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Railway applications - Noise emission - Road test of standard for rail roughness measurement EN 15610:2009

Bahnanwendungen - Geräuschemission - Feldversuch zu EN 15610:2006 über Messung der Schienenrauheit im Hinblick auf die Entstehung von Rollgeräusch

Applications ferroviares - Emission de bruit - Essai de route relatif de norme pour la mesure de rugosité de rail EN 15610:2009

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Foreword

This document (CEN/TR 15874:2009) has been prepared by Technical Committee CEN/TC 256 “Railway Applications”, the secretariat of which is held by DIN.

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1 Introduction

1.1 Background

It is well established that rolling noise originates in the combined ‘roughnesses’ of the wheel and rail running surfaces. Through the rolling interaction of the wheel and rail this roughness imposes a time history of relative displacement across the wheel-rail contact that leads to vibration of the wheel and of the track. This vibration, in turn, gives rise to the noise components radiated by the wheel, the rail and the sleeper. The fact that at low (‘normal’) levels, the roughness gives rise to noise radiation linearly and accounts for the noise fully, has been shown by the comparison of theoretical models and carefully controlled measurements [1]. It has furthermore entered the practice of a number of railways to control the roughness, even of uncorrugated, track as a measure to reduce noise.

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 new rolling stock. The acoustic TSI reflects the understanding of the noise generation mechanisms [2, 3]. In order to ensure that the acceptance test, that may be made at different locations on different rolling stock, is a fair test of the rolling stock and 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 level of combined roughness and the roughness of the rail head running surface. The first condition is characterised by a minimum decay rate spectrum that must be obtained on the reference track (for how this relates to the noise performance of the track see [4] and to [5] for the method of measurement). The second condition is a limit to the spectral level of rail roughness that may exist on the reference track [6].

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

A programme of measurements of noise 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 [7]). In most respects the tests were successful but it was shown, as previously realised, that the part of ISO 3095 concerning roughness measurements is too limited in the following respects:

a) the wavelength range specified is too short for use for high speed trains;

b) too little data sampling is demanded to give the required certainty in the measured spectrum of roughness over the wavelength required;

c) 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;

d) ISO 3095 imposes a fixed pattern of sample records; this sometimes causes the measurement of rail-head defects that are not wanted in the signal and have a significant effect on the estimated spectrum;

e) the standard specified the averaging of the roughness across a number of lines at different distances across the rail head. Since the variation across the rail-head is significant, closer specification of where to measure is required and the data for separate lines should be presented separately.

For these reasons the TSI Committee requested CEN/TC 256, Working Group 3, to draft a new standard solely for the measurement of acoustic roughness. It is the intention that the TSI should, in future, refer to the new standard for this aspect.

1.2 Objectives of the road test

The purpose of the road test is to check that the standard can be interpreted consistently and leads to a consistent estimate of roughness spectrum when used by different measurers with different instruments. Many of the instructions of the new standard have not been practiced by measurers before and so these are also being tested for practicability and effectiveness. The exercise is not concerned with testing instruments or measurement technology. The standard specifies minimum performance criteria but otherwise is designed to be as inclusive as possible with regard to technology.

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

2 Brief review of the nature and requirements of the new standard

For the method of pass-by noise measurement, the current High Speed Rolling Stock TSI (2008) refers to EN ISO 3095: 2005 [8]. The current Conventional Rail TSI refers to ISO 3095:2001. Having said this, there is not a significant difference between the two versions.

The EN ISO 3095 standard itself already sets a limit spectrum for the track on which acceptance tests are made and prescribes a method for its measurement. The limit spectrum set in EN ISO 3095 is not used in the TSI's, rather a tighter limit is set from within the TSI's according to what was found possible by the associated NOEMIE project [7]. The project also found, for high speed trains (above 200 km/h), that a minimum wavelength range up to 0,25 m is required.

2.1 Longitudinal position of measurement records and sample length

EN 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.* Such large localised irregularities are not appropriate to include 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 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 EN ISO 3095, the new standard requires there to be a 15 m sample length in total.

2.2 Lateral position of the measurements on the rail head

EN 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 contact remains inside the reference surface. Its identification from the running band or otherwise is an important subject in the new standard. Three different criteria depending on the situation and the purpose of the measurements are offered:

a) 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,

b) the contact position can be measured for the specific rolling stock at the time of roughness measurement,

c) the contact position can be predicted from the geometry of rail and wheel transverse test section.

2.3 Processing

The data must be processed to remove some unwanted ‘pits and spikes’ and produce a one-third octave level roughness spectrum. EN 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 downward features short in the direction along the rail head, found by the small tip radius probe of the instrument and 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,

a) Hanning window, discrete Fourier transform and averaging in one-third octave bands

or

b) digital one-third octave band filtering.

3 The measurement programme

The idea of the ‘road test’ of the new standard is

a) to have a number of different teams measure roughness according to their own interpretation of the standard;

b) to observe the practices of the teams; and then

c) to examine the data for consistency of output.

Thus the standard should be tested in its practicality, whether it produces a consistent interpretation implemented 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 Loriol 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 exercise the measurement of 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 EN 15610:2009. 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 attend the site at Loriol. Thus, seven teams attended measurements at Loriol and five at Wildenrath.

All teams taking part were provided with software by the coordinator that attempted to perform the analysis defined in the standard. The software was provided in open Matlab code used by some of teams and in open FORTRAN. 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 in the text 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, from those that may be 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. This is the basis of the comparisons presented in this report.

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 due to the train running during that time.

3.2 Test sites

3.2.1 Loriol

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.

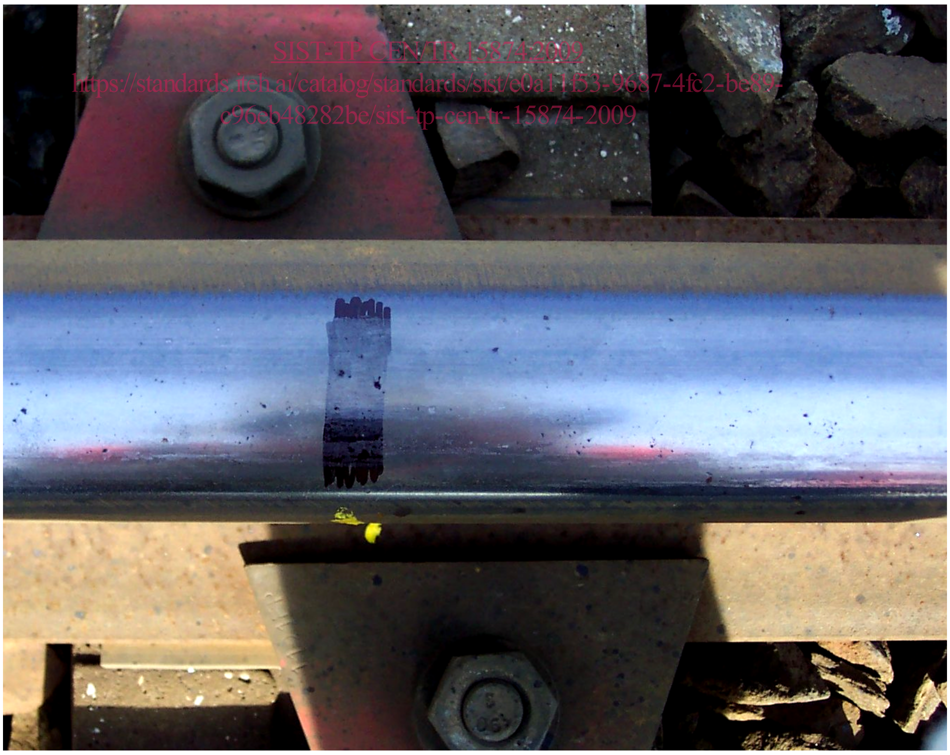

Figure 1 — Photograph of the railhead at Loriol

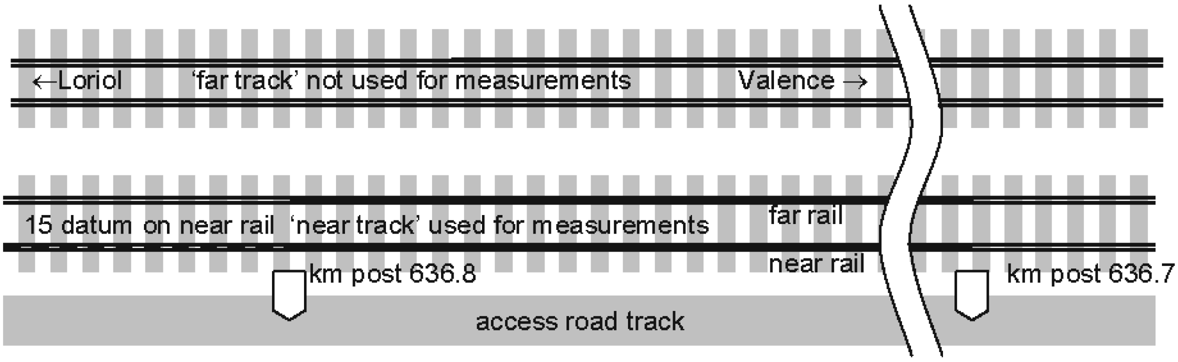

Figure 2 — Layout of the test section of track at Loriol (— reference section, - - - datum)

3.2.2 Wildenrath

Further measurements were carried out between 22nd and 25 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. Figure 3 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/h.

Figure 3 — Photograph of the railhead at the Wilderath test site

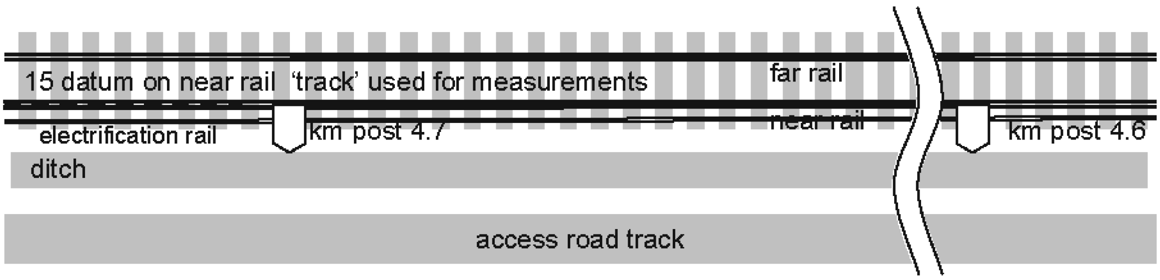

Figure 4 — Layout of the test section of track at Wildenrath (— reference section, - - - datum)

3.3 Teams and instruments

At the Loriol site, seven teams took part with eight instruments. Three separate types of instrument measured 1.2 m records using linear voltage displacement transducers (LVDT's) that moved along a straight edge fixed in position relative to the rail. Two types of instrument measured continuously over the whole 100 m using an accelerometer moved along the rail head by a light 'trolley'. All teams that took part in the test measured at Loriol. The team-instrument combinations for the measurements at Loriol are indicated in Table 1.

Table 1 — The team-instrument combinations at Loriol

Team-instrument	Instrument type	Technology
A	1	1,2 m fixed straight edge with moving displacement transducer
B	1	1,2 m fixed straight edge with moving displacement transducer
C	2	1,2 m fixed straight edge with moving displacement transducer
D	2	1,2 m fixed straight edge with moving displacement transducer
E	4	1,2 m fixed straight edge with moving displacement transducer
G	5	Accelerometer trolley
H	3	Accelerometer trolley

At the Wildenrath site, five teams took part using four of the 1,2-metre fixed straight-edge instruments of two different types. The fifth team used an accelerometer trolley. The team-instrument combinations are set out in Table 2.

Table 2 — The team-instrument combinations at Wildenrath

Team-instrument	Instrument type	Technology
A	1	1,2 m fixed straight edge with moving displacement transducer
B	1	1,2 m fixed straight edge with moving displacement transducer
C	2	1,2 m fixed straight edge with moving displacement transducer
D	2	1,2 m fixed straight edge with moving displacement transducer
F	2	1,2 m fixed straight edge with moving displacement transducer
I	3	Accelerometer trolley

4 Comparison of the practices of the teams

The test coordinator observed the practice of each team in response to the instructions in the standard.

4.1 Choice of lateral position

4.1.1 Loriol

At this site the running band is the product of mixed traffic and this led to a little difficulty for some in deciding the width of the reference surface. Each team used a method of marking the rail at both ends of the test section (some teams used additional positions) and observing the width rubbed off by passing trains (the second method prescribed in the standard). The method worked well with a wide range of paints and markers used, but best with thin coating of ink from marker pens rather than thick coating of paint.

When this method carried out for the modern passenger stock this led to a narrower assessment than for the older, more worn wheels of the freight stock. Team G in particular made a wider estimate than others on the far rail based on the passage of a freight train. Thus team G initially placed three lines 10 mm apart on the far rail. However, all teams were asked to consider the reference surface for the modern passenger stock and this led to a re-evaluation by team G to measure at positions 5 mm apart.

Team H used a lateral rail-head profile measuring device on site before making their decision. The lateral profile was then used in a ‘static’ geometrical calculation of the running position with a standard unworn profile of the wheel. For illustration the output of this calculation is shown in Figure 5. This information was then used in conjunction with the erased band of paint in order to reach the decision. While it was unnecessary under the circumstances of the test with the relevant rolling stock passing regularly so that the marker method could be used, the exercise showed the practicality of the third method offered in the draft standard.

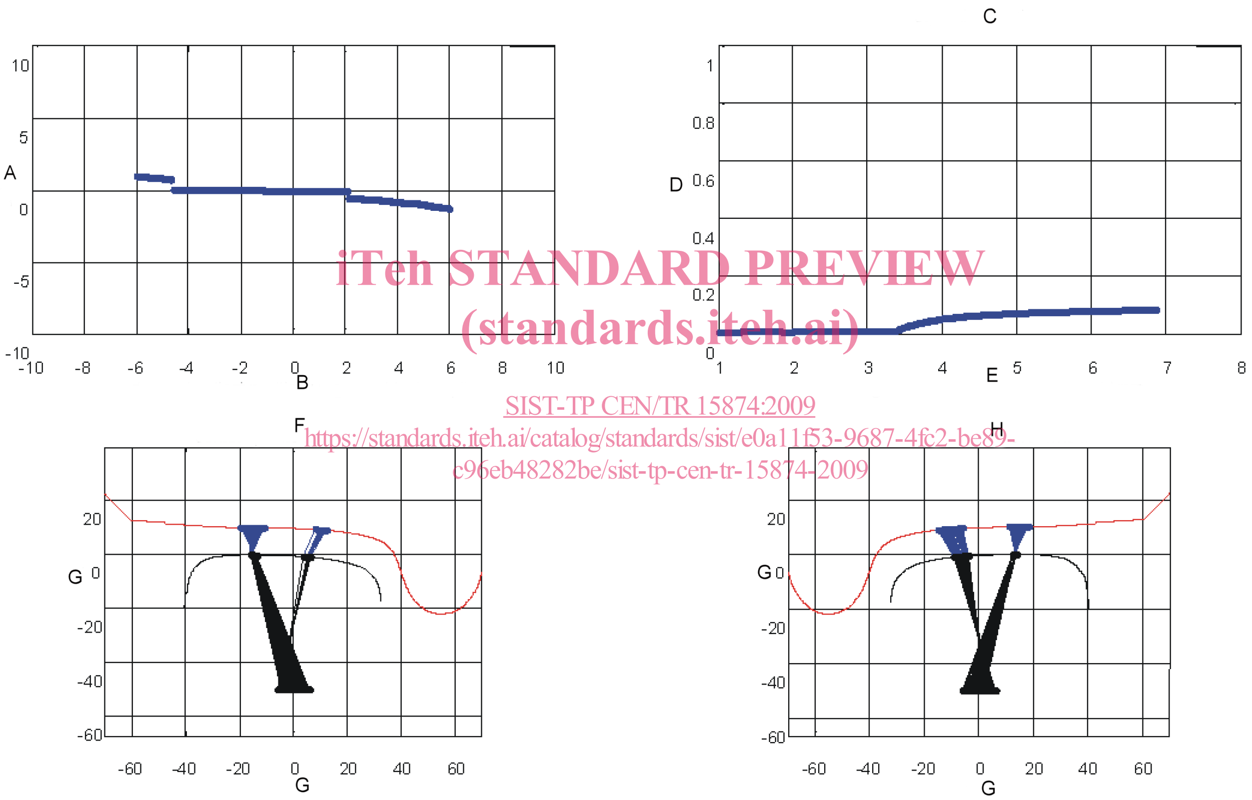

Figure 5 — Output of the on-site guide calculation of likely running position

The decisions on reference surface width and line positions chosen by the different teams is summarised in Table 3.

Table 3 — Chosen lateral measurement positions at Loriol

Team-instrument	Width identified (mm)		Line position(s) chosen (mm from gauge face)		Comments
	near rail	far rail	near rail	far rail	The coordinator chose a line at 39 mm for the datum measurements
A	22	19	39 ± 5	39 ± 5	Centre-line chosen to be same on both rails for convenience
B	28	28	37 ± 5	34 ± 5	
C	22	22	38 ± 5	38 ± 5	Centre-line chosen to be same on both rails for convenience
D	-	-	36 ± 5	36 ± 5	
E	15 – 30	15 – 30	39,5 ± 5	39,5 ± 5	
G	25	35, 25	43 ± 5	37 ± 5, 10	Revised decision on far rail for modern passenger stock
H	-	-	37 ± 5	37 ± 5	

All teams decided to measure 3 lines at Loriol, 5 mm apart. For the near rail, the range of the centre-lines was from 36 mm to 43 mm with no team placing their centre-line further than 4,5 mm from the mean position of 38,5 mm. For the far rail, the situation is not very different with a range of centre-lines from 34 to 39,5 mm from the gauge face. Thus no centre-line was placed more than 3 mm from the mean position of 37 mm.

4.1.2 Wildenrath

The nature of the two running bands at Wildenrath has already been shown in Figure 3. 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. The decisions on the width of the running band, the number of lines of roughness required and their lateral position at Wildenrath are summarised in Table 4.

Table 4 — Chosen lateral measurement positions at Wildenrath

Team-instrument	Width identified (mm)		Line position(s) chosen (mm from gauge face)		Comments
	near rail	far rail	near rail	far rail	The coordinator chose a line at 40 mm for the datum measurements
A	10	10	37	37	
B	16, 11	11	34	37	Initial estimate of running band width was re-evaluated during measurements
C	11	11	35	35	
D	10	10	40	40	
F	10	10	37	37	
I	12	15, 12	37	38	Measured three lines on far rail but decided only one was needed when re-evaluated the consistency of the running band width along the site

At Wildenrath all teams eventually decided that only one line of measurement was required, the confusion being caused by the presence of the second running band and whether a partially worn region between them should be included or not. The observation that this partially worn region was not continuous along the whole 100 m of the test section made those who were wavering clear in their decision that a narrower operating running band was correct.

4.1.3 Conclusion on success of the provisions for identifying the reference surface

Given the differences in the running band of the two sites and their relationship to the rolling stock, the first two techniques used for identifying the reference surface, see 1.2, worked well and led to closely similar positions of the reference surface.

The decision on running band could be aided by some improved wording of the standard advising the measurers to consider the reference surface only to lie within the width that is continuous along the track and also to ignore surface that is only partially worn. The wording relating the reference surface to the rolling stock of interest is clearly necessary and useful as it was invoked at both sites.

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.

4.2 Longitudinal sampling and cleaning the rail head

Different teams had different practices in cleaning the rail head before measurement. The teams using short record instruments used solvent and rags. It was clearly not practicable for the long-record measuring teams to follow this practice. At Loriol the rail head was regularly 'cleaned' apart from easily-moved dust or moisture, by the running trains. The cleaning practice may have been more significant at Wildenrath where, at the start of the test, there were a lot of bird droppings on the rail head. Apart from removal of some gross matter, the one long-record measurement at Wildenrath was made without cleaning this from the rail.

For the 1,2 m-record instruments, most teams took the strategy of scattering the 13 to 16 records locations (approximately) evenly over the 100 m. One team, however, placed their records in a pattern strongly weighted towards the mid-point of the 100 m.

The trolley instruments measured the whole 100 m with extra length on the ends so that start-up and stopping effects could be discarded from the record afterwards.

In the standard, the measurer is instructed to exclude rail-head defects. The reason for this is that a defect on the scale of curvature and length of the wheel-rail contact patch changes the contact stiffness momentarily as the wheel rolls over it. It is known from modelling studies [1, 9] that, for this reason, these features do not lead to a linearly proportionate generation of noise and that a roughness measurement excluding these features agrees well with measured rolling noise [10, 11].

Upon encountering a geometrical feature judged to be excludable, the teams using 1,2 m measuring instruments merely moved their instruments or decided not to include that record in their average. (Most teams took at least 16 × 1,2 m = 19,2 m over the 100 m rather than the minimum 13 × 1,2 m to make up the minimum requirement of 15 m of data.)

Where 100 m of record is taken in one go, it is inevitable that a number of 'rail-head defects' and features such as welds are also measured. However, none of the measurement teams using trolleys identified them and avoided recording them. Rather, it is naturally the practice of these teams to measure the whole 100 m and then to remove these features afterwards. Although this is compatible with the practice of the 1,2 m instrument measurers in avoiding rail head defects, no normative procedure or advice for *a posteriori* identification and removal of data has been given in the standard.

No editing of the raw data of the trolley instruments to remove rail-head defects was done before handing the raw data to the coordinator.

5 The common analysis applied to the raw data

All the data were analysed by the coordinator using the Matlab version of the processing algorithm.

5.1 Spike processing

A point of ambiguity was discovered in the standard that affects the processing of 'spikes'. These are identified as features (maxima) in the data that are short in the rail axial direction, *x*, (height in metres > $w^2/3$) and have a small radius of curvature (absolute value of the second derivative with respect to distance > 10^7 µm/m^2). The ambiguity exists in whether only upward 'spikes' of this type are to be removed or whether downward, 'pits' are also to be removed. Past practice by some organisations is to do both but these organisations did not carry out the subsequent curvature processing that treats the pits by applying a simplified physical argument removing pits by running the large curve radius of the wheel over the data.

It was discussed during the measurement exercises and agreed by all measurement teams, only to remove upward features according to the spike removal processing and to rely on the curvature analysis to treat downward features. This clarifies the philosophy of each part of the processing:

a) the upward features are dirt that can be removed if small enough in relation to the contact patch;

b) the pits are reduced using the physical interpretation of the large radius of curvature of a wheel compared to that of the measurement probe.

All data was therefore treated by the agreed spike removal and the curvature analysis.

5.2 DFT and filtering analysis techniques

The 1,2 m records were analysed using the DFT procedure stated in the standard.

The 100 m records were analysed whole using both the DFT technique and the alternative digital filtering technique offered in the standard. It was found that this could not consistently be applied to 1,2 m or even (concatenated) 3 m records of data because of the starting and ending transients of the filters. It was determined that these transients affect approximately 2 m of data at each end of the record (based on 1 mm or 0,5 mm sampling). Thus the processing was changed to discard 2 m at each end. In the case of long records (100 m) this makes little difference but clearly rules out use of the digital filtering method for 1,2 m instruments.

5.3 Treatment of long records in which rail-head defects are present

As already discussed in clause 4, a clear difference in practice of the teams arose out of the nature of taking 100 m of data in one record compared with those taking individual records of 1,2 m. Thus the 100 m records analysed whole contain the effects of the rail-head defects that were not avoided. (This is commented on with respect to specific results below.) In order to compare results on a more equitable basis between different instruments, the whole 100 m records were chopped into segments of 1,2 m by the coordinator and examined to see if they contained features that were clearly rail-head defects that should be excluded or features that would have caused the straight 1,2 m measurers to have rejected that record. A selection of 15 'clean' 1,2 m, records, approximately evenly spaced along the 100 m was then analysed in the same fashion as the discrete records taken with the 1,2 m instruments.

It is not being suggested here that this procedure of selecting data ought to be sanctioned in the standard. Any practical implications in the efficiency and therefore cost of the work should be taken into account.

5.4 Chatter/screech

At both sites, a number of instruments suffered from a slip-stick excitation of the probe as it was moved along the rail head. This gives rise to a screeching sound during measurements but it was not always easy to hear. It is thought to be a similar mechanism to the 'chatter' of a lathe tool. This is known to occur during roughness