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Improvement of the noise Technical Specifications for Interoperability: The input of the NOEMIE project

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Abstract

The Technical Specifications for Interoperability (TSI) are the technical application documents of both European Directives 96/48/EC (high-speed, HS) and 2001/16/EC (conventional rail, CR). In that respect, noise emission levels of the railway system are considered to be a basic parameter for the acceptance of the rolling stock subsystem.

The rolling noise, caused by the combination of wheel and rail roughness, is considered to be the main noise generation mechanism involved at both conventional and high speeds. Moreover, the track influence is such that the noise emission limit values cannot easily be set up without a tight definition of a reference track, allowing the noise values to be consistent and reproducible on several test sites. Such track conditions imposed by acceptance tests for rolling stock interoperability are described.

In that respect, the NOise Emission Measurements for high speed Interoperability in Europe (NOEMIE) test campaign was launched to provide trackside noise emission values of several high-speed trains at speeds up to 320 km/h. Several existing tracks were realised therefore in five European countries and compared with the reference-track definitions.

A new measurement method, based on rail roughness and track vibration response has been developed, leading to an improved common reference-track definition, called TSI$^+$, for both the HS and CR TSI.

1. Introduction

Railway environmental noise control has recently experienced major developments induced by both technical advances and regulatory demands at European level following ambitious environmental policy goals.

From a technical point of view, the behaviour of the interface between the track and the rolling stock has a major influence on the noise emission value. The main generation mechanism involved at both conventional and high speeds being the rolling noise excitation, is caused by the combination of wheel and rail roughness. The respective noise contribution of both the rolling stock and the track components needs to be established, this latter contribution being considered significant for current commercial speeds up to 300 km/h. Moreover, the track influence is such that the noise emission limit values for vehicles cannot easily be specified without a

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tight reference-track definition, allowing the emission values to be consistent and reproducible on several test sites.

2. TSI: the requirements for noise emission

From a noise emission policy approach, the conditions imposed by the interoperability directive for rolling stock acceptance tests—type testing to be performed to get the EC label allowing to put into service on the Trans European Network (TEN)—are described within the railway Technical Specifications for Interoperability (TSI).

The TSI, which all new rolling stock operated on the TEN have to comply with, impose noise emission limits for railway vehicles. Compliance with these noise emission limits has to be proven by acceptance tests (type testing) before putting the vehicle into service.

A major innovation of the high-speed TSI (HS-TSI) in particular [1], is the more precise definition of a type testing reference track, compared with the former definitions available at international level. Since the parameters of influence on noise may vary significantly within the European network system, this clear reference-track definition is expected to improve reproducibility of the measured noise level of high-speed rolling stock, on different reference test sites throughout Europe. The HS-TSI reference-track specification is based on

- a component definition (ballasted track with pad static stiffness over 500 kN/mm at a 60 kN preload, and monobloc sleepers); and
- a limitation of the rail roughness levels in third-octave-band wavelengths between 0.2 and 0.005 m, given by the following equation:

$$L_{\text{rough}} \leqslant \left[4 - 6\log\left(\frac{\lambda_0}{\lambda}\right)\right] \text{ in dB re } 1\,\mu\text{m}, \tag{1}$$

where λ_0 equals 1 m.

Following an alternate definition of this reference track (ATSI) [2], proposed at the end of 2002, the process for revising the HS-TSI was launched. In parallel, the conventional rail TSI was prepared, with the same reference to a reference track, but based on the alternate definition (ATSI). The definition of the ATSI track is based on

- a limitation of maximum rail roughness, taking advantage of a method presented in the European draft standard pr EN ISO 3095:2001 [3]; and
- a control of the minimum track vibration decay rate (TDR) associated to the damping of the vertical and lateral vibration level along the rail length, in dB/m.

3. The NOEMIE Project: a need for data in the scope of the revision of the HS-TSI

3.1. The main objectives

In the scope of the revision process of the HS-TSI, the NOise Emission Measurements for high speed Interoperability in Europe (NOEMIE project) was launched in order:

- to provide a common database of comparable and reproducible noise emission values of high-speed trains in Europe;
- to contribute to the specification of a reference track to be used in noise emission type testing, which would be part of an operational line rather than a dedicated laboratory test track;
- to propose and validate a common measurement and post processing methodology to characterise the track parameters; and
- to validate the noise emission limit values at a European level.

3.2. General organisation of the project

The NOEMIE test campaign [4] is organised in two main phases:

- In phase 1, several high-speed train series (AVE, TGV-Duplex, Thalys, ETR480, ETR500 and ICE3) are tested on high-speed lines in five countries (Germany, France, Belgium, Italy and Spain). The existing tracks on which tests are performed, were ground so they could be expected to comply either with the TSI or ATSI requirements, and compared to both TSI and ATSI requirements. In this phase also, measurement methods were specified, based on Pr EN ISO 3095:2001 [3] for both noise and rail roughness characterisation, and on a specific method (also described in Ref. [5]) to assess the dynamic performance of the track. Then the data obtained within the measurement campaign were analysed to propose a new specification of the reference track, called TSI^+ (Fig. 1).
- During phase 2, which aims to validate the results of phase 1, two series of rolling stock were to be measured on a TSI^+ track.

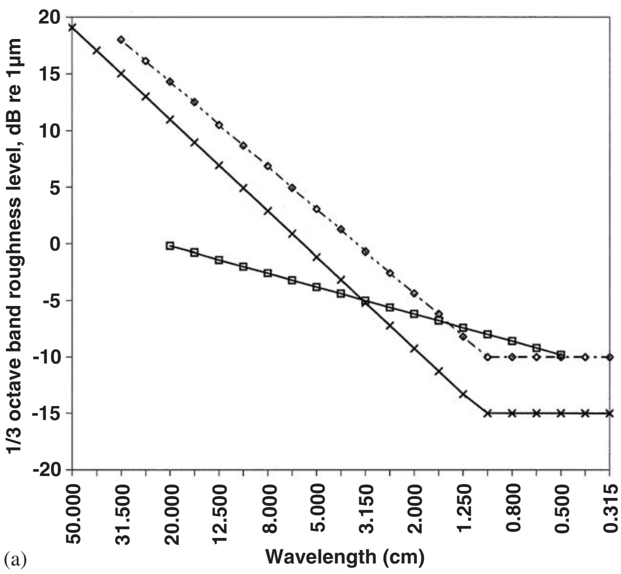
As far as achievable by the rolling stock under trial, the test speeds followed the TSI requirements (250, 300 and 320 km/h), with noise measurements at 25 m from the track, both Transient Exposure Level (TEL) and pass-by time equivalent level ($L_{pAeq,tp}$) noise indicators being assessed. Moreover, the wheel roughness was also checked, in order to make comparisons possible with all the parameters influencing the combined roughness excitation and the associated noise values.

3.3. NOEMIE results issued from phase 1

3.3.1. Pass-by noise emission levels

The results of the NOEMIE noise measurements along with the current TSI limit values for high-speed train sets are presented in Table 1. Both indicators, the TEL as well as the $L_{pAeq,tp}$ were listed for each train type and each test location individually.

The TSI limit values are reported in Table 1 too. The noise levels are rounded to half a dB, for data analysis reasons, although they should preferably be rounded to integer values, to take into account the precision of



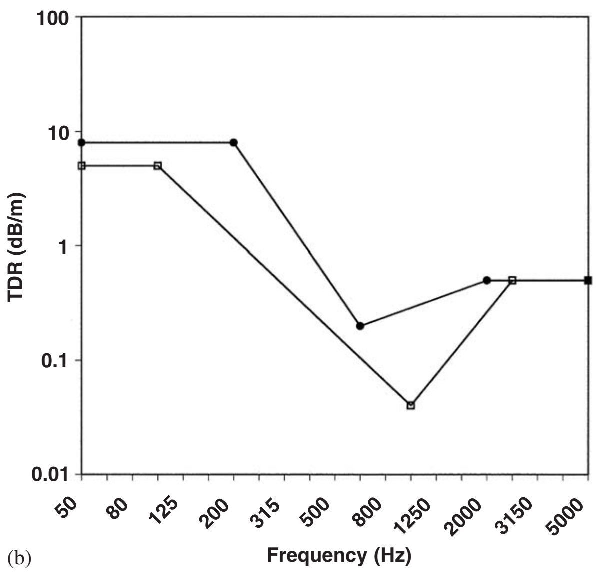


Fig. 1. Limit curves for (a) rail roughness: –◇–, Pr EN ISO 3095:2001; –□–, TSI limit; –×–, ATSI limit; and (b) track decay rates: –●–, ATSI vertical direction; –□–, ATSI lateral direction.

Table 1
Passby noise levels at 25 m

		TEL (dB(A)) Speed (km/h)			$L_{pAeq,tp}$ (dB(A)) Speed (km/h)		
		250	300	320	250	300	320
HS-TSI limits Chapter 4.1.8		87	91	92			
TGV Thalys	Belgium	90	93	94.5	88.5	92	93
	France	87	91	93	85.5	90	92
	Germany	86.5			85.5		
TGV Duplex	France	88	92	93.5	87	91	92
ICE3	France	88	90.5	92	87.5	90	91.5
	Germany	86	90	92.5	85.5	89	92
AVE	Spain	87	91.5	92	86	90	91
ETR480	Italy	91			90.5		
ETR500	Italy	88.5	91		88	90.5	

data acquisition devices for outdoor conditions. Moreover, the small variations in track and wheel parameters are known to lead to a variation of noise levels, even when the effects of roughness variation are minimised by compliance with the TSI specifications. This does not affect the application of noise level limits, such as presented hereafter in precise terms. However, the expected reproducibility should be taken into account when they are set.

The results were found to be in-line with expectations of prediction models. They indicate that

1. the TSI noise emission limits are difficult to achieve, so that current HS-TSI levels can be considered to be very demanding limits for existing high-speed rolling-stock technology. There are particular difficulties:
   1.1. at 320 km/h for most rolling stock under trial,
   1.2. at lower speeds for rolling stock with thin or unsymmetrical wheel web shapes, that increase the wheel noise contribution; as experienced at ETR 480 and at ETR 500,
   1.3. in case of high rail roughness levels, such as stated in Belgium (within the NOEMIE test campaign this should be considered as an exception, since noise measurements were taken at the Brussels-Liège HS line with a nonstabilised track roughness, before the line was put into regular service);
2. even at low rail roughness levels, the rolling noise due to the combined roughness of rail and wheels is the dominant contribution to the trackside noise emission up to train speeds of 300 kph. Moreover, at train speeds above 300 km/h, the aerodynamic noise becomes the dominant contribution to the noise emission (provided there is the low rail roughness level to be expected for reference tracks);
3. the amplitude of variation of the noise levels decreases while the train speed increases;
4. $L_{pAeq,tp}$ values are between 0.5 and 2 dB lower than the TEL values.

3.3.2. Characterisation of track performance

The measured roughness spectra are presented in Fig. 2, and indicate that

- the TSI rail roughness limit was found to be achievable in some cases; but
- the ATSI limit is apparently too demanding for the existing operational rail grinding techniques.

The results show that the vertical Track Decay rates (TDR) of most of the tracks comply with the ATSI limit.

Therefore, a threshold increase in the ATSI and TSI characteristics seems to be achievable and necessary.

Table 2
Noise measurements at standstill

Train series	$L_{\mathrm{pAeq,60\,s}}$
TSI limit	65
TGV Thalys	59.5
TGV Duplex	61.5
ICE3	65
AVE	61[a]
ETR 480	66.5[a]
ETR 500	78[a]

[a]Values not yet confirmed.

3.3.3. Wheel roughness

The wheel roughness levels of the test trains were about 5 dB above the rail roughness limit, showing that, as required in type tests conditions, the combined wheel rail roughness mainly depended on the wheels condition of the rolling stock under trial.

3.3.4. Noise at standstill

Measurement at standstill was carried out and presented in Table 2, which can be compared with the TSI limit for continuous measurement during at least 30 s.

The high discrepancy of the results is due to the fact that the experimental conditions for each trainset under test were not strictly comparable (fan regime, braking compressor, number of vehicles average).

In order to allow direct comparisons between data related to each series of trains, the test conditions should be more tightly defined.

4. Check of the reproducibility of the noise emission in the case of two tracks with soft pads

Following phase 1, complementary studies were performed in the scope of the NOEMIE test campaign, in order to assess the influence of pad stiffness on the trackside pass-by noise emission.

In that respect, a regular ''soft'' padded track section in Solpke (Germany), adjacent to the NOEMIE German ''stiff'' reference track, was prepared as reference track as well. That is, with the exception of the rail pads both track sections are identical (ballasted track, monobloc sleepers, UIC60 rail, rail roughness). From its performance point of view (rail roughness, vertical and lateral TDRs presented in Figs. 2–4 respectively), this new ''soft'' track section may be considered as quite similar to the Lille–Calais French test track. The measurements were performed according to the NOEMIE specifications Draft E [6].

The measured TEL values on both German and French ''soft'' sections are presented in Table 3.

The difference between TEL pass-by noise values, obtained at the two soft padded tracks in France and Germany, is quite low, and at least seems to be less than the uncertainty of the measurement itself, so the reproducibility can be considered as quite acceptable.

Planned complementary tests in Belgium with ICE3 and Thalys trainsets are expected to confirm that result.

5. Improving the TSI track specification

5.1. The existing TSI and ATSI limits definition

During the NOEMIE project advantages and drawbacks of both ATSI and TSI parameters could be assessed under comparable test conditions, vs. noise results. In that respect, testing the ATSI track specification showed that

- the initially proposed ATSI rail roughness spectrum amplitude limits were not realistically achievable on operational high-speed lines;

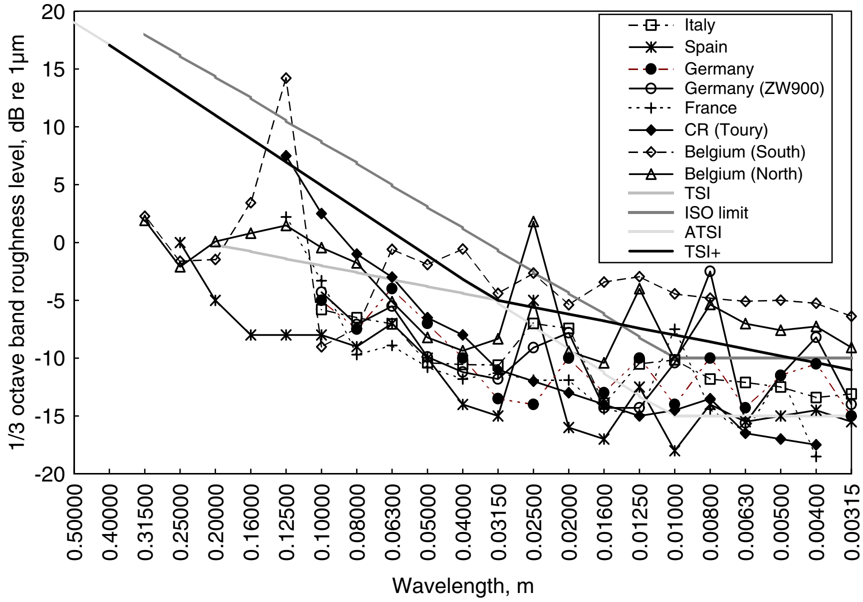


Fig. 2. Measured rail roughness spectra of the tracks.

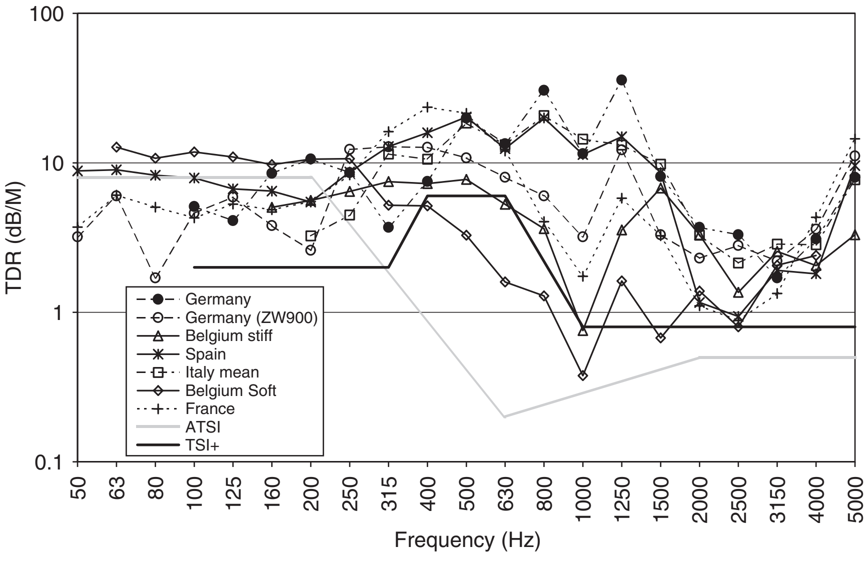


Fig. 3. Vertical track decay rates measured during phase 1.

- the TDR criteria could be tightened to create a test, that is less dependant on variations of the track design, and ensuring, that the wheel noise contribution remains dominant at the test site.

Using the TSI specification in parallel showed that

- Some roughness measurements on "Conventional Rail" tracks would, for higher wavelengths, be difficult to achieve with the TSI roughness limits. This can be observed even on very smooth rails, such as measured in the French site at Toury (see Fig. 2).

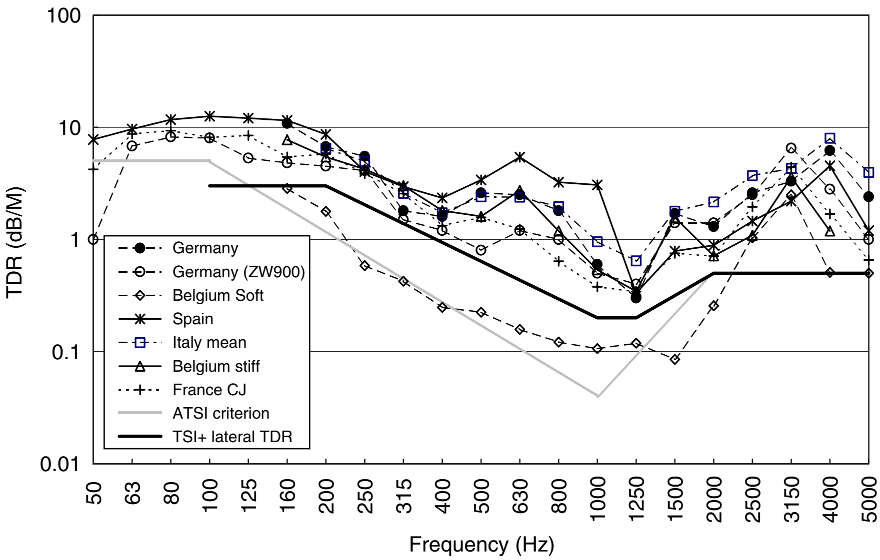


Fig. 4. Lateral track decay rates measured during phase 1.

Table 3
Noise levels (TEL @ 25 m): comparison between the German and French "soft" padded tracks

		Speed (km/h)		
		250	300	320
TGV Thalys	France	87	91	93
	Germany (soft)	87		
ICE3	France	88	90.5	92
	Germany (soft)	88	90.5	93

- Using the pad static stiffness definition allowed two types of reference tracks to be defined: Belgium (stiff), German, Spanish and Italian tracks could be considered as "stiff" padded tracks, whereas French and Belgian (soft) tracks were rather "soft" padded. Those results are presented in Table 4.

However, the comparison with dynamic characteristics at high frequencies, given by the TDR, confirms the insufficient characterisation that is obtained with static pad stiffness only, classifying the Belgian (statically) stiff pads as one of the stiffest pads. A tighter analysis of the results shows that:

- The measured static stiffness (comparable to the Spanish one) is high. It would have then classified this track as one of the stiffest, but it is among the lowest performing group from the TDR and noise measurements point of view.
- It seems then that the performance of this Belgian (statically) stiff track varies with frequency, and that the high stiffness at low frequency is not confirmed at higher frequencies.

Finally, a consistent definition with Conventional Rail TSI Noise topics under discussion had to be looked for, as in the mean time, the pass-by noise limit criteria for the CR-TSI were launched on the assumption that the ATSI track specification would be used in the HS-TSI.

For these reasons, a new 'TSI^{+}' track specification was proposed, in terms of rail roughness (Fig. 2), vertical and lateral TDR (Fig. 3).

Table 4
NOEMIE pad "static" stiffness in (kN/mm), adapted from Pr EN 13481-6:2000 principles for the NOEMIE measurement specification [7]

	−20 °C	23 °C	50 °C
France	137	90	98
Spain	2168	1691	704
Belgium (soft)	92	106	125
Belgium (stiff)	2052	1335	696
Germany	2356	1528	960
Italy		545	

5.2. The methodology used

The TSI^+ proposal was launched taking into consideration:

- the theoretical optimum dynamic characteristics for reducing acoustic radiation from the track, issued from the Silent Track Project [7];
- the characteristics of most of the tracks that are operated in Europe: in that respect, softer pads typical of both HS and CR commercial traffic lines (France, Germany, Belgium), were considered as representative enough to be accepted for type testing purposes.

Then a parametric study using the TWINS rolling noise model [8,9] was carried out to evaluate the influence on the rolling noise sound power, when the track properties were varied from the ATSI to the TSI^+ specification. The study covered both speed ranges (HS and CR) using representative wheel models.

In the first step of the study, the roughness was changed from the ATSI spectrum limit to the TSI^+ spectrum limit. Since a less tight roughness limit at certain wavelengths is set in TSI^+, the trackside noise is expected to increase. In the second step, the decay rate spectrum was changed from one that is ATSI compliant to one that is TSI^+ compliant.

5.2.1. Static vs. dynamic representation

For track dynamic performance characterisation, the tangent stiffness at the static clip load of the fastening system should preferably be represented vs. frequency. For elastic rail fastening systems the measuring method is defined in EN 13481-6 [10]. However, this quantity is not easily measurable and the static stiffness is not sufficient because the ratio between static and dynamic stiffness is known to be varying from 1.2 to about 3 or 4 or even more for rail pads.

The main advantages and drawbacks of both quantities are presented hereafter, the dynamic description being strongly recommended, and adopted in the CR TSI. As a summary, the specification of the pad static stiffness:

- relates indirectly to the noise performance of conventional tracks;
- is a single value;
- is easily measured to a common standard.

On the contrary:

- the pad static stiffness is not a good measure of the tangent unloaded high-frequency dynamic stiffness that is pertinent to noise;
- the high decay rates do not only depend on stiffness but also on damping;
- it precludes the use of rail damping (or other means) as a means of reducing the noise transfer function of the track. These may prove to be more convenient or of better performance in the future.

Concerning the decay rate specification:

- it relates more directly to the noise performance of the track;
- it allows some other future methods of obtaining a low track noise transfer function which may be better and more acceptable for the railways than maintaining stiff pads;
- but is also more difficult to measure, to process and to interpret than the static stiffness.

5.3. Why should lateral TDRs be limited

The TSI, ATSI and TSI$^+$ specifications all allow the use of vertical (dynamic) stiff pads. Indeed, the track noise is lower for such pads, so the associated tracks would be good sites for TSI measurements. When the pad stiffness is high, the lateral decay rates are significant since the lateral wave contribution to the track noise becomes approximately equal to the vertical wave contribution. Although for normal pads the transverse stiffness is approximately 1/4 of the vertical stiffness, this cannot be guaranteed for all possible fastener types. The ratio is a function of the shape factor of the pads and the fastener geometry. Although it may be unlikely, it cannot be assumed that a compliant vertical stiffness implies an acceptable lateral stiffness. In order to eliminate the possibility of an unusual fastener that might have a high vertical dynamic stiffness but a relatively low lateral dynamic stiffness, the requirement for limitation of the lateral decay rate should be retained.

5.4. Noise impact caused by the track changes from the ATSI to the TSI$^+$ specification

Considering that there were no available data for conventional rail CR, such as the results produced within the NOEMIE test campaign for high speed, the impact of the new TSI$^+$ reference track was assessed using simulations. The following conclusions can be drawn:

- Simulations performed with the TWINS model [8] show that the TSI+ specification is 0.5 dB more stringent than the ATSI proposal in the speed range of the CR TSI. In the high-speed range, the TSI$^+$ leads to a 2.0–2.6 dB increase in allowed noise level compared to ATSI. In that respect, the more stringent decay rate specification compensates the required allowance in rail roughness.
- The sum effect therefore is that the CR TSI targets are not much affected, but the HS TSI becomes 2 dB easier to meet.
- In all cases, the track noise is greater than the wheel noise. However, by the change to TSI$^+$, the difference is reduced. This means that tests on a TSI$^+$ track are more likely to show the effects of quiet wheel design when noise spectra are examined.

Such modifications lead to a significant dynamic stiffening of the track towards its practical limit, so that the possible range of track noise levels from different tracks having TSI compliant pads is reduced by about 4 dB.

6. Conclusion

In the scope of railway interoperability, the noise emission values of high-speed trains were assessed within the NOEMIE project (phase 1), showing that the present TSI limits are difficult to achieve with existing rolling stock.

In that respect, specific measurement methods were used to assess the track characteristics, in both the HS and CR domains, and proposed as an appendix to the CR TSI document. New improvements were developed therefore, so a common reference-track definition for the whole speed range can be defined now.

The next steps of the HS TSI revision should reasonably address the possibility of a common indicator, that could avoid a break in the indicator in use between CR, referring to $L_{Aeq,tp}$, and HS (referring to TEL). This could also be of interest for rolling stock at commercial speed between 200 and 250 km/h, which is a speed range currently covered neither by the HS- nor by the CR-TSI.

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