Lucchini CRS *Syope*® damped wheels noise qualification

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ABSTRACT
Railway wheel damping is acknowledged as one of the potential measures to reduce rolling noise. In this paper the results of an experimental test programme to qualify the behaviour of a type of constrained layer damped wheesls are shown. An appropriate combination of worn, machined, standard and damped wheels have been mounted on an ETR500 dual voltage high speed italian train.

1. INTRODUCTION
Railway noise is a complex phenomenon that involves several components and their acoustical properties. The sources can be cathegorised in vehicle dependents (noise emitted by the wheels, aerodynamics, pantograph, motors, gearing, auxiliary equipments, etc.) and track dependents (noise emitted by the rails, sleepers, bridges, etc.). Not only the vibroacustic properties of the various parts is important, but also their geometrical position and their acoustic properties (absorption).

It is outside the scope of this paper to examine in detail the influence of the parameters involved in rolling noise. Actually some tools are available to estimate the noise starting from the vibroacoustical properties of the solid bodies (wheels, rails, sleepers); several contact models can be used and also some simple propagational models can be used. It is now widely accepted that both the wheels and the track are noise sources with comparable power; in particular, usually track noise is dominant at low speeds while wheel noise is dominant at high speed.

Experimentally it has been observed that the sound pressure level at the passage of a train depends on the its speed with a fitting law of the type $L_{p,\ max}=L_p(v_0)+b\ \log_{10}(v/v_0)$, where the steepness b is close to 30 and v_0 is a reference speed (typically 100 km/h). The noise pollution is therefore as more important as the speed increases, and this contrasts with the requirements of modern railways where both the speed and the environmental requirements should increase.

The abatement of railway noise can be searched at the sources or during the path that reaches the receiver. In the past, and also nowadays when other measures fail or prove to be inapplicable, the most used remedy was the use of noise barriers. Unfortunately, they have several drawbacks: their effects is limited by noise diffraction, they have limited effeecs on high buidings or deep valley environments, they have a strong visual impact and, last but not least, they have a high installation cost. Moreover, their effect is (obviously) limited at the area where they are installed.

Track and vehicle measures, i.e. source treatments, require different approaches. As safety is concerned, vehicle mounted devices, such as screen, dampers, or whatever, must be absolutely safe while not modifying, if possible, maintenance procedures and the total life cycle cost of the vehicle. On the contrary, track mounted devices must have a longer durability, should not require maintenance and should be, again, absolutely safe. Normally it is accepted that track measures are more costly than vehicle measures, but they are anyway necessary if it is wished to reach the maximum abatement especially at low and moderate speeds.

Any kind of treatment is better to be used as a retrofit for existing situations without requiring a complete substitution of the components. In the case of a wheelset, this is less critical at they have anyway a limited life; in the case of the track this is much more important as the renewal interval for the track can be also in the order of several decades.

In this paper a noise reduction solution at the source is qualified. Italian steel manufacturer Lucchini S.p.A. already produces the wheels for high speed Italian trains ETR500 and all the Alstom Pendolino family (ETR450/460/470/480). The wheel is standard monobloc with a simple curvature; the axis is equipped with three brake discs. Lucchini has proposed to FS to evaluate the effect on noise reduction of the use of these wheels with a retrofit treatement consisting of a constrained layer with a polymer inside developed and patented jointly with 3M Italia s.r.l. The main advantage of this solution is that it does not require any modification in the vehicle structure, in the maintenance operation, does not reduce safety in any way and has a limited cost.

FS has asked the Dipartimento di Meccanica e Tecnologie Industriali (DMTI) of the University of Florence to perform noise measurements within the frame of an already scheduled test programme for aerodynamic drag measurements. Due to this particular scheduling, it has been not possible to "drive" the test programme to obtain the best results for noise measurements; in particular, it has been not possible to have train passes at speeds below 175 km/h, missing the possibility to eveluate the noise at low speeds where the track component should be dominant. Beyond this limitation, it is believed that interesting results has been found, especially on board where noise has been measured with an axlebox mounted device.

2. DEFINITION OF THE TEST PROGRAMME

The Technical Directions of three important european railway administration (DB, FS, SNCF) decided to perform some aerodynamic tests on an FS ETR500. The test campaign has been conducted during October and November 2000, and the aerodynamic drag was tested in the standard train configuration and with aerodynamic fairings fixed in the bogie area to reduce airstream vorticity and hence to reduce the drag.

The field test has been, as usually in Italy for this kind of tests, the high-speed line Florence-Rome from km 200 (1° Bivio Arezzo Nord) to km 252 (Bivio Rovezzano), close to Florence. In this line stretch it is possible, thanks to overhead line and track characteristics, to reach and pass 300 km/h with only some restrictions due to signalling.

This campaign was a good chance also to measure some acoustical properties of the train; in this respect FS decided to test also some new damped wheels manufactured by Lucchini by simply changing the standard wheelsets with the new type, called *Syope*®.
FS decided to request the cooperation of DMTI that has a long experience of noise measurements on board and track side also for the planning of the programme.
The first decision that was been taken was about the number of *Syope* wheels to be used during the tests, where they had to be fitted, the definition of the roughness of the surface of the tyres and whether the aerodynamic fairings could be used also for noise shielding (the so called "acoustic fairings") without changing the external face but treating acoustically the internal side.

The standard composition of ETR500 has 2 locomotives and 11 coaches, while the test train has 2 locomotives and only 8 coaches (4 2nd class, 1 restaurant and 3 1st class). It has been researched a fairing and *Syope* combination such that it were possible to measure, clearly in different campaigns, several situations with and without fairings. For organisation reasons, the first campaign has been performed with the fairings installed, while during the second the fairings have been dismounted.

It was decided to turn not all but some wheelsets, even if their mileage was particularly low, being the train not in service but used only for tests at the moment of the campaign. The final composition of the train is shown in figure 1, where it can be observed that the bogies have been treated in pairs belonging to adjacent coaches. This minimises the effect of preceding and following bogies on the measurements at 7.5 m from the track centreline. The indicated fairings are obviously present only in the first test campaign.

The test programme was particularly articulated and the measurements have not been performed during the whole campaign. Table 1 shows the detail of the test days. Some tests, as described at the next paragraph, concern track measurements at the train passage.

3. MEASUREMENT PLANNING AND DESCRIPTION

The tests performed by DMTI followed strictly the only protocol available at the moment of tests, i.e. the draft of the European and International Standard prEN ISO 3095 [1]. Despite the fact that it was not an official standard, it was decided to follow it closely as it is the only reference where a multitude of tests on the track are required. It is not the intention of the authors to describe in detail the procedure of the tests required by that standard; we think that a look at table 1 is sufficient to understand that a large number of new measurements have been introduced by the revision of the old ISO 3095 especially for what concerns track measurements.
The results obtained from these measurements will not be described here as they are not strictly related to the qualification of *Syope* wheels; it will be sufficient to say that the newest parameter require by the standard (the rail roughness spectrum) is well below the limit specified in the Annex D. Quite obvioulsy, trackside tests have been made for *all* trains passing in the measuring site, collecting data also for trains different from ETR500, but also these results will not be shown here.

3.1. On board measurements

The DMTI has developed in the years 1993-94 a test device to measure the noise emitted by the wheel [2÷4]. It is composed by a wind protection and two parallel plates; the microphone is elastically suspended in the shade given by the wind protection. The measurements have been compared to trackside measurements and the device was therefore calibrated. A picture of one of these devices is shown in fig. 2.
To accelerate the tests and to compare several wheels, four identical devices were mounted under three coaches as shown in figure 3. Theoretically, the support of the device allows a quite fast rotation of the device to measure after each change of direction; unfortunately, as the tests were conducted night time during a traffic interruption, only a couple of minutes were available for turning. As this time was thought to be unsufficient, two of the devices (#1 and #4)

were permanently operating in the Firenze-Arezzo (south) direction while the others (#2 and #3) were operating in the reverse direction (north).
For evident reasons, the use of these devices was possible only without the fairings.
The noise levels have been analysed and recorded by using a real-time 1/12 octave band dual channel analyser (Larson-Davis LD3200) with a sampling frequency of 11.2 kHz per channel. A tes run log file has been compiled with the position along the line, the actual speed and the time of the measurement. From this log file it has been possible to precisely determine the speed vs distance diagram.

3.2. Trackside measurements
The noise has been measured mainly at 7.5 m from the track centreline and 1.2 m above top of rail, while only some 25 m distance measurements have been taken. This choice, accepted by FS during test setup, is due to the fact that the main goal of the campaign was that of quantifying the noise abatement of several measures taken (acoustically treated aerodynamic shields, turnig of the wheel, *Syope* wheels and a combination of all these parameters); for this reason the bogies were grouped in pairs as already described, allowing a quite precise and repeatable measurements *only* at this distance. At greater distances, the several sources mix up and it is not possible anymore to distinguish them unless much more complicated techniques are used like the microphone array techniques. In the test campaign, technicians from the DB used a microphone array.
Instead of using a Sound Level Meter, it was decided to record the raw signal coming from the microphone in a digital form. All subsequent analyses, as A-weighting and FAST filter response, have been simulated through the use of dedicated small routines.

4. TEST RESULTS

It is clear that the only results directly usable to quantify the noise emitted by train are the trackside data. Nonetheless the measurements on board can give a faster and more direct idea of the reduction obtained with the *Syope* damping treatment. The data from on-board measurements are shown first and are related only to run-ups without fairings; trackside data, relative to *all* possible combinations are shown later.

4.1 On-board collected data
A sample of the distance vs time and speed vs distance profiles is shown in fig. 4. Normally the speed increases from approximately 100 km/h to the planned maximum speed very rapidly. Oviously the measurements taken during braking have been discarded as the noise produced by braking is not strictly related to wheel noise. As a result from the speed profiles of the whole runs considered here, fig. 5 shows the cumulative where it can be seen that the largest number of samples (around 50%) is relative to speeds is the range 200÷250 km/h, around 18% is relative to speeds greater than 250 km/h and the remaining 32% to speeds between 100 and 200 km/h and it is, moreover, not uniformly distributed. This uneven distribution made it impossible to derive from the data completely meaningful results as those shown in [2÷4], but, as already said, it was impossible to modify the speed during the test runs.
The noise measured in the axlebox of a standard turned wheel (device #3) for the test run shown in fig. 4 is shown in fig. 6 together with the difference in the noise emitted by the standard and the Syope wheels. The two wheels are only 16 m apart, and this required no correction of the samples position.
From these figures it is possible to derive some first conclusions.
First of all the noise level is extremely high (up to 135 dB(A) and over) and the dynamics of the measuring chain has been used almost entirely. Only a few times (5 sample in 14 test runs) exhibit an overload and they have been properly removed from the analysis.
The noise levels are extremely variable also at constant speed. This is due to the line profile and details (curves, tunnels, rail joints, switches,...) with a dynamics of up to 8 dB(A). A discussion of the implications od this evidence is reported later.
The difference between the standard wheel and the *Syope*® wheel shows a large variability. For considerable lengths the gain is around -10 dB(A) (km 217 to 221) while in other lengths the gain is positive (km 221 to 223) showing that the damped wheel is more noisy than the standard wheel!
The observation of this phenomenon draw up the attention to the pattern identified, as in almost all the test runs a similar behavior was observed. A correlation has been found between the curvature of the line and the noise emitted. Figure 7 shows the details of test run 2507. To reduce the number of samples and to obtain more stable results, the data have been grouped for line sections of 200 m, and they are shown in the upper figure with the the curvature derived from the line description. From the lower figure, showing the gain of the damped solution and the standard deviation of the samples considered in each 200 m section, it is easy to see the peaks are relative to left curves while the troughs are relative to right curves. The noise emitted by the standard wheel remains constant or even increase in the right curves, while the noise emitted by the *Syope*® wheel decreases dramatically. This shows that the actual position of the contact point and the presence of driving forces have a large importance especially for the damped wheel.

This behaviour has been verified in all the test runs. The data have been grouped for homogeneous line sections (straight, left curves, right curves); within each cathegory, and also to overcome some inevitabile uncertainties and local deviations, only data between 10 and 90 percentiles have been retained (this procedure is correct as the average remains undisturbed while only standard deviation decreases). These results are shown in fig. 8 and in tab. 2: it can be seen that in the straight line gain is around 4.5 dB(A). This results is an average in all the speed range; a finer analysis is performed on the trackside collected data shown in the next paragraph.

It has proven impossible to define a SPL-speed regression curve as the data are almost all grouped in the 200÷300 km/h range. Data at lower speeds are often measured either during braking (and therefore discarded) or during acceleration (transient) phases.

4.2 Trackside collected data

The typical shape of the trackside noise recording is shown in fig. 9.

A limited number of combinations of all possible situations has been measurable. The most important parameters are the wheel surface (only standard wheels are in two different situations (worn and turned) while *Syope* wheels are only turned), the line curvature (the measurements have been performed in a straight section) and the type of fairings (all combinations measured).

The indicator of the noise is the peak SPL(A), as other noise indicators (see [1]) are meaningless in this respect. The reference condition has been considered the standard turned wheel. It can be said that, generally, freshly turned wheels have a noise emission from 3 to 5 dB(A) lower than worn wheels.

The results are shown in both a tabular (tab. 3) and graphical (fig. 10) form. From these it can be concluded that:

- no difference exists in practice between acoustically treated and non-treated fairings, and the results are not reported here for brevity;
- at conventional speed (190 km/h) the gain of fairings is limited (-2.2 dB(A)) compared to Syope wheels (-4.0 dB(A)) and a combination of the two gives the better noise reduction (-5.6 dB(A))
- at slightly higher speed (235 km/h) the gain of fairings is higher (-3.2 dB(A)) but still lower than the Syope wheels gain (-4.6 dB(A)); the combination gives a noise reduction of –6.7 dB(A);
- at 260 km/h, that is very close to the standard actual speed of ETR500 (250 km/h), both the solutions give similar gains (fairings=-5.1 dB(A), *Syope*=-5.2 dB(A)) and the combination of the two give a noise reduction of –8.7 dB(A);
- at high speed (295 km/h) the gain offered by both the solutions seems lower (fairings=-4.0 dB(A), *Syope*=-4.3 dB(A), combination of the two= –7.6 dB(A)), probably because the aerodynamic noise partially reduces their benefit.

CONCLUSIONS

During a specifically conducted tes campaign the behaviour of a new type of damped wheel (*Syope* by Lucchini CRS) has been compared to standard ETR500 wheels and to the different noise reduction solutions (fairings applied to bogie area).

Measurements performed trackside and on-board are congruent and confirm that a combination of both damped wheels and fairings give the highest noise reduction. Wether it would prove impossible or non economic to apply both the solutions, *Syope* wheels can give noise reductions higher than fairings in *every* tested situation.

It should be noted that from a maintenance point of view the *Syope* wheels require no specific provisions as they can be used for replacement on any disc braked vehicle, while fairings can limit the observability of some vital parts of the bogie.

On-board measurements showed a typical behaviour depending on the line curvature that was never been observed before mainly for the different data recording procedures. It would be certainly interesting to investigate more deeply this aspect of noise generation.

ACKNOWLEDGEMENTS

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Night 11-12/10/2000	• Rail acceleration measurements for track characterisation (no train passing)
Day 13/10 **Night 16-17/10/2000**	• Rail acceleration measurements for vertical and horizontal decay estimation (no train passing) • Track acceleration measurements during train passing • Noise measurements at 7.5 m from track centreline
Night 18-19/10/2000 **Day 20/10/2000** **Day 24/10/2000*** **Night 25-26/10/2000***	• Track acceleration measurements during train passing • Noise measurements at 7.5 m from track centreline • Rail lateral noise emission during train passing

*Table 1.Test programme followed by DMTI. During days marked with * tests have been conducted simultaneously trackside and on board.*

	Straight	Right curves	Left curves
% of line lenght	48	26	26
% of samples	43	26	31
Global gain	-4.6±2.3		
Homogeneous line type (all data)	-4.5±1.6	-6.8±2.1	-3.3±1.6
Homogeneous line type (considered data)	-4.5±1.0 (10%-90%)	-7.0±1.4 (10%-90%)	-3.3±1.1 (10%-90%)

Tab. 2 Syope wheel gains for different line curvatures..

Speed km/h	**Standard dB(A)**	**Standard + fairings dB(A)**	**Syope dB(A)**	**Syope + fairings dB(A)**
190	88.4	86.2 (-2.2)	84.4 (-4.0)	82.8 (-5.6)
235	93.2	90.0 (-3.2)	88.6 (-4.6)	86.5 (-6.7)
260	97.0	91.9 (-5.1)	91.8 (-5.2)	88.3 (-8.7)
295	98.4	94.4 (-4.0)	94.1 (-4.3)	90.8 (-7.6)

Tab. 3. Trackside peak SPL for all tested solutions. Standard wheels: average on bogie pairs # 3, 4, 5 and 8; Syope® wheels: average on bogie pairs # 6 and 7

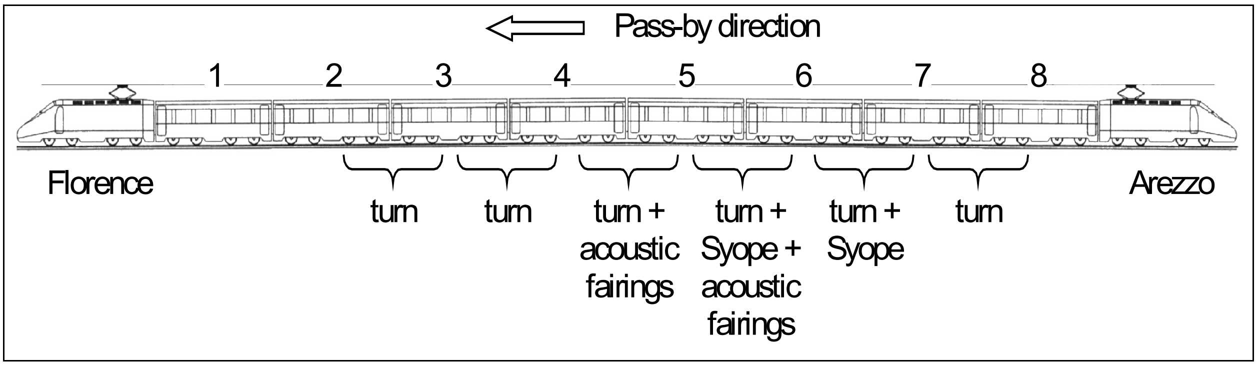


Fig. 1. Train composition

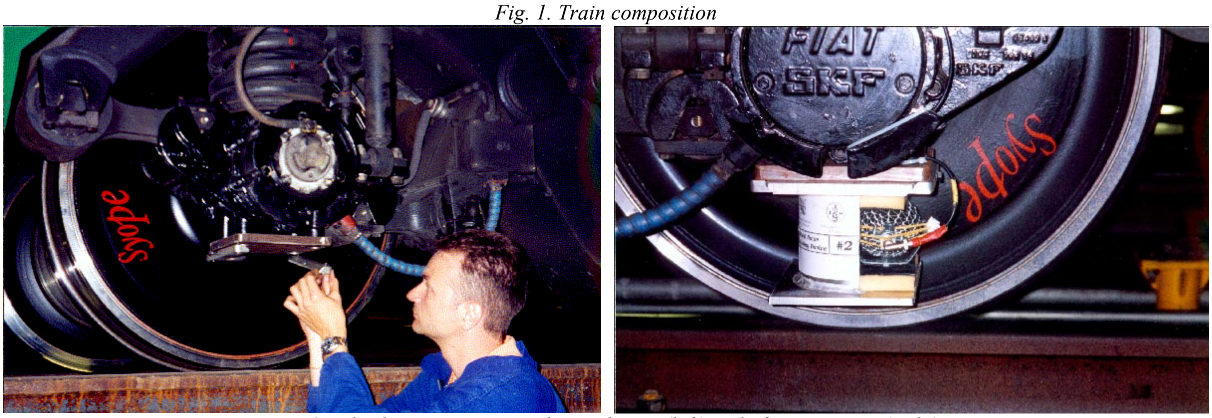


Fig. 2. Wheel noise measuring device during (left) and after mounting (right).

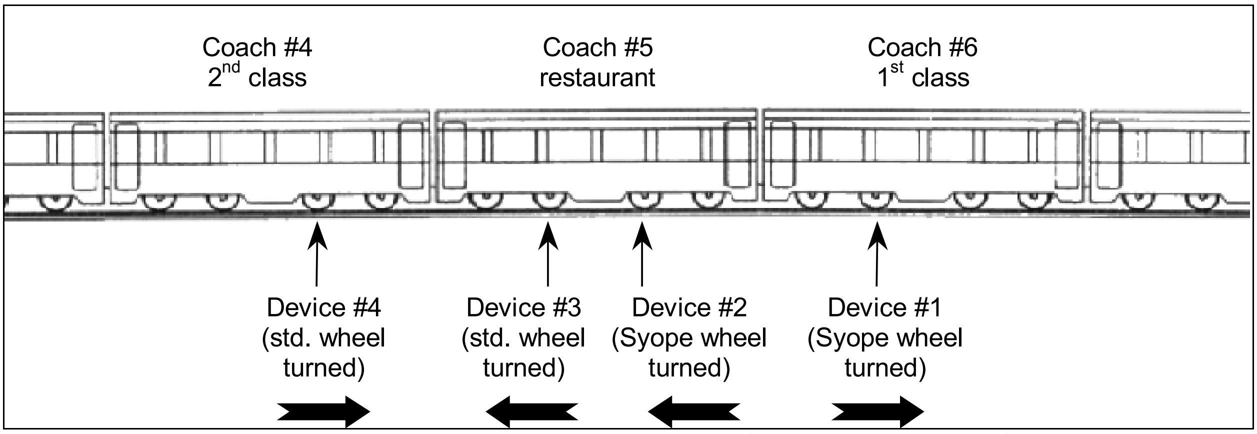


Fig. 3. Axleboxes instrumented with noise measuring device developed by DMTI with the direction of measurement.

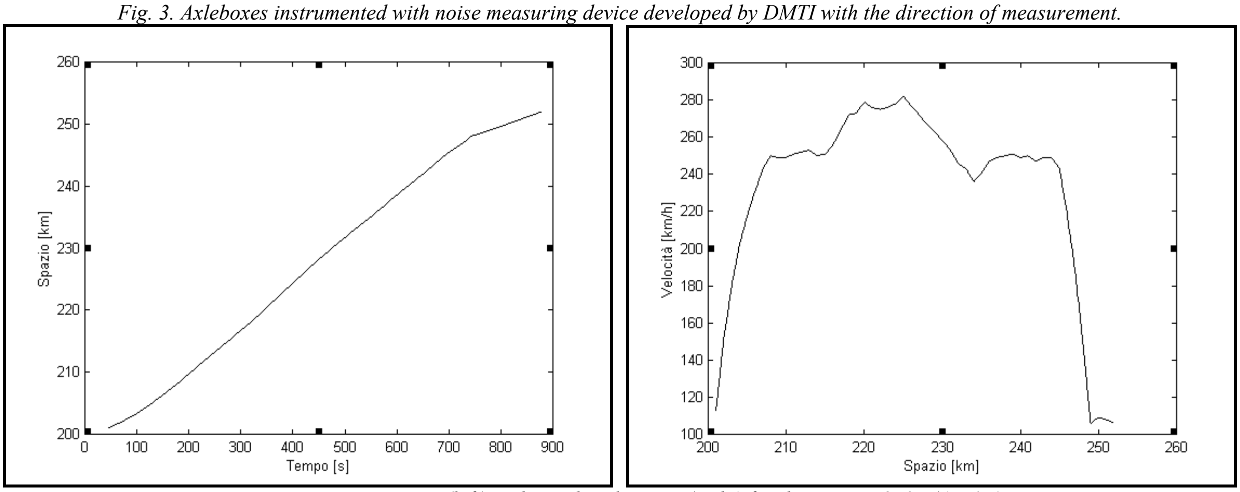


Fig. 4. Distance vs time (left) and speed vs distance (right) for the test run 2507 (Δt=1 s).

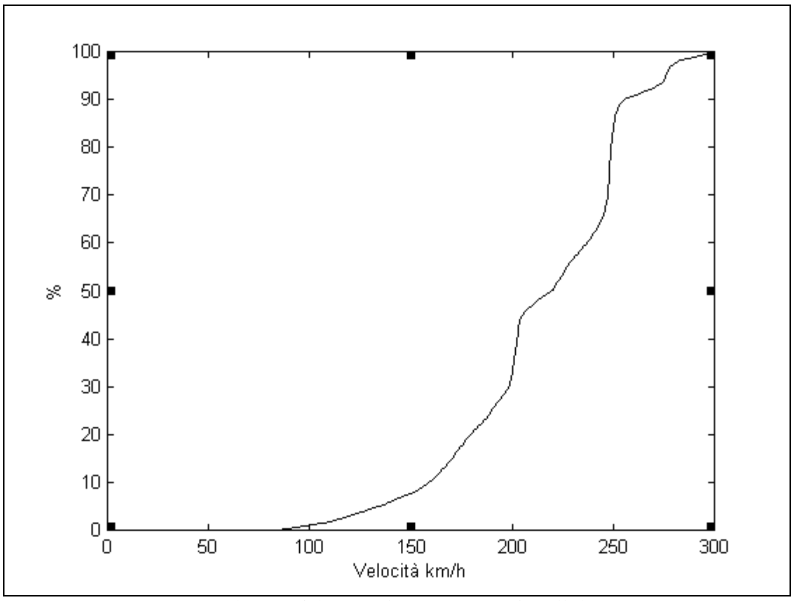


Fig. 5. Cumulative of the speed occurrencies for all the test runs

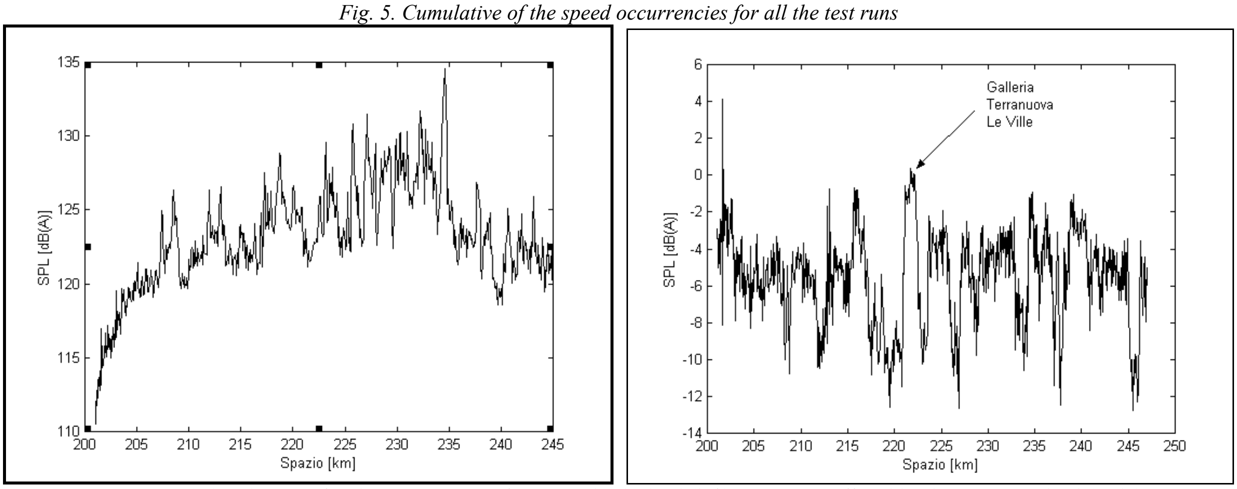
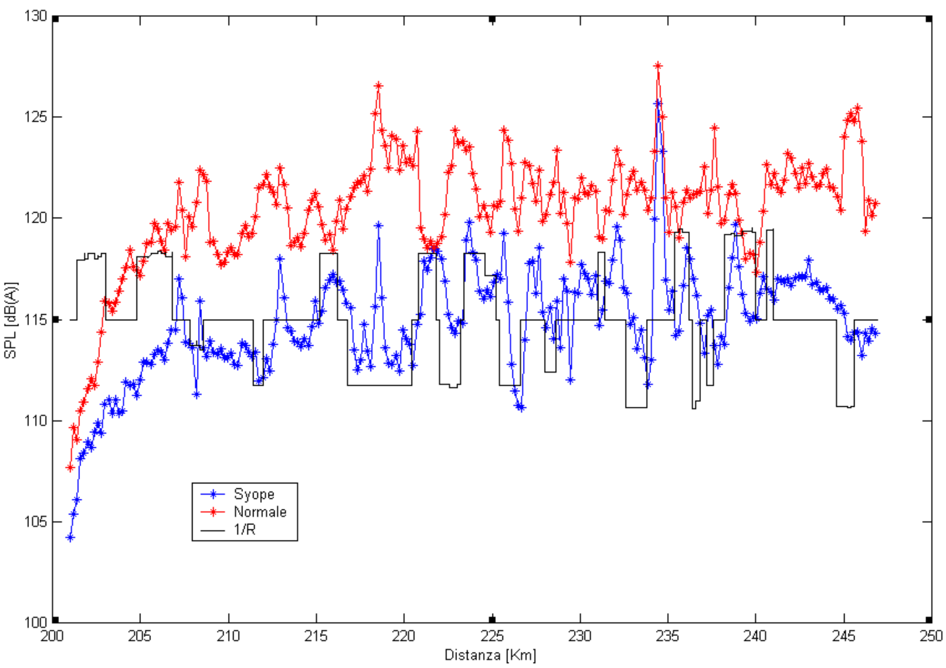


Fig. 6 SPL(A)vs distance for the test run 2507 for a standard wheel (left) noise gain offered by the Syope® wheel (right).



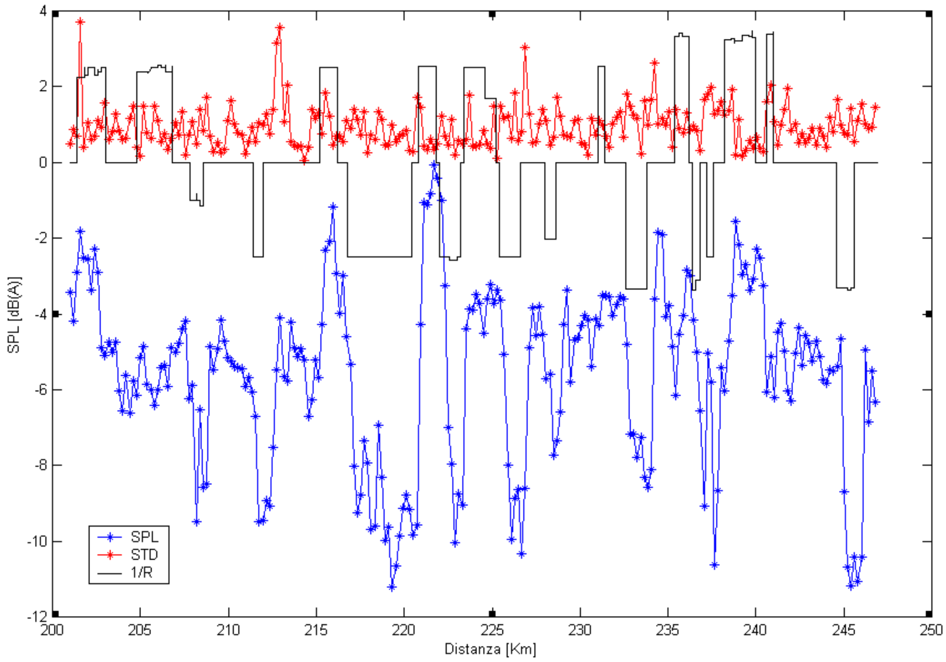


Fig. 7. SPL averaged over 200 m (upper) and difference (lower) for test run 2507. In the two diagrams it is indicated the line curvature multiplied by 10000 [m^{-1}]; in the lower diagram it is also shown the standard deviation for the data averaged in the 200 m sections.

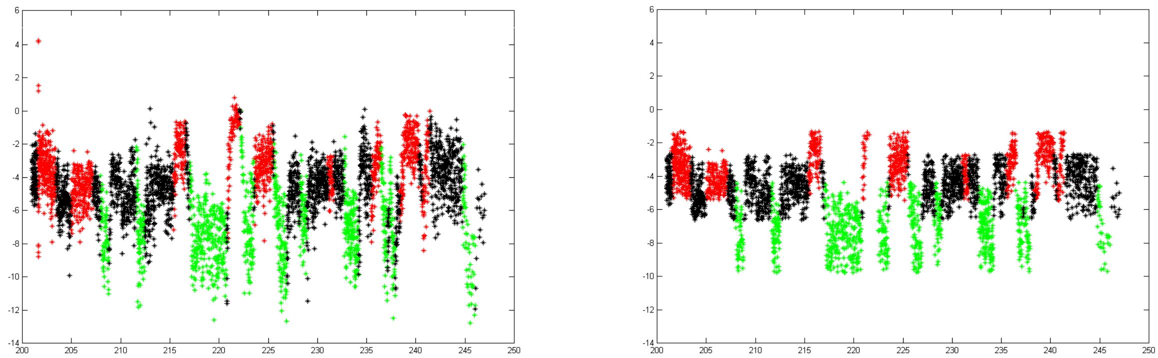


Fig. 8.Left: Syope gain averaged over 200 m (black=straight, green=right curve, red=left curve). Right: considered data between 10 and 90 percentiles.

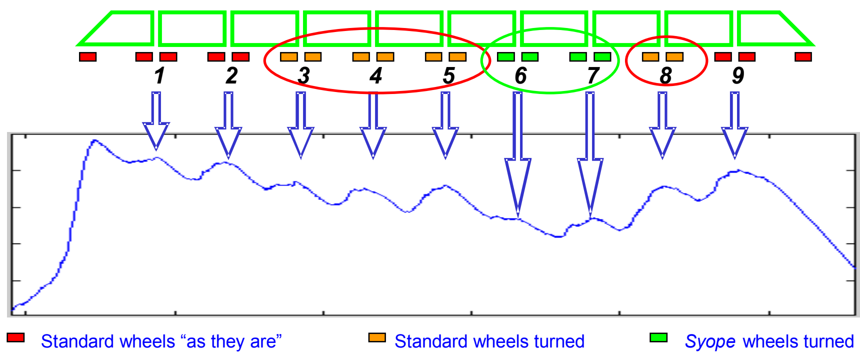


Fig. 9. Typical noise signature and bogie pairs numbering

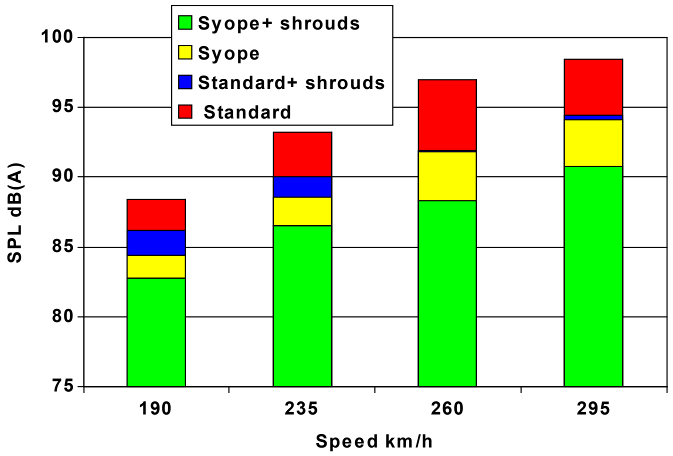


Fig. 10. Trackside peak SPL for all tested solutions. Standard wheels: average on bogie pairs # 3, 4, 5 and 8; Syope® wheels: average on bogie pairs # 6 and 7