Acoustic Effectiveness of Damped Wheels and Impact on Life-Cycle Cost of Different Typologies of Passenger Trains

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Summary

Railway noise reduction at the source is the preferred way indicated by the European legislator, although certainly the hardest to be obtained from an engineering point of view. A cost-benefit analysis of the available solutions should drive the political decisions. This paper describes the impact of a specific low noise wheel, with noise reduction effects proven in normal service, on the Life-Cycle Cost of different types of vehicles. The analysis is conducted on several types of passenger rolling stock, i.e. high speed trains, both conventional and tilting, Electrical and Diesel Multiple Units.

1 Introduction

Rolling noise is the main source of railway noise in a wide range of speeds, approximately up to 250÷300 km/h where aerodynamic noise becomes prevailing. To reduce rolling noise it is necessary either to reduce the wheel and rail *combined* roughness or the radiation properties of the bodies involved. Unfortunately the *combined* roughness is not adjustable by changing transverse profiles but only by grinding the rails, a methodology that is valid only when wheel and rail roughness are similar, i.e. for disc braked wheelsets. Measure to reduce wheel roughness for tread braked vehicles are not described here.

Measures acting on track radiation are quite various and can be complicated; it was shown that carefully designed rail dampers can noticeably reduce rail noise (up to approximately 5 dB) but that their effect on overall noise is much lower (in the order of 2÷3 dB) if not used in conjunction with low noise wheels [1].

This paper deals with damped wheels, which are used in commercial service with relevant overall noise reduction. One of the classical arguments against the use of "low noise" wheels is their extra cost as both first fitting and spare parts, neglecting not only all the other associated costs (maintenance, disposal) but, even more important, the advantages given by their use and the associated savings.

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While it is clear that in very loud situations the use of low noise wheels can not solve the noise problem, in many "border" cases their use can save the erection of noise barriers, of which the cost is nowadays in the order of 1 M€/km of double track. The paper will show how the costs associated with the use of damped wheels are only a fraction of that value, even if considered for the entire life of a train.

2 The Lucchini Sidermeccanica *Syope*® Wheel: Description, Performances, Considerations

Lucchini Sidermeccanica SpA approached the low noise wheels field in 1995, and the *Syope*® treatment was readily developed to provide levels of damping much higher than the *rolling damping* [2]. The treatment consists of a steel layer constraining a special adhesive polymer sheet developed by 3M attached to the wheel web. The *Syope*® treatment can be retrofitted on any existing axial symmetric disc-braked wheel mounted on the axle at room temperature (press-fit) [3]. A modified version of the treatment, named *Syope Braw*®, is under development for wheels with web-mounted brake discs [4]. The behaviour in service and during numerous test campaigns is described in a number of papers [5, 6, 7, 8, 9,10] to which the reader is referred for further details. Roughly speaking, the observed $L_{pA,max}$ (*overall* A-weighted maximum level, measured at 25 m from the track axis with the Fast time constant during pass-by) reduction, treating the wheels of an existing vehicle with the *Syope*® treatment is in the order of 3 to 5 dB, without any treatment or modification applied to the track.

The use of "special" wheels is always debated as the inevitable associated costs and complications (maintenance, disposal, non-destructive testing, risks associated to objects mechanically mounted on the wheel, etc.) must be carefully addressed.

Since the first tests in 1998 on the Fiat Ferroviaria SpA (now Alstom Ferroviaria SpA) train set ETR470-0, the experience gained in several years of testing and service allows to say that:

- some wheels travelled for more than 5 years before the end of their useful life and for more than 1.1 million kilometres without any reduction of safety (i.e. detachment of the steel constraining plate);
- no special attention or procedure was needed during the service. For the final user, the wheel treatment can be defined as a "fit and forget" measure that effectively reduces noise without any impact on maintenance procedures;
- withdrawal and disposal followed the usual procedures as no risks or additional costs are associated to the treatment. Scrap steel can be re-melt in the electric arc furnace without generating noxious gases (dioxin).

3 Life Cycle Cost Analysis and the Implication of Syope® Wheels

Life-cycle costs (LCCs) are all the anticipated costs associated with a project or program alternative throughout its life. This includes costs from pre-operations through operations or to the end of the alternative. By applying the principles of LCC analysis, it is possible to evaluate several designs and select the one with the lowest LCC [11,12]. The definition of the typical system profile is crucial. It is generally recognized that it is necessary to perform an LCC analysis early in a project's life. This is particularly evident in those systems for which the operational support forms a substantial part of the LCC. An example of the impact of the R&D development is shown in Fig. 1, together with an LCC profile for system acquisition where operation and support costs are the greatest part of the life-cycle cost.

Rolling stock purchasing is a complex activity that involves many technical, economical and environmental issues. Train operating companies (TOCs) have developed in the years, often with the help of consultancy experts (typically from defence), their own models to evaluate LCC. While R&D, engineering and manufac-turing costs are relevant to the industry, operating costs are associated with normal service and therefore are sustained by TOCs that, on their side, control the efficiency of their rolling stock in terms of RAM indices (Reliability, Availability and Maintainability). The procurement of new rolling stock is therefore normally accompanied with a Technical Specification including an in-depth decomposition of the vehicle and the allocation of availability, maintainability and reliability with associated indices (MTBF, MTTR, and the like).

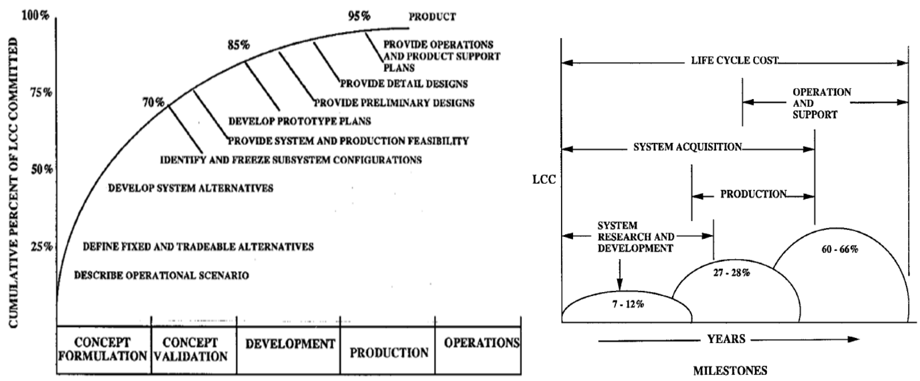

Fig. 1. Actions affecting LCC (left) and typical LCC profile for system acquisition (right) (from [12])

At the same time, an analysis of the faults and of their impact on service has to be done with the classical FMECA (Failure Mode, Effects, and Criticality Analysis) applied to the Function Block Diagram (FBD) of the vehicle in order to find the Reliability Block Diagram (RBD). This last document is particularly important as redundancy is taken into account and the calculation must be performed on all the mission profiles identified by the customer. For the railway sector, criticalities of the failures are commonly classified on the type of service disruption that is consequent to the failure. Maintenance is commonly split in preventive (programmed, on-condition and predictive) and corrective maintenance. All the associated activities have an impact on the LCC, both in the design phase, where all the problems should be addressed at their best, and in the operation phase.

The *Syope*® wheel is normally proposed as an additional feature to be applied on existing or new rolling stock. Limiting the analysis to new rolling stock, for which an LCC analysis can be conducted "from the cradle to the grave", it is fundamental to evaluate the impact of the treated wheel on a vehicle's cost, including all direct and indirect aspects. This identification is fundamental in order to understand if the use of such wheels requires a different LCC model or if it is sufficient to input in the model the extra cost of the treated solution.

The activities that can be linked to the pre-delivery phase of a new rolling stock, already shown in Fig. 1, may be affected by the use of a damped wheel. They can be analyzed as follows:

- *concept formulation:* if the new train typology allows the use of damped wheels, there are no additional activities or costs associated to their adoption as the desired wheel properties (strength, stiffness, weight) can be obtained *independently* from the damping;
- *concept validation:* i.e. the validation of the solution including safety assessment of the vehicle. In this case the use of the treatment is neutral as it does not affect the mechanical properties of the wheel [13]. No specific procedures need to be used to evaluate the behaviour of the wheel in service under the usual loads. No extra costs are therefore associated to this phase linked to the use of *Syope*® wheels;
- *development:* there is no impact on development costs of the vehicle, as the treatment introduces negligible masses (calculations remain valid);
- *production:* wheelsets installation is not affected at all by the use of the damping treatment on the wheels. There are therefore no additional costs associated in the vehicle production phase.

As shown in Fig. 1, operations can be a relevant part of the total LCC. Also in this case it is necessary to evaluate the effects of the use of a damped wheel on the forecast overall cost of the vehicle for its entire life. Activities and consequences can be analyzed as follows:

- *availability:* that the use of damped wheels does not affect in any way the fleet availability, i.e. there are no failures associated that can reduce this parameter. No extra costs are therefore anticipated to take into account the possible reduction in the availability associated to the use of damped wheels;
- *reliability:* no reduction in the reliability of the wheelset subassembly is to be expected by the use of damped wheels. Being a non-structural treatment, the constrained layer damping technique leaves unaltered the behaviour of the wheel, neither introducing new modes of failure nor changing the failure rates for the usual wheels. There are therefore no associated costs;
- *maintainability:* wheelset maintenance is a complex subject, but it can be said that for routine operations (for example ultrasonic testing or visual check), no modifications to the standard maintenance routines is requested. Wheel reprofiling can be done with the usual tools and machine tools (either underfloor or parallel lathe). The use of damped wheels leads to no modifications in the LCC calculation scheme.

As a consequence, *Syope*® wheels are "neutral" for the LCC calculation that can be used by simply increasing the cost of the wheel of the amount related to the damping treatment. Also for the disposal at the end of life, there are no additional costs associated.

4 Simulation of the Impact of *Syope*® Wheels on LCC

Alstom Ferroviaria SpA, one of the companies of the Alstom Transport group, is the manufacturer of all the tilting trains running in Italy, and the same will apply with the new Trenitalia ETR600 and Cisalpino ETR610 (tilting train, max speed 250 km/h). For reasons that will not be analyzed here, there is a general tendency to purchase passenger rolling stock with distributed power with electric or diesel power (the so called EMU or DMU, i.e. Electrical or Diesel Multiple Units). These train sets are normally seen as a whole, simplifying the management and the effect of low noise vehicles. The calculation of the LCC of a train is a complex activity that can not be done with the goal of writing a paper. The only possibility to have an idea of the impact of the application of damped wheels is to use already prepared LCC calculation schemes, simply by introducing the corresponding extra cost of the wheel. A fully developed and validated LCC model was available for four types of vehicles:

- a high speed (v_{max}=250 km) dual voltage tilting train with distributed power (EMU, 7 coaches, 8 wheels/vehicle), with an expected life of 25 years (three wheel changes expected);
- a high speed conventional trainset with distributed power (EMU, 7 coaches, 8 wheels/vehicle, v_{max}=250 km/h) , with an expected life of 25 years (three wheel changes expected);
- a regional train (EMU, 3 coaches on 2 motor bogies + 2 Jacobs bogies, 16/3=5.8 wheels/vehicle), with an expected life of 30 years (three wheel changes expected);
- a regional train (DMU, 3 coaches on 2 motor bogies + 2 Jacobs bogies, 16/3=5.8 wheels/vehicle), with an expected life of 25 years (two wheel changes expected).

The LCC model includes numerous sensible data that cannot be detailed here for confidentiality; it is anyway important to highlight that the estimation is conducted on trains already in service or in the delivery phase, and this ensures the maximum validity to the calculations. Different approaches to maintenance and different types of service are included in the simulations, and this gives the calculation an even greater validity, clearly slightly increasing the spread in the results.

Both the impact on maintenance cost, which is important to economically compare the application of low noise wheels on an existing fleet and the use of noise barriers, and the impact on LCC on the new rolling stock, including the cost of the new train set, were evaluated. The latter value is especially most important as it quantifies the overall impact of the damped wheels for the entire useful life of the train.

The results are shown in Table 1. From these values it can be concluded that:

- costs associated to the trainset range from 0.26% to 0.87% of the LCC. It is likely that for more complex trains this value will further decrease, while for simpler trains it could increase;
- impact on operation costs only are similarly quite variable (from 0.54% to 2.3% of the LCC) mainly depending on the complication of the considered vehicle. Not surprisingly, the highest value is obtained for a rather simple vehicle (a trailing car with little equipment of a high speed non-tilting EMU) while for the lowest value is obtained for a motor car of a DMU trainset whose complication and associated operating costs are inevitably higher.

Table 1. Evaluation of the impact of damped wheels on operation costs and on LCC

	Impact on operation costs %	Impact on Life-cycle cost %
Tilting EMU (250 km/h)		
Train set (7 cars)	1.5%	0.74%
Motor car (#1)	1.3%	0.66%
Trailer car (#4)	2.0%	0.87%
EMU (250 km/h)		
Train set (7 cars)	1.6%	0.79%
Motor car (#1)	1.4%	
Trailer car (#4)	2.3%	
Regional EMU		
Train set (3 cars)	1.27%	0.35%
Motor car (#1)	1.08%	
Trailer car (#2)	1.14%	
Regional DMU		
Train set (3 cars)	0.64%	0.26%
Motor car (#1)	0.54%	
Trailer car (#2)	1.55%	

To provide absolute figures, the LCC cost of the fleet of 20 non-tilting EMU is estimated in the order of 405 M€, 5.8 M€ of which are the extra cost associated with the use of the *Syope*® treated wheels.

5 Conclusions

The use of damped wheels with low noise emission is often debated as their use is inevitably linked to extra costs for wheel purchase. The evaluation of this alternative is only partly satisfactory as wheels are an important component whose cost contributes to the total LCC of the train together with many other important factors.

The evaluation of the extra costs associated to the use of damped wheels was therefore performed on different trainsets for high speed, long distance and regional passenger trains (either with electrical or Diesel traction) showing that the impact on costs is limited and that there is a distinct advantage in using low noise wheels in those situations where noise limits are not respected for a few decibels.

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