Track Quality Achieved on HSL-South

Reduction of short-wave irregularities cuts life cycle cost

Theo Winter, Project Director of Rheda 2000 v.o.f, BAM Rail b.v.
Peter A.J. Meijvis, Project Engineer and Head of Rheda 2000 v.o.f. Engineering, Delta Marine Consultants b.v.
Wijnand J.M. Paans, Site Engineer of Rheda 2000 v.o.f., BAM Rail b.v.
Michaël J.M.M. Steenbergen, Research Engineer, Delft University of Technology, Railway Engineering Group
Coenraad Esveld, Professor, Delft University of Technology, Railway Engineering Group

1 Introduction

The Netherlands join the Trans-European high-speed rail Network when the HSL-South line, connecting Amsterdam to Brussels and Paris, opens for service. This double track line is divided by the connection to Rotterdam in a northern and southern section (Fig. 1).

A horizontal split in contracts has been applied between the substructure and the superstructure. The substructure which consists of for instance bridges, an aqueduct and various tunnels have been divided into different sections and built by seven mainly Dutch contracting consortia. The superstructure has been built completely by Infraspeed, a consortium consisting of Siemens, Royal BAM Group and Fluor Daniel. The contract has been awarded as a Design, Built, Finance and Maintenance contract (DBFM). The maintenance period is 25 years in which an availability >99% has to be achieved. After this maintenance period, an extra 5 years of normal maintenance has to be assured. This explains the importance to achieve a high initial track quality: a long lifetime of the structure must be guaranteed with a minimum of maintenance. Therefore the Rheda slab-track system of Pfleiderer Track Systems (now Rail.One) has been applied, engineered and built by Rheda 2000 v.o.f. ; a partnership consisting of BAM Civil, BAM Rail and Pfleiderer within the Infraspeed consortium.

The short-wave irregularities (length-scale 0-5 m) in the track have a large impact on the required maintenance. They lead to high-frequency interaction between the train and the track, especially on a high-speed line, and generate high wheel-rail contact forces. These can lead to rapid damage or track deterioration. For the HSL-South, the geometry in the short-wave regime is entirely determined by the quality of the geometry of the welds between the straightened long-rails. The long-waves components of track irregularities are mainly responsible for passenger discomfort.

This paper discusses the quality of the new HSL-South line in both aspects. The focus will be placed on the quality in the short-wave regime, the effects on the level of dynamic train-track forces and the effects on lifetime and maintenance.

Figure 1 The Dutch HSL-South line *(courtesy Project Organisation HSL-Zuid)*

Key data of the Dutch HSL-South	
Length of Rheda slab track	81.5 km double track (on a total of 90km)
Length of longrail	120 m
Number of flash butt welds	2647
Number of aluminothermic welds	468
Sleeper distance	± 0.63 m
Rail profile	UIC 60 (60 E1)
Rail inclination	1:20
Track gauge main line	1437 (±1) mm
Track gauge switches	1435 mm
Rail fastening system	Vossloh 300-1 NL/HSL
Sleepers	Pfleiderer bi-block B355.1 NL U-60M
Maximum cant	180 mm
Design speed	300 km/h
Maximum gradient	25‰
Track design life time	25+5 years
Neutral rail temperature	20°C
Switches	BWG 1:12, 1:34.7, 1:39.17 (fb fakop)

2 Brief overview of the slab track construction on the HSL-South

Apart from many civil structures the track substructure, with a design lifetime of 100 years, is formed mainly by 30 or 35 m long monolithic slabs. They act as a kind of continuous viaduct, founded on piles (named Settlement Free Plates). This is done in order to avoid settlements under the given poor soil conditions and to meet the strict limitation for differential displacements of the substructure of 1 mm per 2 m.

The Rheda 2000 slab track superstructure consists of prefab concrete bi-block sleepers cast into a reinforced concrete slab on site (Fig. 2). This concrete slab consists of relatively short distinct sections (3.7 – 6.5 m), separated from the substructure by a 4 mm polypropylene geotextile intermediate layer and fixed with diamond-drilled 40 mm diameter stainless steel dowels into the substructure. This construction does not affect the force distribution in the substructure. Adjustable Vossloh fastening systems, mounted on the sleepers, carry the long-rails (120 m sections) which have been flash-butt welded.

Figure 2 The finished slab track on the Dutch HSL-South

3 Dynamic track quality in the long wave regime

The HSL-South is required to comply with the UIC 518 norm [1] (track geometry quality level QN1), and the UIC 513 norm [2] (comfort index < 2). The measurements according to UIC 518 have been done by the Eurailscout UFM-120, whereas the measurements according to UIC 513 have been carried out by the Thalys TGV-PBKA. The test speeds of the UFM-120 have been 40, 80 and 120 km/h; for the Thalys speeds of 160, 200, 230, 270, 300 and 330 km/h have been used.

An example of the measured vertical geometry and the PSD measured by the UFM-120 is shown in Fig. 3 for the East track of the Northern section. Results on other track sections are similar.

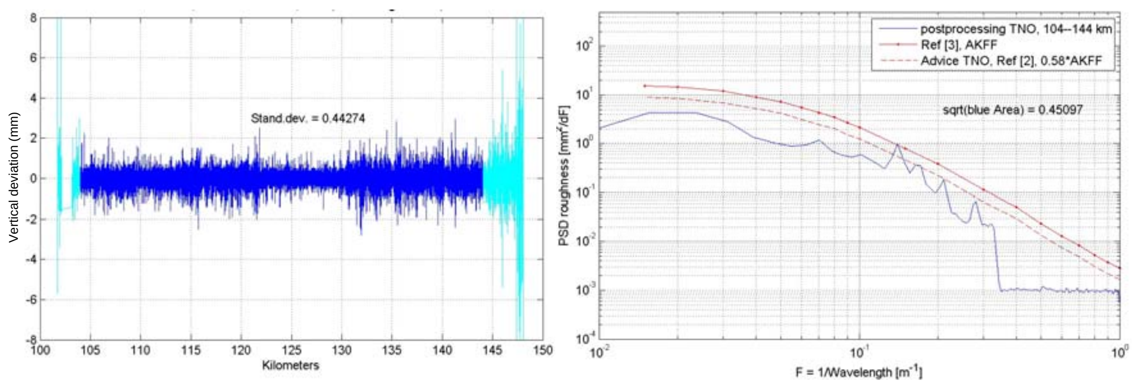

Figure 3 Registered vertical geometry and power spectral density of vertical track geometry on the Northern line section, East track

Fig. 4 shows the measured standard deviations on the HSL-South compared to the measurement of 0.63 mm of 2004 on the German Köln-Frankfurt high-speed line (slab track), taken over a length of 141 km, after 3 years of operation [3]. The rail track geometry on the HSL-South has been measured in accordance with the German DB Guidelines [4, 5] which allow the use of the UFM 120.

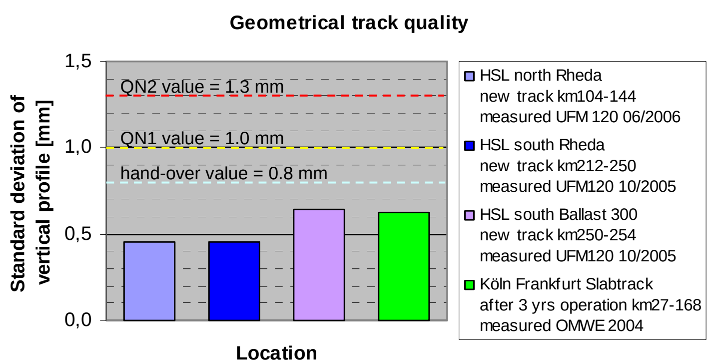

Figure 4 Comparison of the standard deviations of the vertical rail profile on the HSL-South and the Köln-Frankfurt high-speed ballastless track after 3 years of operation

The bogie and coach accelerations registered during high-speed test-rides of the Thalys TGV-PBKA have been processed according to UIC 513. ISO frequency weighing has been applied to the measured acceleration spectra. Next, RMS-values for intervals of 5 seconds of measured accelerations have been determined. Histograms have then been made with the distribution function for the 5 second intervals of these RMS-values. Comfort indices have been determined based on the resulting histograms according to the formulae in UIC 518 for N_{vd} (standing passenger) and N_{va} (seated passenger). This procedure has been applied for 4 different sections of 5 minutes. The test results for both the northern and the southern section are summarized in the graphs of Fig. 5, where also average values and standard deviations are shown.

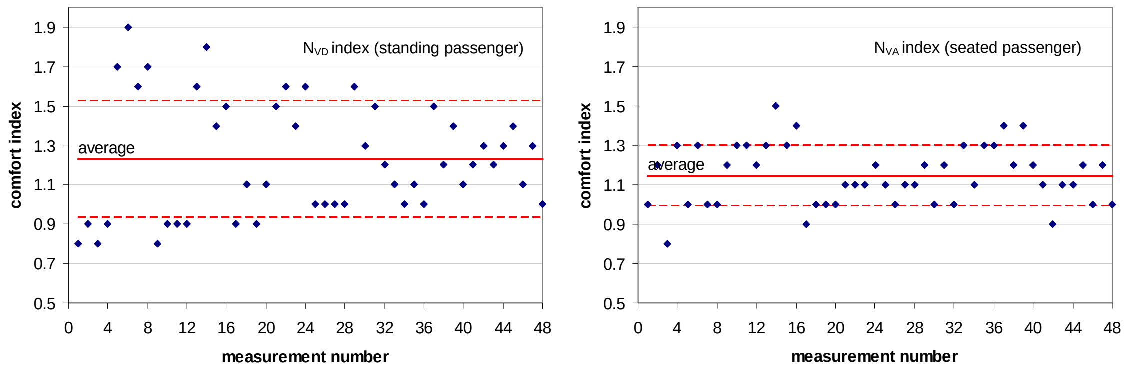

Figure 5 Comfort indices from the high-speed test runs according to UIC 513 on the HSL-South

The index legend according to UIC 513 is:

- N < 1 very good comfort
- 1 < N < 2 good comfort
- 2 < N < 4 moderate comfort
- 4 < N < 5 poor comfort
- N > 5 very poor comfort

It can be concluded from Fig. 5 that the average comfort index is close to 1, indicating a very high track quality in the long wave regime.

4 Dynamic track quality in the short wave regime

As stated in the introduction, short-wave irregularities are mainly responsible for track deterioration. Since Infraspeed is responsible for the track and the maintenance for a period of 25+5 years, the track quality in the short-wave regime, determined by the weld quality, was an important issue.

The longrails on the HSL-South have been welded mainly using flash butt welding. Aluminothermic welds have been used only for switches, expansion and insulation joints, transitions between UIC 60 and UIC 54 and repair works. The manufacturing process of flash butt and aluminothermic welds on the HSL-South is illustrated in Figs. 6 through 8.

Figure 6 Flash butt rail welding on the HSL-South

Figure 7 Aluminothermic rail welding and manual pre-grinding on the HSL-South

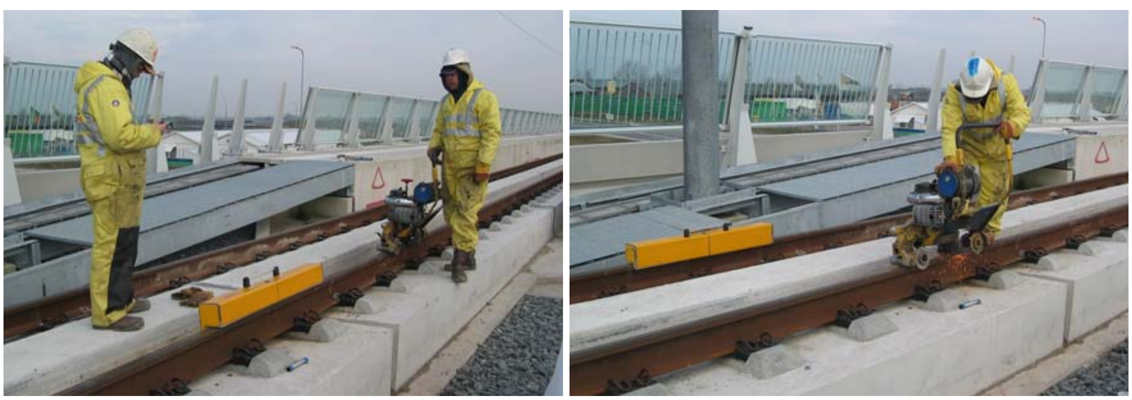

Figure 8 Geometrical weld quality control (with RAILPROF device) and fine manual grinding on the HSL-South

The geometry of the welds has first been assessed according to the TSI-standard, prescribing a vertical upset within the limits of +0.1 to +0.3mm, with a fluent shape over a length of 1m. Since a new rail is straight, an addendum, consisting of a vertical tolerance of 0.0 to +0.1mm, was allowed. The geometry was measured using a digital straightedge (RAILPROF) equipped with graphical interface (PDA), which displays the measured geometry.

The initial geometry quality proved unsatisfactory on two parts of the track, leading to the deployment of the Plasser GWM 550 grinding train. Furthermore it was expected that the final overall grinding (Speno RR 24 and 48) would also lead to better geometrical results. Apart from that, two more criteria were introduced, related to ongoing research in this field by TU Delft. According to the first, negative values were accepted if the maximum slope in the 0.2-2 m waveband was smaller than 0.7 mrad. The second criterion was conform to the new assessment method developed by TU Delft [6,7] and adopted by the Dutch rail infra provider (ProRail) in 2005. This method had been developed to restrict dynamic wheel-rail interaction forces. It makes use of the digital straightedge to determine a speed-dependent quality index (QI) for the weld geometry along the rail. This QI is calculated by determining the gradient of the weld geometry, and normalizing it with a speed-dependent norm value (in this case, for 300 km/h, the norm was set to 0.7 mrad). The QI, which correlates well with the dynamic contact force, should be smaller than 1 for acceptance. The geometrical weld quality control process on the HSL-South is shown schematically in Fig. 9. Apart from the assessment, for all welds the QI has been registered, before and after passage of the grinding train.

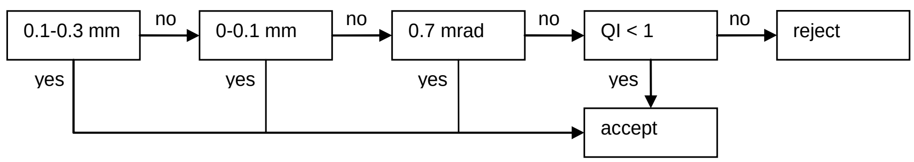

Figure 9 Flowchart of the geometrical weld quality control process on the HSL-South

In Fig. 10, the percentages of welds complying with the above norms and guidelines are specified for the whole HSL-South.

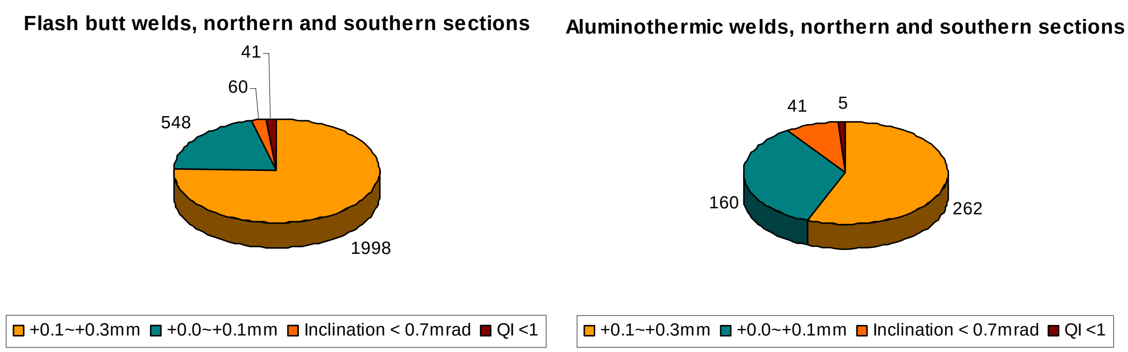

Figure 10 Achieved weld quality on the HSL-South

As was mentioned already, the GWM 550 grinding train ground two track sections on which the initial geometry quality proved unsatisfactory (296 welds). In Fig. 11 the cumulative QI distribution of the welds is compared before and after grinding with the GWM. Before grinding with the GWM the 95 percentile value of the QI is 7.5; this reduces to 1.6 afterwards.

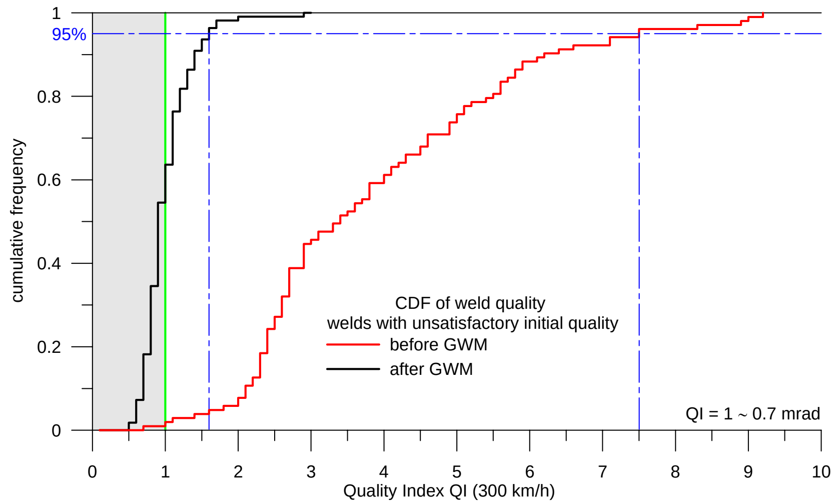

Figure 11 Effect of GWM-grinding on the cumulative distribution of the QI of rail welds with unsatisfactory initial quality on the HSL-South

In Fig. 12, cumulative distribution functions (CDF's) are shown of the QI of the rail welds on a double track section of 6 km (A44 – Bennebroekerweg). This part is chosen as a representative section. The CDF's are shown both before and after final grinding with Speno, for the west and the east track.

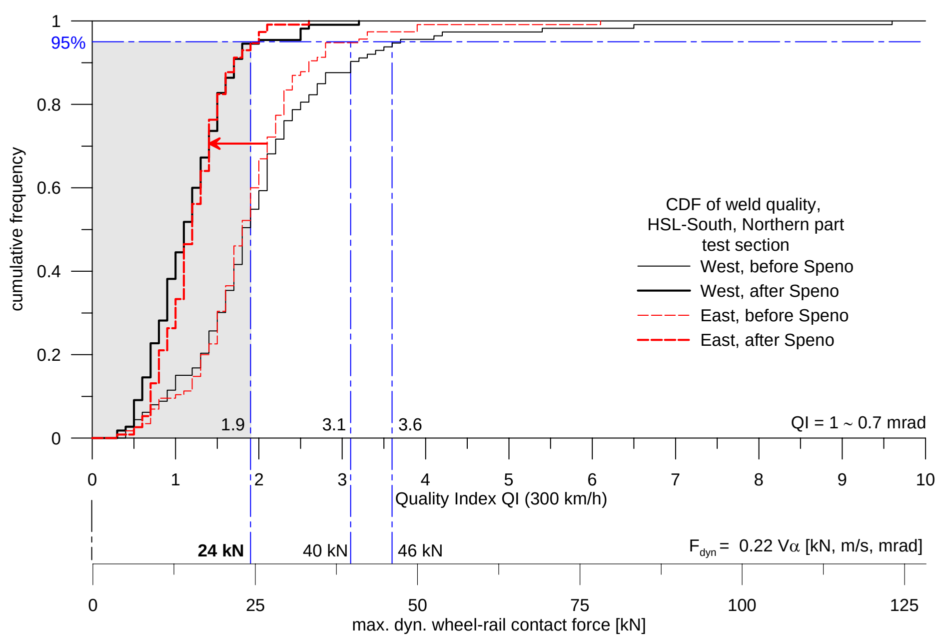

Figure 12 Cumulative distribution of the QI of rail welds on a representative section of the HSL-South before and after passage of the Speno grinding train

The QI-method links the geometry of a weld to the level of dynamic contact forces (see refs. [7, 8, 9]). Therefore, the CDF's in Fig. 12 can be simply translated into CDF's for the dynamic forces occurring at the welds on this track section. This is done on the horizontal axis at the bottom. A number of conclusions can be drawn from Fig. 12. The approximately equal quality level of the east and west track before grinding with Speno can be interpreted as a distributed geometrical weld quality obtainable over a railway network with accurate manual fine-grinding. Since QI = 1 for 300 km/h corresponds to a slope of 0.7 mrad, which is the 95 percentile value of new straightened rail [10], it is possible to achieve 300% of the QI of new straightened rail in welding new rail with accurate manual grinding. The Speno grinding train reduces the QI of the 95 percentile value with about 50%. It can be observed from the relative difference between the east and west tracks in Fig. 12 that the reached quality level after grinding with Speno depends on the initial quality level of the welds, implying that Speno can achieve a rather constant improvement. The 95 percentile value of the dynamic wheel-rail force at the welds is about 45 kN before grinding with Speno and 24 kN afterwards, which is very limited for high-speed track.

A general simple relationship between the number of cycles to failure N (describing the fatigue life) and the stress range $\Delta\sigma$ can be described by the *S-N* curve according to:

$$N = C(\Delta\sigma)^{-m} \text{ or } \frac{\text{Lifetime}_{\text{new}}}{\text{Lifetime}_{\text{orig.}}} = \left(\frac{F_{\text{orig.}}}{F_{\text{new}}}\right)^3; \quad F = F_{\text{stat}} + F_{\text{dyn}}$$

where the fact has been used that in general m = 3 up to N = 5E6 for steel (EuroCode 3). Thus, the fatigue life can be assumed to be proportional to the 3rd power of the stress range (Fig. 13). The rail bending stress range is proportional to the total wheel load on the rail (static and dynamic components). The static wheel-load for a Thalys high-speed train is 170/2 or 85 kN; the dynamic load is determined by the geometrical weld quality. Using the 95 percentile values in Fig. 12, the total wheel-load reduces from 130 kN to 109 kN, which is a reduction with a factor 1.2. This reduction results in an extension of the fatigue lifetime of the welds with a factor 1.2^3 or 1.7.
A similar calculation for the graph in Fig. 11 (GWM grinding) yields a total wheel-load reduction (from 181 to 106 kN) with a factor 1.7, or a significant lifetime extension with a factor 4.9.

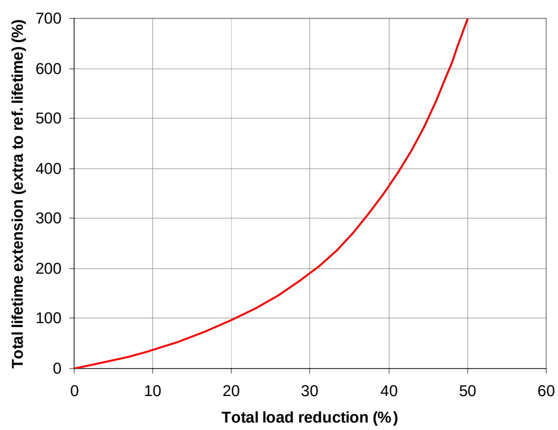

Figure 13 Relationship between the total wheel load reduction and the rail weld fatigue lifetime extension

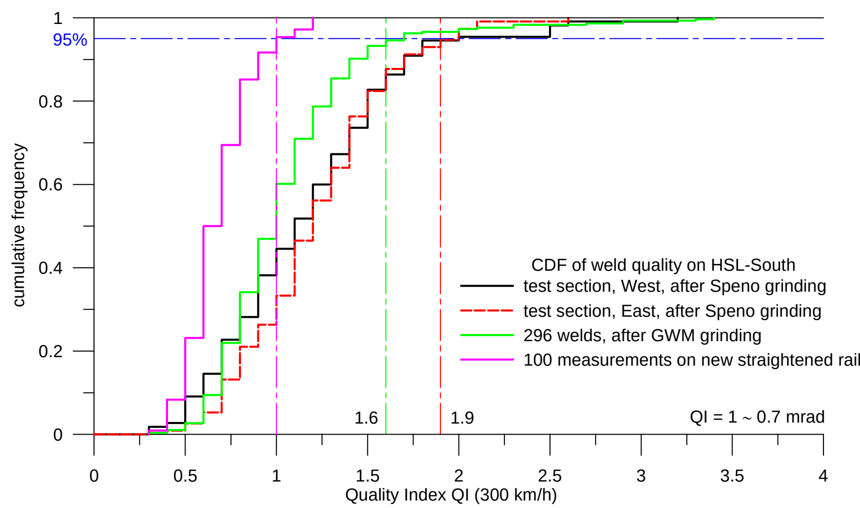

Figure 14 Cumulative distributions of measured QI of new rail and rail welds on the HSL-South; comparison of Speno (6 km test section) and GWM (about 300 arbitrary welds)

In Fig. 14, the results obtained by Speno (from Fig. 12), by the GWM (from Fig. 11) and the measurements on new straightened rail (from [10]) are compared. For small QI-values, the results achieved by Speno and the GWM are approximately equal, but for higher QI-values the obtained result obtained by the GWM is much better; the CDF is 'steeper'. This is a result of the different grinding methods applied by Speno (continuous mobile grinding, Fig. 15) and the GWM (stationary grinding). The result obtained after grinding with the GWM is less dependent on the initial geometry, which could clearly be observed when comparing individual weld geometries before and after grinding for both cases. The final result that can be obtained with the GWM strongly depends on the applied grinding time. Based on the results of Fig. 14, the 0.7 mrad limit seems a too strict value, and 1 mrad (0.7 mrad x 1.6 = 1.1) seems more appropriate or feasible as a limit value in the QI determination for welds in new high-speed tracks, as has been confirmed in a recent study by the TU Delft [11].

Figure 15 The Speno grinding train on the HSL-South

The different grinding methods also have another interesting effect, which can be observed from test train runs. Acceleration recordings with a frequency upper-limit of 20 Hz on the front bogie of the test Thalys show moderate peaks each 120 m for a train speed of 160 km/h. An example is shown in Fig. 16. These peaks do not appear in the test runs at 300 km/h. They seem to be related to the unstraightened ends (upsweep) of the long-rails, which typically result in an irregularity with a wavelength of about 2 m, or a frequency around 20 Hz at 160 km/h. Bogie resonances are located between 10-15 Hz, which are therefore easily excited by these ends at 160 km/h. Much shorter wavelengths (<2 m), as contained within wavelength spectra of welds, cannot be detected when filtering at 20 Hz, therefore welds are excluded as a cause. The periodical peaks are much less pronounced on the track sections which have been ground by the GWM (Fig. 17). Apparently, the GWM grinding train removes the effect of unstraightened rail ends.

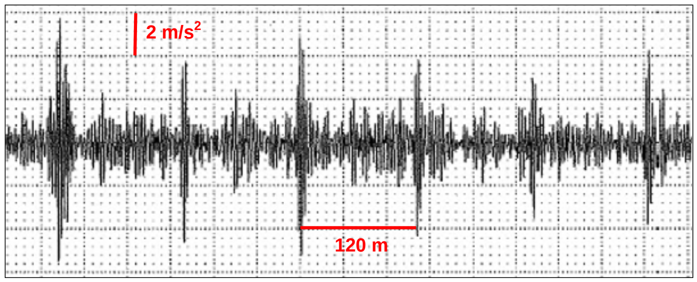

Figure 16 Vertical bogie accelerations (low-pass filtered at 20 Hz) registered at the centre of the front bogie of the test Thalys; influence of unstraightened longrail ends at 160 km/h

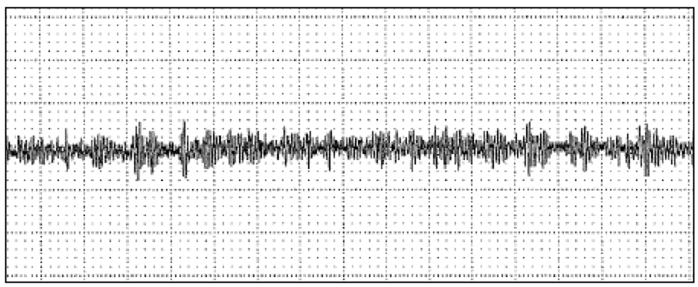

Figure 17 Vertical bogie accelerations registered on a track section ground previously by the GWM (scale: identical to Fig. 13)

5 Conclusions

- The average comfort index measured on the HSL-South is close to 1, indicating a very high track quality in the long wave regime, providing a high level of passenger comfort.
- The method of the QI to determine geometrical rail weld quality has been successfully applied on the HSL-South. The result is a high track quality in the short-wave regime, which is expected to result in an extended lifetime and a minimum of maintenance.
- Grinding of welds with a grinding train has a positive effect on the geometry, reducing dynamic forces and fatigue. In order to reach a good result with Speno (RR24/48), a relatively high initial quality is required in manual precision grinding. This is not the case for the Plasser GWM 550, which can improve very bad welds. Moreover the GWM 550 removes the effect of unstraightened rail ends (upsweep) to any required perfection, depending on the grinding time.

References

[1] UIC 518 Testing and approval of railway vehicles from the point of view of their dynamic behaviour – Safety – Track fatigue – Ride quality, International Union of Railways, 2nd edition, 2003.

[2] UIC 513 Guidelines to evaluating passenger comfort in relation to vibration in railway vehicles, International Union of Railways, 1st edition, 1994.

[3] Kočan, D. Erfahrung mit der Fahrbahn der SFS Köln-Rhein/Main nach drei Jahren Betrieb, Eisenbahningenieur, 2005, 56 (11).

[4] Anforderungs Katalog zum Bau der Festen Fahrbahn 4, überarbeitete Auflage, DB, 2002.

[5] Richtlinie 821.2001: Prüfung der Gleisgeometrie mit Gleismessfahrzeugen, DB, 2004.

[6] Steenbergen, M.J.M.M., Esveld, C. and Dollevoet R.P.B.J. New Dutch Assessment of Rail Welding Geometry. European Railway Review, 2005, 11, 71-79.

[7] Steenbergen, M.J.M.M., Esveld, C. Rail weld geometry and assessment concepts. Proc. IMechE, Part F: Journal of Rail and Rapid Transit, 2006, 220 (F3), 257-271.

[8] Steenbergen, M.J.M.M., Esveld, C. Relation between the geometry of rail welds and the dynamic wheel-rail response: numerical simulations for measured welds, Proc. IMechE, Part F, Journal of Rail and Rapid Transit, 2006, 220 (F4), 409-424.

[9] Esveld, C., Steenbergen, M.J.M.M. Force-Based Assessment of Rail Welds. In Proc. of 7th World Congress on Railway Research, Montreal, Canada, 4-8 June 2006.

[10] Esveld, C., Steenbergen, M.J.M.M. Force-Based Assessment of Weld Geometry. In 8th International Heavy Haul Conference, Rio de Janeiro, Brasil, 14-16 June 2005, Proceedings IHHA pp. 51-58.

[11] Steenbergen, M.J.M.M., Esveld, C. Determination of target and limit values for geometrical weld assessment on high-speed railway tracks, Report 7-07-220-12, Delft University of Technology, 2007.