# The STARDAMP Software: An Assessment Tool for Wheel and Rail Damper Efficiency

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## Introduction

STARDAMP (Standardization of damping technologies for the reduction of railway noise) is a Franco-German research project within the DEUFRAKO framework that unites end users, manufacturers and research institutes. A general description of the project has been presented at DAGA 2012 [1]. The target of STARDAMP is to support the transfer from R&D of rail and wheel dampers to their regular application. Indeed, rail and wheel dampers are interesting solutions that permit further reductions of railway noise, beyond the gain that can be achieved by reducing wheel roughness (by a change in braking system). However, a rail or wheel damper that reduces the noise by X dB in every situation does not exist; the performance always depends on the considered track, rolling stock and operating conditions.

A software tool has been developed within STARDAMP that is dedicated to the prediction of the efficiency of wheel and rail dampers. The necessary input can be produced using relatively simple laboratory measurements. The tool is designed not only for the use by experts within the development of wheel and rail dampers. Indeed, a main goal of STARDAMP was to provide an easy-to-use tool to infrastructure managers and public authorities in order to help the decision making process regarding railway noise mitigation measures.

## A few words on rolling noise

This section gives a very short introduction to rolling noise and its mitigation measures. For more details we refer to reference [2].

The origin of rolling noise can be found in the asperities that are present on any wheel tread and rail head. This surface roughness introduces a relative displacement of wheel and rail and causes both components to vibrate and to radiate noise. Wavelengths of roughness that are relevant to rolling noise are approximately between 5 mm and 0.5 m. When a train runs with speed $V$ over surface asperities of wavelength $\lambda$, this produces vibrations of frequency $f$ as given by

$$f = \frac{V}{\lambda} \qquad (1)$$

The relative displacement imposed by the roughness causes vibration of the rail and / or wheel, depending on the receptance of each component in the considered frequency range. Typical calculated receptances of a standard ballasted track and a monobloc wheel are displayed in Figure 1. The double peaks that are visible in the wheel receptance curve are due to rotational effects [3].

Clearly, the behaviour of the rail (effectively an infinite beam on elastic support) is very different from that of a wheel (which has a modal response). Also, one distinguishes different frequency domains that are "dominated" by the rail or the wheel. The local deformation of wheel and rail is not taken into account by these receptances. This effect is described by an additional contact receptance. It is inversely proportional to the contact stiffness, which depends on material properties and the local geometry involved (notably the contact patch dimension).

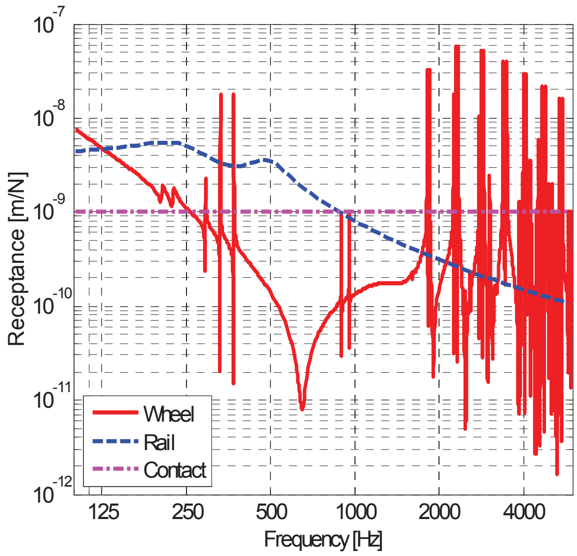


Figure 1: Wheel (LK 900 bare wheel), rail and contact receptances (vertical direction).

All this suggests that rail noise dominates at lower frequencies while wheel noise dominates at higher frequencies. In fact, however, the track contains other components than the rail that also radiate noise. Especially the sleeper contribution is generally important at low frequencies.

As indicated above, the relevant roughness spectrum covers the wavelength range between 5 mm and 0.5 m. Typically, both rail and wheel roughness decrease towards smaller wavelengths (i.e. higher frequencies). Additionally, a contact filtering effect occurs due to the finite size of the contact patch between rail and wheel. As a consequence, the 'filtered roughness' that is effectively seen by rail and wheel has a strong frequency dependence (of about -9 dB/ octave in the higher frequency bands). Due to the wavelength-frequency relation of Equation (1) this also means that the excitation spectrum is shifted with train speed, leading to a 9 dB increase of excitation in the upper frequency bands for a doubling the speed. This 9 dB/doubling or 30 log($V/V_0$) dependence is indeed frequently assumed, e.g. in the TSI Noise [4]. However, not only the overall level but also the relative importance of track and vehicle components of noise changes with frequency. The relative importance of the wheel contribution increases with speed.

# The principles of rail and wheel dampers

In structural dynamics, a damper is defined as a system that adds damping to a structure, i.e. converts a part of its vibration energy into heat. STARDAMP exclusively deals with rail and wheel dampers that correspond to this definition, excluding devices that mainly act through shielding.

## Rail dampers

A rail behaves similarly to an infinite beam on an elastic support. Its damping is therefore not characterised by modal damping coefficients but by a decay rate that determines the spatial decay of waves in the longitudinal direction. Even though different types of waves can propagate along the rail (bending, longitudinal and torsional waves) its behaviour can be sufficiently described by one vertical (the more important) and one lateral decay rate. These decay rates Δ are expressed in units of dB/m, and are related to the imaginary part of the complex wavenumber $k_i$ as

$$\Delta = -20 \log_{10}(\exp(k_i)) = 8.686\, k_i \qquad (2)$$

Note that a doubling of decay rates leads to a 3 dB reduction of noise radiated by the rail so decay rates are usually plotted in a logarithmic scale.

Decay rates mainly depend on the stiffness of the elastic support (the rail pads) because the damping inherent in the rail itself is very low. Rail and rail pads represent a mass-spring system with a resonance frequency of around 300 Hz to 1 kHz, depending on the rail pad stiffness. Above this resonance the rail becomes decoupled from the sleepers and decay rates drop below 1 dB/m. At frequencies well below the resonance, vertical decay rates found in practice are of order 10 dB/m. Indeed, the low frequency behaviour mainly depends on the ballast properties which generally do not vary too much from one site to another.

In summary, stiff rail pads permit significant reductions in the vibration of the rail compared with soft rail pads. However, stiff rail pads lead to higher sleeper vibration, and thus, to higher noise radiation of the sleepers. Rail dampers allow the track decay rate to be increased in the mid frequency range without increasing sleeper vibration. Such rail dampers are generally mass-spring ‘absorber’ systems attached to the rail at mid span between the sleepers. An example is shown in Figure 2. These mass-spring systems have a high internal damping and multiple tuning frequencies in order to be effective over a broad frequency range (for more details see e.g. [5]). Figure 3 shows an example of measured track decay rates in vertical and lateral direction for a track fitted with stiff pads with and without dampers. Obviously, the use of rail dampers is more beneficial on a track with soft rail pads than on a track with stiffer ones.

Figure 2: Rail damper manufactured by Schrey&Veit.

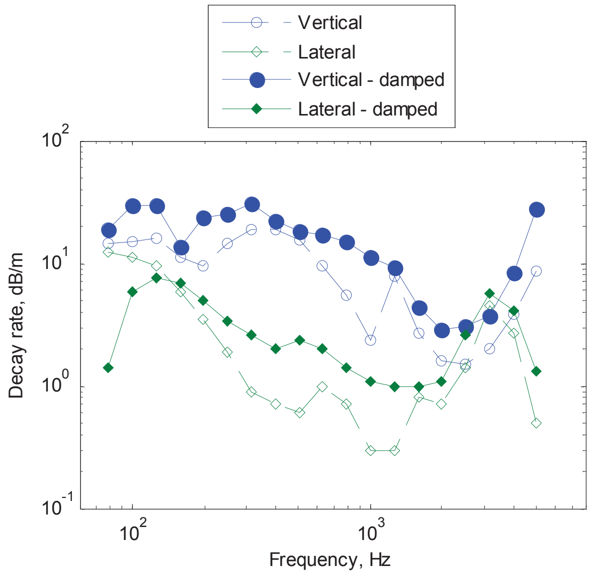


Figure 3: Vertical and lateral track decay rates, comparison of measurements performed with and without dampers. Courtesy of SNCF.

## Wheel dampers

Wheel dampers act by increasing the modal damping of the wheel. The modal damping of bare monobloc wheels is generally very low; however, the wheel-rail contact leads to some additional damping. The effect of dampers should therefore be higher than this ‘rolling damping’ in order to produce a net benefit. This has been illustrated in reference [6].

Available wheel dampers include tuned mass-spring systems with a similar design to the rail dampers shown above. Another design is shown in Figure 3, consisting of slotted metal plates and a resilient layer that is put under shear between these plates. Besides dispersion of energy in a resilient material, dry friction can add damping. This principle is exploited using friction rings that are clamped to the inner side of the wheel rim.

As the wheel contribution to total noise increases with speed, wheel absorbers are especially effective at higher speeds.

Figure 4: Wheel damper manufactured by GHH.

## The STARDAMP software

Software has been developed within the STARDAMP project which is called the 'STARDAMP-tool' in the following. The graphical interface is shown in Figure 5. The software is based on the same theoretical model contained in the TWINS software [7]. It implements an analytical description of the wheel-rail interaction where the contact forces are calculated as the ratio between the wheel-rail roughness spectrum and the sum of rail, wheel and contact mobilities. Both vertical and lateral degrees of freedom at the contact are considered. From the contact forces, wheel, rail and sleeper responses are calculated and the power levels estimated through radiation efficiencies. Finally a simple propagation model on an absorptive flat ground gives the sound pressure levels at specific field positions.

Vertical and lateral rail mobilities are calculated by a Timoshenko beam model on a double layer continuous elastic support, which accounts for pads, sleepers and ballast. Sleepers are modelled either as a rigid mass or as a finite Timoshenko beam, depending on direction and track type. To define the track, several combinations of track types, sleeper types, rail types and pad stiffness and damping values can be selected. Most importantly, the track can be ballasted or slab-track, in this second case the continuous elastic support has a single layer only. For ballasted track the sleeper can be monobloc (concrete or wooden) or bibloc. The STARDAMP-tool can analytically determine decay rates from the track response or, when dampers are applied on the rail, can use measured values.

The wheel geometry is too complicated to allow usage of simple analytical models, therefore the wheel is described in terms of Finite Element (FE) computed natural frequencies and mode shapes at the contact point and at a limited number of positions on the external face. This information is stored in an external text file (Modal Parameters file) which is loaded in the tool; wheel mobilities are then calculated through modal summation and modal damping ratios can be added either adopting standard values or after measurements. Modal models of three typical undamped wheels of freight, regional and high-speed trains are implemented in the software. The user can also include their own. When assessing wheel damper effectiveness, specific new modal parameters file have to be prepared by the user.

The contact stiffness in the vertical direction is computed by linearizing the relationship between wheel-rail approach and applied load as formulated for example in [8]; contact vertical receptance is readily derived from stiffness. Lateral receptance is obtained in a similar manner but in this case the effect of spin creepage (rotation about the axis perpendicular to the contact plane divided by mean rolling velocity) is also considered.

In contrast to TWINS, the STARDAMP-tool performs the complete post-processing including roughness excitation and contact filtering. Typical roughness spectra corresponding to wheels with cast iron brake blocks, K-block brakes and disc brakes are supplied. Generally, the number of accessible options is reduced with respect to TWINS in order to permit the use by non-expert users through a rather simple Graphical User Interface (GUI), see Figure 5. Lastly, to increase reliability, the final results shown are an average over three contact positions: the nominal one (70 mm from flange back) and ± 10 mm from this.

The STARDAMP-tool permits the direct assessment of rail dampers, wheel dampers, or a combination of both without the need to run several successive simulations. In fact when the software is set for assessing one or both damper types it runs consecutively twice: the first time it computes pass-by noise levels for a baseline model without dampers while the second time it estimates noise levels considering the damper effect in terms of modified wheel modal parameters or measured track decay rates or both.

The software is written in Matlab and runs as a complied standalone application. The GUI can be operated in English, French or German.

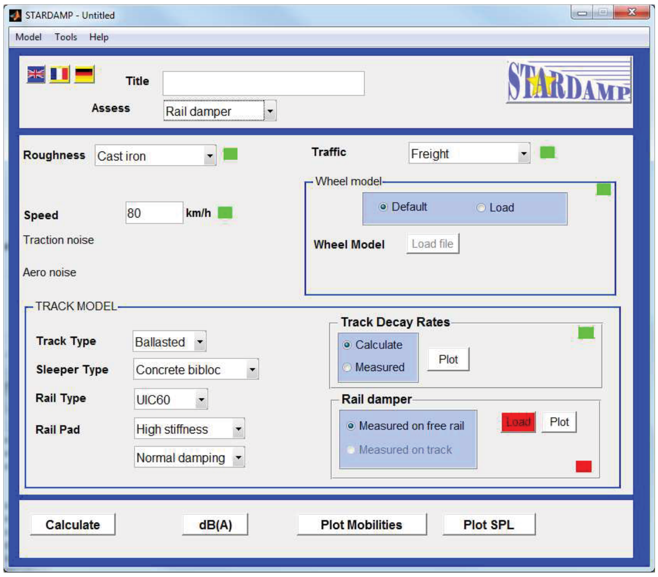


Figure 5: STARDAMP graphical user interface.

## Track input data

Currently, rail dampers are most often tested by equipping a section of track and performing pass-by noise measurements. In addition, the track decay rates before and after the installation of dampers can be measured, which permits rolling noise simulations to be performed in parallel. However, the installation of dampers on a real track is costly and time consuming. Moreover, the measurement of track decay rates has to be performed very carefully in order to obtain representative results. Indeed, it is preferable not only to check the track receptance at different sections (as suggested by standard EN 15461 [9]) but to repeat the entire track decay rate measurements at different sections.

One area of research within the STARDAMP project has been to develop a methodology to estimate track decay rates of a track equipped with dampers without installing the dampers on the real track and to assess their effectiveness by means of the STARDAMP-tool. The rail response is assessed by combining track decay rates measured on a real track with decay rates measured in a laboratory on a free rail that is equipped with dampers. The measurement procedure can be found in reference [10] along with a validation of the method. Track decay rates measured on a free rail can be uploaded into the STARDAMP-tool.

### Vehicle input data

The vehicle is defined in terms of wheel type and number of wheels per unit length. As in TWINS, the wheel response is calculated by using a finite element model of the wheel together with measured damping data. An additional module, called MP-Editor, has been developed in order to simplify the treatment of wheel modal data and its transfer from the FE-calculations to the STARDAMP-tool. Results from FE-calculations can be imported to the MP-Editor, where natural frequencies and damping can be edited according to experimental results. These are obtained by performing an experimental modal analysis of the wheel equipped with dampers. Measurements on the bare wheel can be performed in order to simplify the identification of distinct wheel modes but are not needed for the construction of a bare wheel model (which is directly derived from the FE calculations together with default damping values). The MP-Editor also permits the computation of wheel receptances for comparison with directly measured receptances. This is helpful in order to control the updated wheel model.

### Output

The STARDAMP-tool computes one-third octave band spectra, octave band spectra and overall $L_{Aeq}$ pass-by levels for a microphone distance of 7.5 m or 25 m from the track. In addition to the total levels, separate spectra for wheel and track (rail+sleeper) contributions are given. Whenever dampers are assessed, the gain is directly determined in terms of overall $L_{Aeq}$ levels.

## Conclusion

The STARDAMP-tool permits assessment of the performance of rail and wheel dampers based on relatively simple laboratory measurements. This makes it useful for engineers involved in R&D of damping solutions. At the same time, the tool can be used by non-experts thanks to its simplified interface. Using the pre-defined scenarios and provided input data, the tool can serve for demonstration of damping solutions under different conditions (track and rolling stock properties). New experimental data can be readily introduced and used along with pre-defined data.

The aim of the STARDAMP project was to provide a reference procedure for the assessment of rail and wheel dampers. This should help to unmask exaggerated rolling noise reductions that are sometimes announced for certain products without specifying the context in which these reductions can be achieved. At the same time STARDAMP will help to recognise the potential of damping solutions for each specific situation.

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