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Testing a new rail roughness measurement standard

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Railway rolling noise arises from the combined roughness of the wheel and rail surfaces. The rail roughness is therefore an important parameter in the assessment of train pass-by noise. The Technical Specifications for Interoperability (TSI's) in Europe require noise to be measured on a 'reference track' the conditions of which are controlled. A spectral limit for the rail roughness is a major part of that control. The CEN commissioned TC 256 Working Group 3 to draft a new standard for rail roughness measurement. The final draft of the new standard is now complete and will soon be published. This paper describes a 'road test' that was part of the standard development process. This test involved asking eight teams from all over Europe with seven different instruments to measure roughness at the same site, independently making their own interpretation of the standard. The paper outlines the aims of the new standard and describes the road test. It presents results and conclusions of the test that have been used already to improve the standard. Consideration had to be made of how rail-head defects are treated and how different measurement technologies are used.

1 Introduction

In recent years, in line with the European Union's strategy for harmonisation of internationally running train services in Europe, new Technical Specifications for Interoperability (TSI) have been written for the acceptance testing of rolling stock. The acoustic TSIs for conventional and high speed rolling stock [1, 2] reflect the understanding that rolling noise originates from the combined 'roughnesses' of the wheel and rail running surfaces [3]. In order to ensure that the acceptance test depends as little as possible on the local track design, the TSI specifies conditions for a 'reference track' on which pass-by noise measurements are to be made. The reference track is controlled in terms of the noise produced per unit combined roughness and the roughness of the rail head running surface. The first condition is characterised by a track decay rate spectrum that must be exceeded. (For how this relates to the track's noise performance see [4].) The second condition is a spectral limit to the level of rail roughness of the reference track.

1.1 The need for improved roughness measurements

To ensure that comparable and repeatable pass-by noise measurements are made, the TSI calls upon ISO 3095 [5]. This standard also contains an annex concerning the measurement of roughness.

A programme of noise measurements from both high-speed and some conventional speed rolling stock was undertaken to test the practical applicability of the TSI method of measurements (NOEMIE project [6]). One output of NOEMIE was to show that the ISO 3095 roughness measurement method is limited in the following respects:

- the maximum wavelength specified is too short for use for high speed trains;
- too little data sampling is demanded to give the required certainty in the measured spectrum of roughness over the wavelength required;
- the standard is written on the assumption of a particular measurement technology; it is preferred that only a performance criterion be implied for the quality of measurements obtained;
- ISO 3095 imposes a fixed pattern of sample records; this causes the occasional measurement of rail-head defects that are not wanted in the record and have a significant effect on the estimated spectrum;

- the standard required averaging of the roughness across a number of lines at different positions across the rail head. Since there is great variation across the rail-head, closer specification of measurement position is required and the data for each line should be presented separately.

For these reasons CEN Technical Committee 256, Working Group 3 (WG3) was requested to draft a new standard [7] solely for the measurement of acoustic roughness.

1.2 Objectives of the road test

Many of the provisions of the new standard [8] have not been practised previously. Moreover, the new standard aims to set criteria for roughness measurement as performance criteria rather than to specify the technology.

It was therefore proposed by WG3 that, before it was completed and published, the new standard should be tested for practicality and effectiveness. That is, to check that the standard is interpreted consistently and leads to a consistent estimate of roughness spectrum when used by different measurers with different instruments.

In order to gain a proper understanding of the practical difficulties and of the outcome in terms of consistency of practice as well as results, it was seen as essential that a 'road test' should take place in an industrial context, *i.e.* making measurements with instruments normally already used on operational railway lines having normal constraints of access time and safety procedures, *etc.*

A full report of the test has been published by CEN [9]. The test and its main findings are however summarised here.

1.3 The TSIs and standards

For the method of pass-by noise measurement, the current High Speed TSI (2002) refers to prEN ISO 3095: 2001 although a revision of this TSI (shortly to be published) refers to ISO 3095: 2005 [5]. The Conventional Rail TSI already refers to ISO 3095: 2005. Having said this, there is not a significant difference between the two versions.

The ISO 3095 standard itself already sets a limit spectrum for the roughness of the track on which acceptance tests are made and prescribes a method for its measurement. The limit spectrum set in ISO 3095 is not used in the TSI's. Instead, a tighter limit is set according to what was found possible by the associated NOEMIE project [6]. That project also found, for high speed trains (above 200 km/hr), that a maximum wavelength up to 0.25 m is required.

It is the intention that the TSI should, in future, refer to the new standard for roughness measurement.

2 Requirements of the new standard

2.1 Longitudinal position

ISO 3095 specifies a set of six positions for 1 or 1.2 m records of the rail-head profile. These are fixed with respect to the microphone position. This leads occasionally to the measurement of rail-head defects, welds *etc.* It is not appropriate to include such large localised irregularities in the roughness spectrum since they create forces and noise that are not linear with their depth (the contact geometry, and therefore the contact stiffness, changes radically). They also strongly distort the mean of the six sample records leading to both an overestimate of the level and uncertainty in the true operational roughness level. This has been a problem many times in the past and specifically at one of the test sites in the NOEMIE project. In the new standard, the choice of location of the measurement records is made by the measurers and they are advised not to include such irregularities. Moreover, the new standard envisages that a certain track section is to be characterised rather than assuming a microphone position. (The placing of a microphone might be decided on the basis of the results or there may be no associated noise measurements at all.)

To keep the variance in the estimated spectrum at 0.25 m wavelength consistent with that at 0.1 m in ISO 3095, the new standard requires a 15 m sample length in total.

2.2 Lateral position

ISO 3095 requires that the ‘running band’ on the rail head be identified (as ‘clearly visible’) and 1 or 3 lines of roughness measurement record be taken depending on its width. The new standard refers to a ‘reference surface’ that must be defined by the measurer. The relationship of noise measurements to the measured roughness will then be valid as long as the wheel-rail contacts of a measured train remain inside the reference surface. Identification of the reference surface from the running band *or otherwise* is an important subject in the new standard. Three different criteria are offered depending on the situation and the purpose of the measurements: (1) the running band is visible and is known to be a product of the rolling stock for which the roughness measurement is to be used, (2) the contact position can be measured for the specific rolling stock at the time of roughness measurement, (3) the contact position can be predicted from the geometry of rail and wheel transverse profiles.

2.3 Processing

The data must be processed to remove some unwanted ‘pits and spikes’ and produce a one-third octave level roughness spectrum. ISO 3095 does not prescribe how the processing is done although it recognises that large differences can result. The processing is much more tightly controlled in the new standard. To remove the effects of dust or grains of dirt on the railhead, an algorithm is included that removes ‘spikes’, *i.e.* very short (much shorter than the wheel-rail contact patch), sharp, upward deviations. This recognises that such features would be crushed or strongly deformed in the contact not leading to significant relative displacement

between wheel and rail. A second algorithm, ‘curvature processing’, is specified to deal with similarly short downward features that would be sensed by the small radius probe tip of the instrument but that would not affect a much larger radius wheel.

For the production of the wavelength spectrum of roughness from the measured data, the new standard specifies alternative analysis methods, (i) Hanning window, discrete Fourier transform and averaging in one-third octave bands, or (ii) digital one-third octave band filtering. In the latter case 2 m from each end of each record must be abandoned after filtering to avoid the effects of filter transients.

3 The measurement programme

The idea of the ‘road test’ of the new standard was (i) to have a number of different teams measure roughness according to their own interpretation of the standard, (ii) to observe the practices of the teams and then (iii) to examine the data for consistency of output. Thus the standard should be tested in its practicality, whether it produces a consistent interpretation in the practice of different teams and whether it results in consistent roughness spectra.

Two sites were offered for the measurement exercise, one on a running line at Lorient in the south east of France and the second at the Siemens Transportation Systems test track facility at Wildenrath in northern Germany. Since the purpose of the standard is to fulfil the requirement of the TSI’s, it is important that the sites should have low roughness levels around and below the TSI limit curve.

A number of measurement teams were invited to come to each site and carry out measurements according to their reading of prEN 15610: 2006. The measurement teams had to bear their own costs and so it was not reasonable to require all teams to attend both sites. It was requested therefore that all teams taking part should at least attend the site at Lorient. Thus, seven teams attended measurements at Lorient and five at Wildenrath.

All teams taking part were provided with software by the coordinator to perform the analysis defined in the standard at that time, *i.e.* before it was afterwards amended according to the findings of the road test. This was done so that teams could test and comment on the calculation procedure and raise any areas of uncertainty in the definition of the processing.

3.1 The test procedure

At each site the teams measured separately so that there was no cross-contamination in the interpretation of the standard. The host team at each location, required to be present for the safety arrangements, therefore went first.

Each team was shown the test section of track, in each case 100 m long between kilometre markers at the trackside. The teams were then asked to characterise the roughness of the test section with no other information given except that indicated below concerning the rolling stock to which their reference surface should correspond. After the measurement was made according to their free interpretation of the standard, each team was asked to measure a 15 m sample of roughness along a single line

specified by the coordinator. This was done to provide a means of identifying any differences in results that may be due to instruments or the natural limits of repeatability, rather than due to different choices of measurement line lateral line positions and longitudinal sampling.

Each team were at liberty to process the data themselves but all data in terms of displacement along the rail head, were given to the coordinator. The coordinator then processed all data with the software distributed before the measurements.

All measurements were made within the space of a few days of one another at each site but it remains an assumption of the exercise that no significant change in roughness occurred during that time.

3.2 Test sites

Measurements were carried out between 14th and 24th May 2007 at Loriol on a conventional-speed service line in southern France. The line at this site is mostly trafficked by freight trains with some regional multiple units, locomotive-hauled passenger stock and a few TGV's. Figure 1 shows a sample of the rail head typical of the Loriol test section. Here the running band was wider and less distinct than at Wildenrath. In these circumstances the teams were guided to test the contact position of the passenger stock in deciding the position of the reference surface. A method used by one team is illustrated in Figure 1.

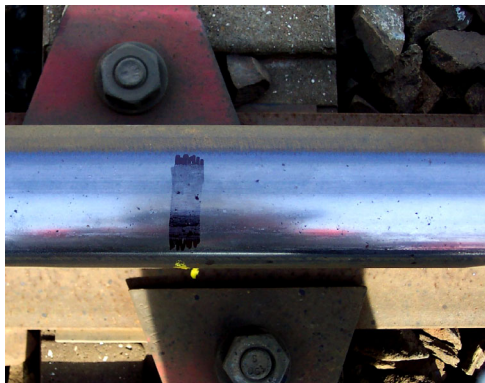


Fig. 1 Photograph of the railhead at Loriol

Further measurements were carried out between 22nd and 25th April on the main ring of the Siemens Test Track Centre at Wildenrath in northern Germany. The rail-head had been ground about 6 months before the test using a special 'acoustic grinding' with longitudinal grinding action. Fig. 2 shows a typical sample of the rail head at this site. There were very few significant defects of the rail head within the 100 m 'reference section' of track. However, an interesting consideration arises; the site is used for testing rolling stock with (mainly new) 1 in 20 and 1 in 40 coned wheel profiles. This has resulted in two clear separate (narrow) running bands. The line speed is 120 km/hr.

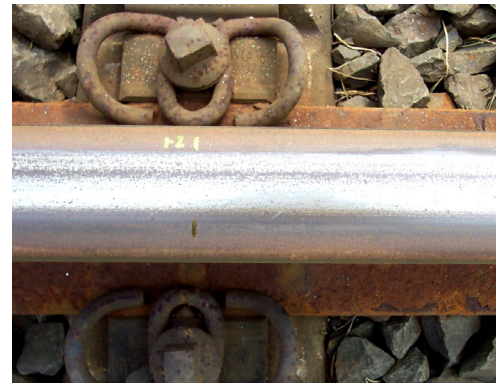


Fig. 2 Photograph of the railhead at the Wildenrath site.

3.3 Teams and instruments

The team/instrument combinations taking part in the test programme are only identified by letters A to H as listed in Table 1. There were three different models of straight-edge instrument used from two manufacturers. These move a probe mounted on a linear variable differential transformer (LVDT) along a straight edge fixed above the rail. Two other instruments (different manufacturers) used accelerometers dragged along the rail-head on a trolley. In each case the signal was then integrated twice with suitable filtering to provide a displacement output.

	Technology
A	1.2 m fixed straight edge, moving disp. transducer
B	1.2 m fixed straight edge, moving disp. Transducer
C	1.2 m fixed straight edge, moving disp. Transducer
D	1.2 m fixed straight edge, moving disp. Transducer
E	1.2 m fixed straight edge, moving disp. transducer
G	Accelerometer trolley
H	Accelerometer trolley

Table 1 Identification and types of instruments

4 Observations on practice

At Loriol, teams were asked to place the reference surface for passenger trains on the mixed traffic line. The teams therefore used measurements of the running band position by looking at a marker line partially removed after the appropriate rolling stock had passed (Fig. 1).

All teams decided to measure 3 lines at Loriol, 5 mm apart. No team placed their centre-line further than about 4 mm from the mean position.

The nature of the two running bands at Wildenrath has already been shown in Fig 2. This situation may well arise in measurements of rail roughness in the future and in connection with the TSI's where two country's rolling stock runs on the same tracks. The measurers were directed to consider the more recent, brighter band of the two. With this guidance, all teams decided to measure one line of roughness (running band less than 15 mm wide) and lines were placed with similar consistency to that at Loriol.

At Loriol one team measured the rail head profile and calculated a theoretical (static-geometry) contact position

for an unworn wheel, thus demonstrating the practicality of the third approach in the standard to determining the reference surface position.

5 Comparisons of roughness spectra

Since the absolute accuracy of instruments cannot be determined at the required sub-micron resolution, the correctness of a measurement can only therefore be judged on the extent to which instruments agree.

A great many results were produced from the test programme. For the current presentation, space allows only results from the Loriol test site on the central line to be shown to be shown.

Note that instrument H used a probe that only measured down to wavelengths of about 2 cm since its probe for measuring shorter wavelengths was not working on the day of the measurements.

5.1 The datum line spectra

In order to examine the repeatability of the measurements using the equipment on the same line of roughness, Fig. 3 presents a comparison of the datum measurement at Loriol. This shows close agreement achieved for wavelengths shorter than 0.02 m with E a little below the others in this range. For longer wavelengths there is a greater difference.

Within the 15 m record, there is a rail-head defect. This causes the higher level of the spectra of H and G, the two continuously measuring (trolley) devices, in the wavelength range from 0.02 to about 0.125 m. Although contiguous measurements were made with all instruments, this local geometrical feature does not influence the spectra from the 1.2 m instrument since it falls near the end of a 1.2 m record and is strongly attenuated by the Hanning window. The continuous measurement records are however analysed by the digital filtering technique.

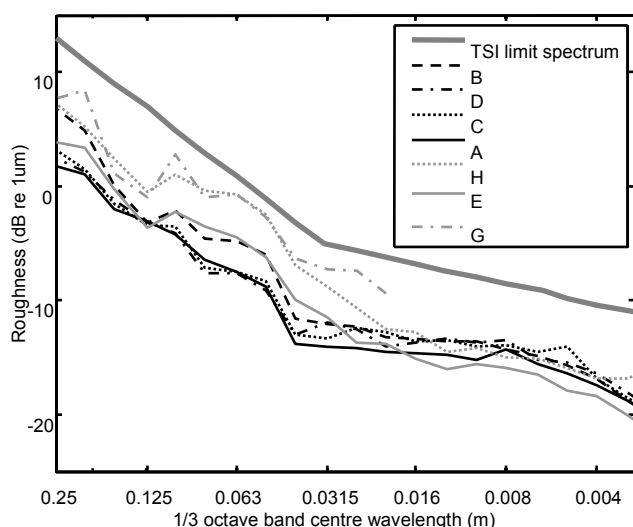


Fig. 3 All instruments compared on the datum line at Loriol.

Given that the datum longitudinal sampling was prescribed, the differences in the spectra are a function of the processing applied and the difference in recording continuously or in 1.2 m segments. The differences do not arise from the different measurement technology used;

accelerometer or LVDT. To emphasize this, Fig. 4 shows the spectra where the local geometrical feature is cut out of the trolley measurements. The measurements are much closer

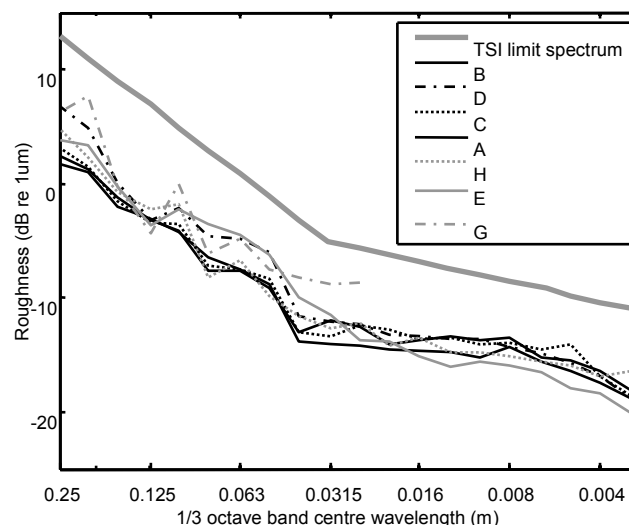


Fig. 4 All instruments compared on the datum line at Loriol – defect removed from records from H and G.

5.2 The 100 m test section results

The last section showed the variation found when instruments are used to measure the same line of roughness. The main test section results are now compared to examine how much further variation is introduced by differences in sampling practice laterally and longitudinally. Results are shown for the central line of roughness only since the variation is similar to the outer lines.

Fig. 5 shows the spectra from all instrument-team combinations for the Loriol far rail. Since it has already been shown that the avoidance of rail head defects is an important issue for the trolley instruments, local defects have been avoided in the analysis.

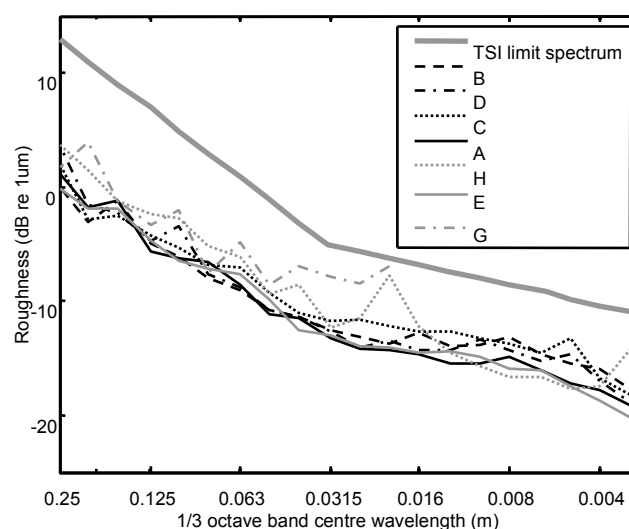


Fig. 5 Spectra from all instruments on the far rail at Loriol.

Overall the comparisons show that some greater variation due to sampling differences over the test section does exist compared with that on the datum line. This variation is

mostly still within an approximate ± 2 dB band across the range but it could be said that there is greater risk of measuring a spectrum that lies beyond this. Since this risk is to include a local geometrical feature, the risk is on the 'safe' side since it will tend always to increase the estimated roughness level.

The trolley instruments identify a periodic component of roughness (corrugation) at 2 cm. This may be due to the inclusion of the whole 100 m in these measurements rather than a limited 15 m to 18 m total sample length selected and recorded using the 1.2 m instruments.

6 Findings

All instruments have been shown to be capable in principle of measuring roughness at the required level of resolution except for G which failed to operate fully on the occasion.

All three cases for locating the reference surface laterally (Sect 2.3) have been used in the exercise and have been demonstrated to be practical to apply. The first two have been shown to produce fairly consistent judgements by different teams. The third method was only used by one team. This success of the standard in producing consistent practice in the choice of lateral position of the reference surface is important because these practices are newly introduced by the standard.

The greatest difficulty is in reconciling the measurements made 100 m at a time and those made in 1.2 m records. This is not a matter of the transducer technology but the length of the record which leads to different treatment.

Closely associated with the difference in practice between continuous measurements and discrete short records, is the judgement to be made on the exclusion of localised geometrical features. For this reason a selection of photographs of particular rail-head features has been produced along with their measured profiles and advice on how they should be treated. This has been added to the new standard.

There is an approximate ± 2 dB variation, 'limit to the repeatability' of measurements, when different teams measure the same line of roughness with different instruments.

There is a risk of greater variation than this due to the judgements made on what to exclude. This risk is on the safe side since it leads to over-estimation of the spectrum that is relevant to rolling noise generation.

7 Conclusion

A 'road test' of the draft roughness measurement standard has been carried out by comparison of measurement of up to seven team-instrument combinations at two sites. The test was designed to differentiate between variation in measurements from instruments and those from the interpretation of the provisions of the standard regarding the sampling of measurement records.

The results of the test were used to make a number of changes to the standard before its publication. The test has thus made an important contribution to its practical applicability and robustness.

Acknowledgements

Measurement teams took part in the test at their own cost. Siemens AG Transportation Systems and the SNCF provided the tests sites and facilities. The independent coordination has been funded by the EC via the European Committee for Standardization (CEN).

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