Lucchini RS solutions for quieter freight cars wheels

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Zusammenfassung

This paper aims to review the present scenario related to the noise behaviour of railway applications to show which are the challenges coming from nowadays and future requirements and to describe how the Lucchini RS design solutions can be conveniently adopted for improving the acoustic behaviour of the wheels. In fact, during the last decades, the reduction of noise pollution has become one of the main fields of study for progress and development. In particular, the main reference for the noise behaviour of railway vehicles is the Noise TSI (Technical Specification for Interoperability), that defines a limit of 83 dB for the acoustic emissions, which is more and more considered as the minimum target to be achieved when noise reduction systems are implemented. The freight vehicles are recognized as the noisiest railway vehicle and wheels are considered the main noise source because of the interaction with the rail. An important step forward was the introduction of composite blocks, but, a more effective option is to add a vibration damping device: Lucchini RS developed the Hypno® system for tread-braked applications and the Syope® panel, when the braking method changes from blocks to axle-mounted brake discs.

Keywords: TSI, noise emission, wheel, brake system, vibration reduction

1 Historical Development of Noise Reduction Solution

Wheels are among the most important components of the rolling stock; being the direct interface between the vehicle and the rails, they are potentially subject to problems like shelling, out-of-roundness and, last but not the least, are one of the main sources of vehicle noise and their behaviour has a strong impact on the Life Cycle Cost (LCC) of the application.

As for noise, a detailed investigation of its technical aspects reveals that it is deeply related to complex interface contact conditions, e.g. stick-slip behaviour, and to the vibration modes of the wheel: legislation [1], market requirements and specific users' requests have led, over the years, to a consequent penetration into the multileveled fields of knowledge. Noise issues are of course very important for passenger applications, like suburban and long-distance services; on the other hand, they also affect the wheels in freight cars application, especially in the exploitation scenarios with freight cars running through densely populated areas, which is a common situation in Europe. At the start, stringent regulations were made in order to reduce the noise pollution of passenger cars; beside this backgrounds and restrictions, the first investigations in noise damping system date back to 50 years ago. First papers were given during the International Wheelset Congress (IWC) 1978 in Colorado; during the Hannover fair in 1979 a first publication and introduction of a wheelset with noise damping system was made. Additional systems with a tilting ring under the rim, like "Enac" were also introduced in the 90s and mainly used in France.

In 1980 a proposal with sinter block brakes material was launched in an extra program with labeled cars. The noise damping result was quite sufficient, mostly the rolling noise reduction, but the wear of the wheel increased in some cases to more than 50%, thus making this combination uneconomical: it should also be considered that at those times the sensibility to the environmental impact of railway applications was not as great as today.

High hopes came up in the 90s, when tests in Switzerland demonstrated a decrease of rolling noise of around 10 dB (A) with speed up to 120 km/h in freight cars with composite blocks. This was a great result: no extra costs, no more wear and huge noise reduction, even if, from other viewpoints, brake performance were not so efficient and the system needed to go through approval and acceptance. These test results were the basis for the development of LL brake blocks materials.

Among the topics to be considered to offer best solutions for both services (passenger and freight), the material and design selection is most likely the important decision. In this discipline Lucchini RS meets all requirements and is well known as a worldwide partner: in its portfolio several examples can be found for Low Noise passenger wheelsets with wheels in optimized steel grades, like UPLOS® and SUPERLOS® (just to name a couple of solutions defined by Lucchini RS) [2], equipped with low noise dampers like Syope® (patented solution [3]) and Galene® [4]. More than 20000 wheelsets in commuter and long-distance services all over the world, with mileages close to 3 million km, demonstrate the attractive and look-ahead spirit of Lucchini RS research and development and also the positive feedback of the operation performances.

However, the application of low noise wheels in the freight car sector is different and relatively young. Basically, the introduction of low noise wheels for freight is more complicate particular due to economic viability of this type of railway transportation, which requires low LCC coupled with a quite demanding technical and design scenario (high axle loads, up to 25 t and above and, in some cases, relatively small wheel diameters, e.g. 760 and 730 mm).

Historically, freight wheels are mainly block-braked due to the fact that in the past this was the only possible configuration and up to now it is still the cheapest one. Brake performances may lead to high temperatures in the rim, up to 500°C and more, due to friction and contact between wheel tread profile and the brake blocks. As a consequence, the residual stresses in the rim change their sign (from compressive to tensile), thus increasing the risk of eventual local cracks propagation, which may cause dramatic wheel failures. Thermostable wheels are designed in order to avoid such service problems related to the braking system: the long and fascinating story of the development of deep shaped wheels, from ORE design to SURA® [5], is well known and is also presented in [6].

In the last years, in some freight applications also disc-braked systems were adopted; these systems allow to be more flexible in wheel design and to adopt noise damping systems usually exploited on passenger applications, like Lucchini RS Syope®, as it will be explained in the following.

2 Design approach for the solutions required to optimise the freight cars wheels noise emission

The common braking system adopted for freight car is with brake blocks acting on wheel tread. The acoustic behaviour of the wheel is deeply influenced by the adopted brake blocks material, which can be cast iron or composite (LL or K, representing the new generation of brake-blocks): in particular, cast iron shoes are noisier, while composite ones are more convenient from the acoustic point of view (see TABLE I.). In order to show the acoustic effects of different brake shoes materials, a comparison was done by using the STARDAMP® software (see §3.1), considering the same wheel braked with cast iron blocks and with composite ones. By such benchmark, the noise reduction benefit connected to composite blocks adoption is evident.

In order to avoid service problems related to the brake blocks acting directly on tread surface and to the potentially high thermal loads associated with severe braking scenarios (especially when composite shoes are adopted), the so-called "thermostable wheels" [6] were developed. Such wheels are designed to avoid excessive deformations and internal stresses, that occur mostly on the rim, even in the worst expected in-service braking conditions. The Lucchini RS solution for thermostability is branded SURA® and it is covered by European patent EP2046585 [5]. SURA® is a family of wheels, covering several diameter ranges. For instance, for European freight applications various solutions are available for wheel diameter ranging from 920 to 840 mm, from 840 to 760 mm and from 760 (or 730) mm to 680 mm.

Figure 57: Brake blocks acting on wheel tread

Figure 58: Typical SURA® layout

The SURA® patented special curved web shape allows the adequate stiffness for reducing as much as possible the lateral rim displacements and rim residual stress during severe tread braking. On the other hand, such deep curved web design is not optimized against noise emissions which are already a focused topic and it's expected that in the near future even stricter regulation for freight cars will be applied; in fact, among the various railway applications the ones operating for freight transportation are considered the worst because they tend to travel more during the night time and the vehicles are typically quite long, thus increasing the number of noise sources.

Taking into account that the design of thermostable wheels like SURA®, as previously explained, is not acoustically optimized, Lucchini RS developed a noise reduction solution for tread-braked applications, called Hypno® [4]. The noise reduction systems have the purpose to reduce the wheel vibrations, acting as a damper; in the case of Hypno® the wheel absorbers are fixed to a groove under the rim and to the hub. The dissipation principle of Hypno® is based on the hysteresis cycle due to friction forces which born from relative deformation/vibration between rim and web during the rolling. The system consists in plates made by steel, in order to resist to the high temperatures that could be reached during braking due to high heat transfer from the rim to the web (around 500°C when traveling down the transalpine railway lines). This solution is already been implemented on some fleets used for freight, but also for passenger transportation.

As an alternative to the tread-braked configuration hystorically adopted for freight cars, in the last years a new wheelset design was introduces, with axle-mounted brake discs and no thermal loads acting on the wheel. This solution allows the adoption of acoustically optimized wheel design, e.g. with straight web shape (typically used for High Speed applications). Such wheelset configuration is presently not so common for freight cars because it requires a huge adaption of the existing bogies architecture, so axle-mounted brake discs are mainly adopted on the new generation freight cars.

Figure 59: Hypno® absorbers

Figure 60: Wheelset with noise absorbers Hypno®

Figure 61: axle-mounted brake discs

In the case of such new wheelset design, since tread braking is not applied, the noise reduction solution studied by Lucchini RS for passenger coaches and High-Speed vehicles is called Syope® [3]. Syope® is a multilayer panel composed by a metal layer and a visco-elastic polymer; this polymer is biadhesive, so it is positioned between the wheel and the metal layer and it is applied on the wheel web with a press machine. Thanks to the polymer dynamic deformation characteristics, the energy dissipates through heat.

In general, the Syope®-damped wheels are mainly used for High Speed service, e.g. in Europe and China.

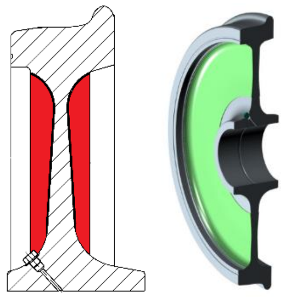

Figure 62: Syope® absorbers

3 Noise Behavior of wheels with noise reduction system designed by Lucchini RS

3.1 Test Campaign: experimental measurements of Wheel's Damping Factors and Numerical Simulation of Wheel's Acoustic Behaviour

In order to estimate the acoustic behaviour of wheels, it is possible to operate both experimental characterizations and numerical simulation. The modal analysis impact test consists in exciting the wheel with and instrumented hammer and measure the induced wheel vibration by triaxial accelerometer placed close to the excitation point. In this way it is possible to calculate, for each position in which the accelerometer is places, the Frequency Response Function (FRF) [7] [8] between the acceleration and the excitation force also called Accelerance. During the test the wheel is leaning through its internal hub lateral side on an elastic rubber support. In this condition the wheel is free to vibrate when excited on the tread surface. The other important results are the damping factors (η) calculated for all the resonance frequencies with the peak-picking method.

As for numerical simulations, one of the tools that can be conveniently implemented for a theoretical estimation of the noise emissions due to wheel/rail interaction and to compare the acoustic performance of different designs is Stardamp® (Standardization of damping technologies for the reduction of railway noise) [9]. This is a software, based on the TWINS algorithm that has been introduced as a reference in the European Standard for wheel design [10], that calculates the noise emission of a wheel in terms of Sound Pressure Level (Lp) at a certain distance (7.5 or 25 m away from the rails centerline) or

Sound Power Level (Lw). Stardamp® is a useful tool to compare the noise emission of solid wheels with different geometries and damping devices (if any). It enables the distinction of the noise emitted by the wheel from the noise emitted by the track and then provides the combined noise. Of course, when the track becomes dominant over the wheel emission, noise improvements of the wheels side become less effective. Input parameters are:

- The modal model of the wheel (either frequencies and mode shapes) provided by a FEM software (e.g. Ansys®), complemented in the case of damping devices, with the modal damping factors obtained by the experimental modal test on the wheel;
- The modal model of the track complemented by the track decay rates, depending on rail pad stiffness and damping, use of ballast or concrete and sleeper type;
- The roughness of the wheel and the rail;
- Wheel load;
- Vehicle speed (a typical valued considered for fright cars is 80 km/h)

In this paper all results are then expressed in terms of A-weighted Sound Pressure Levels emitted by the wheel, at 7.5 m far from the railway and 1.2 m of height. An example of the output of comparative acoustic characterizations performed with Stardamp® is reported in Table 1. , where the sound pressure is reported for the Lucchini RS SURA® wheel braked with different system (the other parameters

Table 1: Overall Levels of A-weighted Lp estimated on Lucchini RS SURA® Wheel with Different Brake Systems

Brake System	**Lp [dB(A) re 2x10^{-5} Pa]**
Cast iron	78
K-Block	72

remain the same). Though these simulations, the obtained values should be considered as theoretical, but they can represent a good basis for comparing different designs in terms of noise behaviour.

3.2 Results of Hypno® System

The effect of Hypno® can be estimated firstly during the experimental test in laboratory, measuring the damping factors of the wheel with and without the system mounted on; and then using these data to perform the simulation with Stardamp® software to obtain information about the noise behaviour in both the configurations. In the following, the wheel that is considered for the comparison is Lucchini RS SURA® Ø760. Figure 7 shows the η calculated with peak-peaking method while Figure 8 represents the diagrams of Lp in both configurations of the wheel and Table 2 summarizes the different contributions in terms of the overall frequency band Lp, to ease the comparison. From the results reported, it is clear how the Hypno® system reduces the noise emission very effectively.

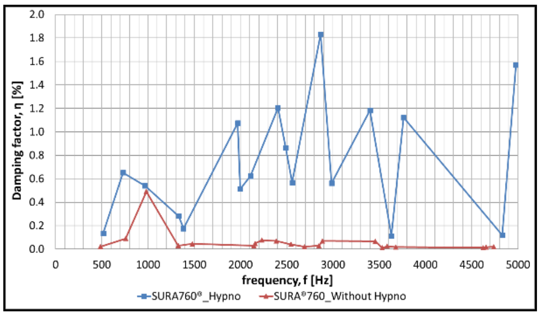

Figure 63: Damping Factors; SURA® 760 with and without Hypno® system

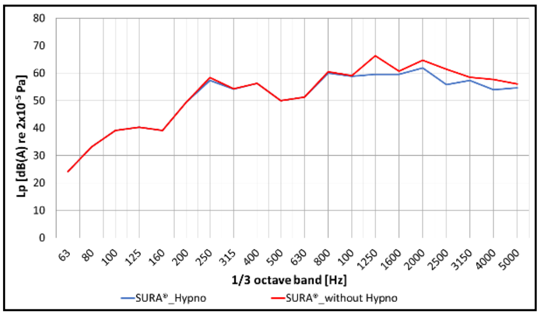

Figure 64: Sound Pressure vs frequency; SURA® 760 with and without Hypno® system

Table 2: Overall levels of A-weighted Lp estimated on Lucchini RS SURA® 760 wheel with and without Hypno System

SURA® 760	**Lp [dB(A) re 2x10^{-5} Pa]**
Without Hypno®	72
With Hypno®	69

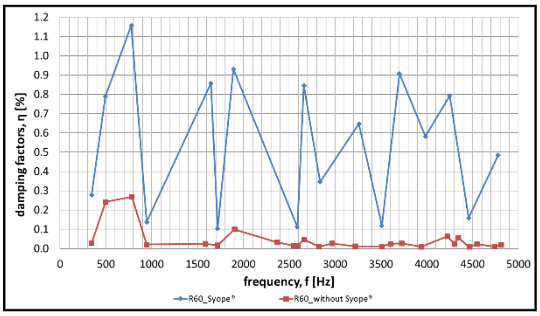

Figure 65: Damping Factors; R60 wheel with and without Syope®

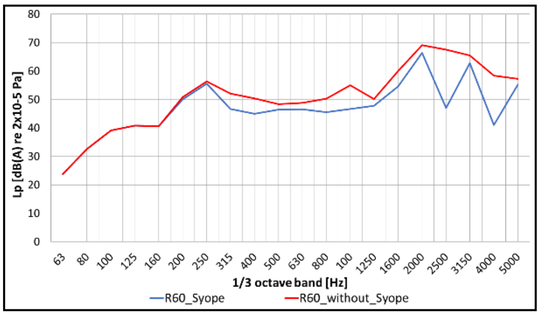

Figure 66: Sound Pressure vs frequency; R60 with and without Syope®

Table 3: Overall levels of A-weighted Lp estimated on R60 wheel with and without Hypno System

R760	**Lp [dB(A) re 2x10^{-5} Pa]**
Without Syope®	73
With Syope®	69

3.3 Results of Syope® System

Similar as before the effect of Syope® panel on the noise emission can be estimated starting from modal analysis impact test in laboratory and then using the damping factors measured in this way to perform the calculation through Stardamp®. In this case the comparison is made, without Syope® and then with the panel attached, on a straight-web-shaped wheel designed for a freight wheelset braked by axle-mounted discs; the other parameters remain the same. Figure 9 shows the η obtained from experimental tests, while Figure 10 represents the diagrams of Lp in both configurations of the wheel and TABLE III. summarizes the different contributions in terms of the overall frequency band Lp, to ease the comparison. From the results reported, it is clear that the Syope® system brings great advantages in terms of noise behaviour, even better than Hypno®, but it shall always be considered that this solution is limited to non-tread-braked wheels.

3.4 Benchmark between the solution made by Lucchini RS and the rings solution

Another possible solution to reduce noise emission historically adopted for railway wheels is to insert steel rings in a groove under the rim. The idea is based on increasing the stiffness of the rim and so reduce the possibility to vibrate. Even if it is a cheap design, this is not so good compared with the previously described Lucchini RS solutions. Figure 11 shows the damping factors obtained from experimental tests, while Figure 12 represents the diagrams of Lp in both configurations of the wheel and Table 4 summarizes the different contributions in terms of the overall frequency band Lp, to ease the comparison.

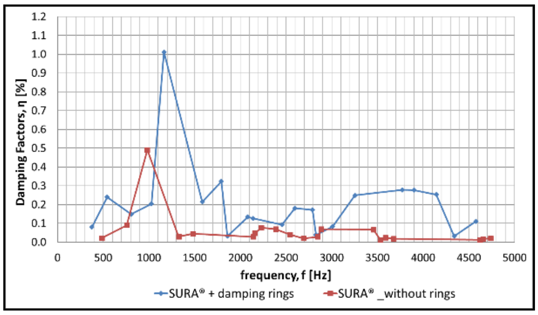

Figure 67: Damping Factors; SURA® with and without damping rings

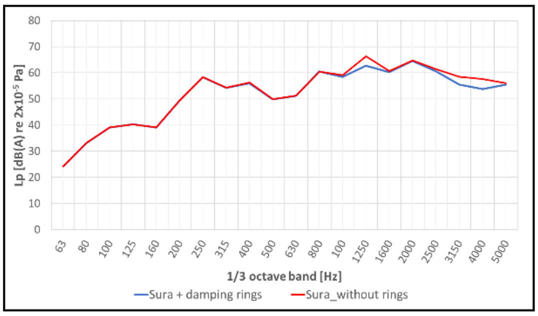

Figure 68: Sound Pressure vs Frequency; SURA® with and without damping rings

Table 4: Overall levels of A-weighted Lp estimated on SURA® with and without damping rings

SURA®	**Lp [dB(A) re 2x10^{-5} Pa]**
Without damping rings	72
With damping rings	71

4 Introduction to the innovative projects where Lucchini RS is involved

In the last years, Lucchini RS was partner of many innovation European programs aiming to the reduction of the freight cars noise. In general, such programs are launched to develop and test innovative freight wagons, noise mitigation being one innovation point; among them, Lucchini RS is presently participating to 5L Demonstrator / TIS, coordinated by SBB (Swiss national railway), and to Innovativer Güterwagen / BMVI, coordinated by VTG and DB and financed by the German government. In both cases Lucchini RS provided wheelsets with noise reduction systems (Syope® for 5L Demonstrator / TIS; Syope® and Hypno® for Innovativer Güterwagen / BMVI) for the in-service tests (see Fig.13).

The noise-related data collected during the freight cars journeys are not fully available at the present time, however, according to the already available service feedback, the Lucchini RS solutions for noise reduction appear among the best undergoing exploitation testing.

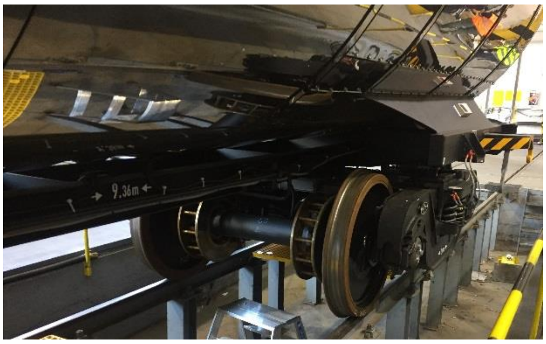

Figure 69: Wheelset with Syope® supplied for the Innovativer Güterwagen project.

5 Conclusion

For a railway vehicle, wheels and rails are the main noise source of the system. Among different railways vehicles, the ones operating for freight transportation are considered the worst because they tend to travel more during the night time, and they are much longer thus contributing in larger part to noise emission. Being new generation brake blocks and wheels not able to fulfil by themselves the noise emission limits gave from the new EU regulations, Lucchini RS designed two specific noise mitigation solutions: Hypno® and Syope® (the latter applicable only in case of non-tread-braked-wheels). Based on numerical simulations, experimental testing and service exploitation results, these solutions prove to be effective and can be conveniently adopted by operators in order to comply with the most demanding noise emission requirements for railway applications.

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