce wheel noise, a significant contributor to pass-by noise. The problem faced by Lucchini engineers was how to quantify the noise reduction provided by the new design. One problem is separating the noise generated by the wheels from the multitude of other noise sources on a fast-moving train. Another problem is that it costs a huge amount of money to take a train out of service, change its wheels and run noise tests. For that reason, Lucchini engineers wanted to run a single test using just one set of Syope wheels that would compare their noise to that of the other wheels.

Tracking a point source of noise

Standard measurements using a single microphone are not capable of separating the noise generated by different sources, especially when they are passing by at very high speeds. We humans track a moving noise source by using both ears to locate the nominal source and moving our heads to track the noise source movement. A microphone array approach uses the same principle. But the use of 21 widely-spaced microphones provides far greater sensitivity than two ears. 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, hence the name phased array. Instead of physically moving the microphones, offsetting the time history data by progressively varying delays points the array centerline to a virtual location.

Lucchini contracted with engineers from LMS International, Leuven, Belgium, to use the phase microphone array technique to address this problem. In general, off-center sources that are averaged over time tend to interfere and cancel each other out, while a coherent source, in this case the train wheels, is enhanced.

Varying the delays between the microphones for each time sample makes it possible to point the array at a nominal target as it moves down the track. It is then just a matter of repeating the analysis for each set of wheels and for each frequency line in the bandwidth of interest. The Doppler effect is removed by an adaptive resampling method prior to this phased array analysis in order to obtain correct frequency information. At each time step in the analysis, the digital filters are reallocated to account for the change in frequency caused by the Doppler shift.

Description of test

An ETR470 Pendolino train from Fiat Ferroviaria was equipped with the special Lucchini damped prototype wheels and run 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 3.3m from the track, at track level. An accelerometer measured the rail vibration, and a far field microphone was positioned at 7.5m from the nearest railway track, at a height of 1.2m. 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. The sine-tone source on the train serves as a reference to correct the positioned information and to check the validity of the procedure.

The ETR470 Pendolino train (photo courtesy of Fiat Ferovaria)

An optical barrier was used to trigger the acquisition and to gather correct position information of the train passing by. A time history from each microphone is recorded onto disk using the LMS CADA-X system. This software package provides the capability to digitally import field data from nearly any recorder, mobile data acquisition system or telemetry device. It includes editing tools, optimized for huge multichannel datasets that can merge data taken by different devices, demultiplex channels, resample data taken at different rates, locate marked events. Other capabilities of this package include the ability to: 1) direct and digital import from data recorders 2) multichannel time domain editing, interpolation, and resampling 3) frame statistics, counting, and histogramming to detect important sections
4) frequency analysis and digital filtering for data correction and conditioning
5) principal component analysis to indicate the number of independent loading sources.

Enormous data analysis task

The enormous data analysis task was performed with a custom program developed by LMS engineers. The traces were replayed and filtered off-line in a batch process. The first stage was to determine the relative position of the wheel as it goes by each microphone. This was accomplished by measuring, for each frequency of interest, the relative delay between the source and each microphone. Then the signals from each of the microphones were averaged over time. Every other source on the train was effectively averaged out. The entire process was repeated for each wheel and for each bogey, or set of two wheels, at each time step at every frequency within the range of interest. Each frequency change required a different set of delays to account for the Doppler effect. This involved an enormous processing task that took about eight hours in a batch process on a high-end Hewlett-Packard workstation. In the analysis results, the energy level decrease of the tone was only 0.5dB, confirming the validity of the procedure.

The raw time history data clearly shows the increased acoustic noise and vibration levels caused by the pass-by of the bogeys. A dynamic pressure field created by the train entering the leaving the array is also evident. High pass filtering was used to remove these shockwaves, leaving data that corresponds to normal pass-by noise levels. The first method used to analyze the data was to calculate an autopower spectrum corresponding to the points of time during which the individual bogeys are passing by. This made it possible to quantify the emitted noise of the four groups of wheels. A time-frequency analysis colormap clearly shows four bursts of noise corresponding to two of the four bogeys. From this rough data, it can be clearly seen that the noise levels of the third group of wheels, the Syope wheels, are lower, especially at frequencies above 1500Hz. However, this relatively simple analysis method does not provide a way to quantitatively measure the difference in noise and between the different bogeys, nor to measure the differences between individual wheels. The colormap also clearly shows the sine tone at 2kHz as the train arrived. The Doppler effect can be easily seen. As the train neared the array, the frequency was 2256Hz while the leaving frequency trap to 1796Hz.

Precisely measuring each wheel's noise

After the signal was de-Dopplerized and the random noise was removed, a far more precise comparison could be made. The analysis provided Lucchini engineers with exactly what they were looking for – a precise measurement of the level of noise reduction that could be achieved with the new wheels. These measurements played a crucial role in the development process by validating the engineering calculations that were used to design the wheels and helping to elicit interest from potential customers. This example clearly demonstrates that the phased microphone array approach is an extremely powerful measurement tool that can be used to address a wide range of environment noise problems.

Syope is a railway wheel with a special damping system to be used for disc braked wheelsets designed for passengers coaches and high speed trains. The innovation lies in the application of a constrained viscoelastic layer on the two sides of the wheel; the layer is made of a high mechanical and chemical resistant viscoelastic adhesive, covered by an aluminium or steel layer. Existing standard wheels do not require any geometrical modification for the application of this type of damper and also no mechanical fixing systems are required. The assembling of the dampers to the wheel follows a simple technology developed by Lucchini. The weight increase for Syope wheels is extremely low only: 3.5 kg for the aluminium constrained layer and 8.5 kg for the steel constrained layer. Tests have revealed that Syope wheels generate up to 10dB less noise than ÔstandardÕwheels.

Delhi lights

Impatient drivers in New Delhi, where there are 3.3 million vehicles, have been banned from hooting to tell those ahead of them when the lights have changed to green.

noise notes