Roughness growth – A practical case

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Abstract

Rail roughness must be kept under control in a test site to ensure that it remains valid for type tests even some time after grinding. The paper presents the results of an analysis conducted on a high-speed track in Italy. Roughness measurements were carried out monthly for one year, starting one month after grinding. The analysis made by using a modified version of the long roughness measurement protocol gives a significant insight of the roughness growth phenomena.

1. Introduction

Even if standards in force (ISO 3095:1975) do not require rail roughness measurement for type testing, future standards (EN ISO 3095:2004) will. Both Technical Specifications for Interoperability – Rolling Stock for High Speed and Conventional Rail refer to a draft version of the standard (prEN ISO 3095:2001) and require rail roughness measurements [1]. It is worth to remind that the application of TSI is mandatory, while the application of EN or ISO standard is on a voluntary basis.

Roughness spectrum limits are so stringent that standard track normally exceeds them. It is rather common the case that a track must be ground to reduce the roughness to an acceptable limit, but as long as normal traffic passes over the rails it is expected that roughness will increase in time.

This paper shows the evolution of roughness over a significant lapse of time on a high speed line. As the goal of the paper is not to assess the validity of the test site for noise measurements, the roughness protocols described in the standards will not be followed, and a new protocol [1] for long roughness measurements will be partially applied. The new protocol allows the identification of local defects and improves the statistical reliability of the results.

2. Test site description

Italy has up to now only one high-speed line, from Florence to Rome. Maximum speed in service is 250 km/h, while speeds in the order of and above 330 km/h were reached only in the North section of the line between Florence and Arezzo, opened in 1992, with line out-of-service. Tests are normally conducted at night as no traffic is allowed on the entire section during all tests.

The line mainly crosses a nice portion of the Tuscany countryside, with many bridges and tunnels. There are only two places where the line satisfies, at least partially, the criteria described in the standards for noise measurements: tangent track, free field, low background noise. The first potential site coming from North (Florence) is Matassino, where during the last years extensive tests on noise barriers were conducted. Unfortunately train speed in this site can not reach 300 km/h (trains are still accelerating after S. Donato tunnel) and in recent years it was not considered valid anymore for high speed measurement campaigns.

The other place is P.C. Renacci (P.C.=*Posto di Comunicazione*, Junction Point), at km 227+713 (around 40 km South of Florence). This place was used by the author several times for different measurements; results obtained there were published, for example, in [2-5].

An aerial view of P.C. Renacci facing East is shown in Fig. 1. Clearly visible are the river Arno and the Milan-Naples A1 Motorway. North (left) building is P.C. Renacci, where the junction switches are located; South (right) buildings are SSE Renacci (Electric Substation). Noise measurements are normally conducted on the East side of the line, as the presence of the highway in the West side prevents the use of a microphone at 25 m from the track. The author normally prefers a test site close to P.C. Renacci, measuring even-numbered northbound trains, but for the activity shown in this paper the southbound track was considered as the rails were ground on 31 May 2003 almost for the entire extent from P.C. to SSE, starting after the switches. This site was also chosen by RFI (Rete Ferroviaria Italiana, the Italian infrastructure owner) for noise measurements, not related to the activity illustrated here, made on July and on November 2003.

Figure 1. Aerial view of P.C. Renacci (13 December 2003).

Roughness measurements were taken on the ground track using as a reference the “zero-point” defined by RFI for its activities. A picture facing South of the area close to the zero point is shown in Fig. 2. It is evident the high steepness of the scarp which, especially at 25 m from the track axis, clearly contrasts with the requirements of the standards (ISO 3095 requires that “the ground needs to be essentially flat and within a level from 0 to -1 m, relative to the top of rail”).

Figure 2. View close to the RFI zero point, looking South towards SSE Renacci on the exceptionally hot 2003 summer (1 July 2003) and a cold cloudy winter dawn (13 January 2004). The much lower level of neighbouring yard tracks is clearly visible.

3. Measurement campaign planning and implementation

Thanks to the very good relationships with RFI personnel it was possible to access the high speed line without many formalities and, above all, daytime and without interrupting the normal traffic. A calendar of monthly campaign was set up, considering holydays, vacation periods and leaving backup possibilities for bad weather and other unpredictable reasons.

The calendar was generally respected, resulting the distance between consecutive measurements from 23 days to 45 days. Measurements were numbered consecutively and are listed in Table 1. Environmental conditions were always favourable to perform the measurements with the exception of measurement 9, which was done after a rainy night following a strike: the rails were particularly rust and, as shown later, this influenced the results.

TABLE 1

Measurement details. Rails ground on 31.05.2003

Measurement number	Date	Measurement hours	Time [min]	Weather	Initial temperature [°C]
1	30.06.2003	10.26-11.43	77	Sun	28.5
2	04.08.2003	09.40-10.12	32	Sun	30.5
3	01.09.2003	09.36-10.20	44	Cloud	29.5
4	30.09.2003	09.56-10.38	42	Sun	28.0
5	05.11.2003	10.36-11.12	36	Cloud	18.0
6	04.12.2003	11.13-12.18	65	Chill	-2.5
7	13.01.2004	11.04-11.37	33	Cloud	6.0
8	05.02.2004	10.39-11.22	43	Sun	3.0
9	02.03.2004	11.12-11.53	41	Cloud	13.5
10	01.04.2004	09.18-10.03	45	Sun	15.5
11	14.05.2004	10.03-10.50	47	Sun	21.0
12	07.06.2004	09.31-10.11	40	Sun	21.0

Roughness was measured on six parallel traces for an extent of 120 m centred on the RFI zero point. For data processing purposes, a new zero point was assigned to the North origin of the measurements, which therefore run from 0 m to 120 m; at x=60 m there is the RFI zero point. Traces were named according to Fig. 3. Their position relative to the running band was chosen during the first campaign on 30.06.2003 and it was held even if railhead wear and interaction with trains produced a widening of the running band.

Time necessary for measurements is extremely short and, if no trains are passing on any of the tracks, it is in the order of half an hour. Consider that trace *leftcentre* was always measured for 400 m, therefore extending the measurement well beyond the scope of this work. Only results relative to traces *leftcentre* and *rightcentre* are presented here; the maximum efforts have been done to ensure the repeatability of the measurement (warming the electronics, not walking on the rails to prevent the presence of dust, etc.) and they are considered to be sufficiently representative of the time behaviour of this line.

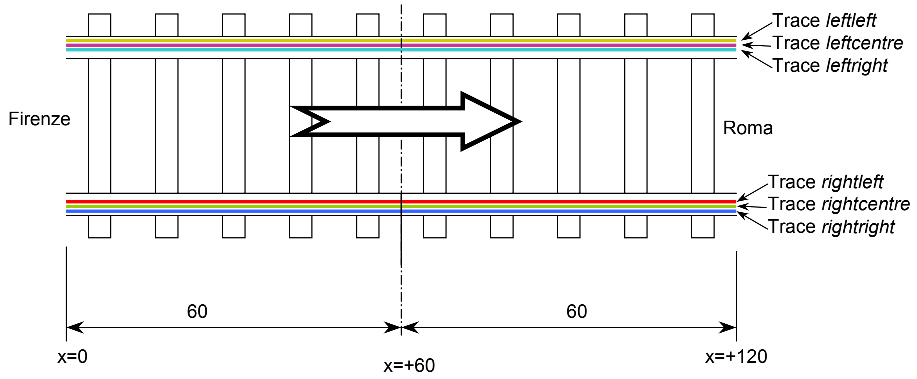


Figure 3. Trace names and general layout of the test field

4. Railhead initial aspect and modifications

Unfortunately it was not possible to attend the grinding operations on 31 May 2003. Figure 4 shows one of the first pictures taken after grinding, where rotating stones grinding marks are clearly visible. The definition of the running band resulted to be quite hard, as it was desired not to measure on the outer portion of the bright stripe where grinding marks were more evident.

The aspect of the running band changed in time in a very non-uniform way. Italian rails are inclined by 1:20, and the profile coupling with ORE S 1002 wheel leads to a double contact: the contact point passes suddenly from the wheel tread/railhead top position to wheel flange/railhead flange side position, leading to non-uniform wear (and to stability problems at the higher speeds). A situation very different was found by the author in a country were rails are inclined by 1:40 [1].

As a sample, two other photographs are shown in Fig. 5. After six months grinding marks were still evident; only after one year the situations seems normal.

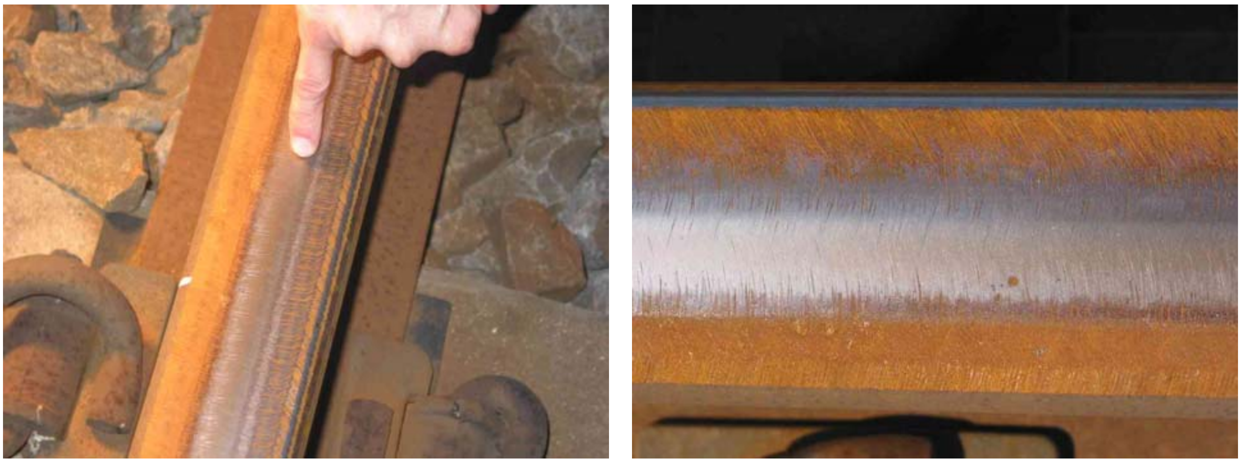


Figure 4. The first photos of the railhead on the left rail (30 June 2003).

Figure 5. Railhead aspect after six months (left, 4 December 2003) and after one year (right, 14 May 2004).

5. Local irregularities detection in roughness traces

A preliminary analysis on the data was done by using the procedures described in [1]. In particular, all the twelve *leftcentre* and the twelve *rightcentre* traces were split in 100 mm-long sections and for each of them the Defect Indicator Factor *DIF* was computed. After removal of the first and the last 2000 mm to eliminate CAT initial values, the number of defects was found with different values of *DIF* (Fig. 6). From the analysis of the *leftcentre* trace some things emerged:

- although the traces are shorter than those presented in [1], the number of defects is much greater. Looking at the single traces, a globally higher roughness level was observed, even if peaks are not very important. The pass criterion failed mainly for energy reasons rather than for *kurtosis* reasons;
- different portions of the track exhibit different number of defects, meaning that grinding process was not completely under control at least for noise purposes (longitudinal profile). Looking at the map of defects, for example for *DIF*>40, it is clear that the maximum number of defects is found closer to the new origin (Fig. 7), where the grinding operation probably started;

- the situation tends to improve after one month (the number of defects reduces clearly) but when the defects reappear they do where they were before, confirming that defects were always present even at lower level and did not disappear completely;
- some measurements contain an abnormally high number of defects. These are measurement 4 and 9. While for the latter there is a clear explanation (see 3, above), the former is not justified. The rest of this work is conducted by removing these two traces;
- in any case the number of defects increases more ore less steadily with time.

Similar trends are shown by the *rightcentre* trace; in both cases an area with a significant number of defects is close to section 625, which means around 4.5 m from the RFI zero point. The advantage of the application of the techniques described in this paper is that the results from error analysis may suggest to shift the microphone to a different location.

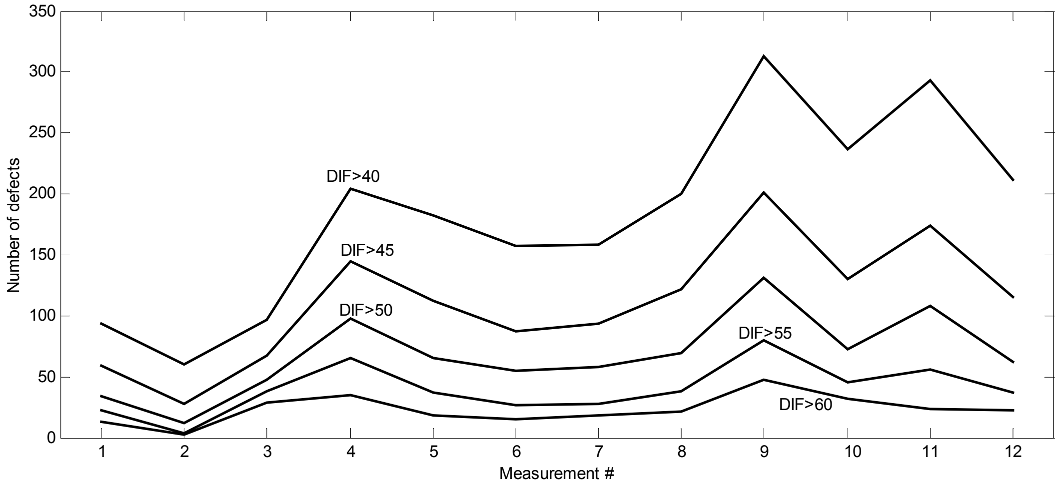


Figure 6. Number of defects found using the *DIF* criterion with indicated values for all *leftcentre* measurements.

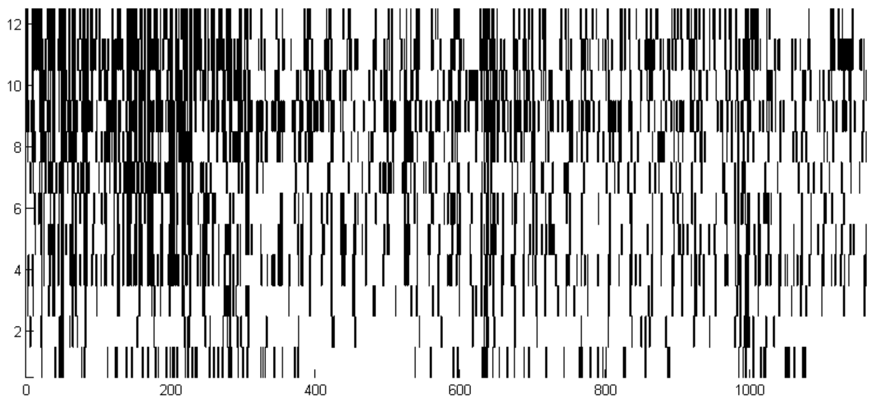


Figure 7. Defective sections found with *DIF*>40 criterion for all *leftcentre* measurements (x-axis: section, y-axis: measurement number).

6. Spectral analysis of roughness data

Spectral analysis was conducted by using the perfect filtering technique described in [1]. Instead of using the section removal criterion described there, it was preferred to use the longest available non defective section on the rails.

Only removing clearly defective traces and using the softer criterion *DIF*>60 it was possible to identify sufficiently long sections in both the rails.

For the left rail this resulted in the 16.7 m long section between sections 410 and 567 (41.0 m to 56.7 m from the origin), obtained after removal of traces 4 and 9; for the right rail the longest section is 19.2 m from section 721 and 913 (72.1 m to 91.3 m from the origin), obtained after removal of trace 12. The length of the two sections is in any case sufficiently long to give a reasonable estimation of wavelengths with a statistical error in the order of ±1.2 dB for the 315 mm centre band wavelength. For clarity purposes, Fig. 8 shows the results for only some measurements.

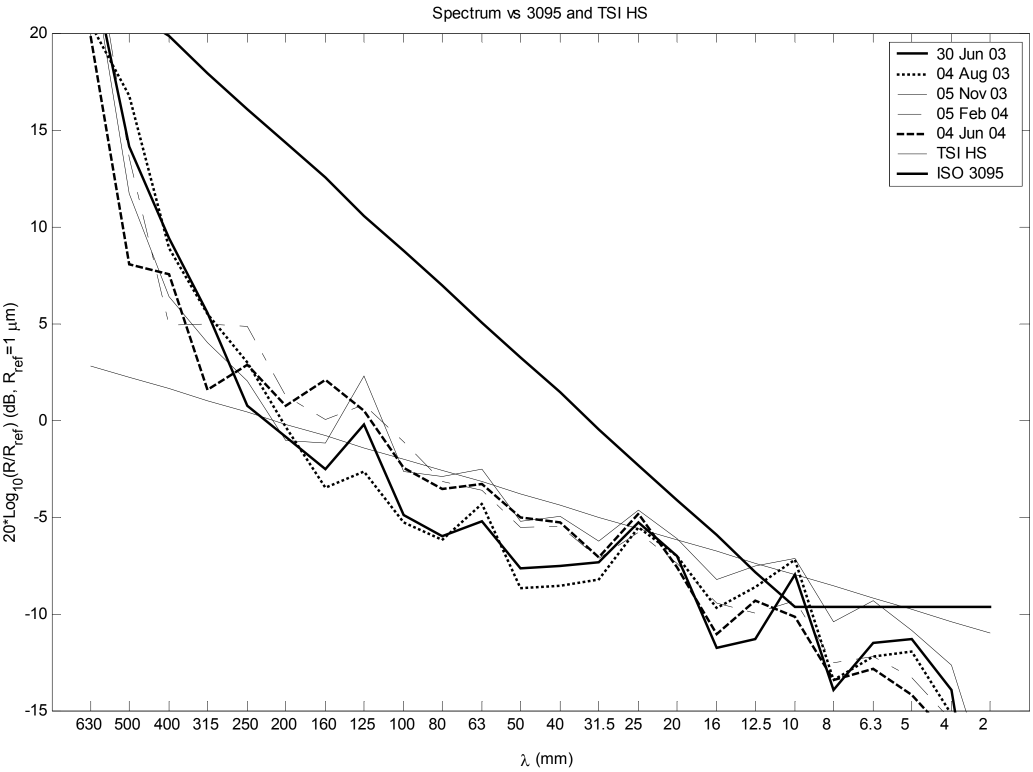
From these results it can be concluded that:

- the values in both the spectra are relatively low, confirming that where there are no local defects the level of roughness is acceptable;
- despite the fact that the whole track was ground at the same time, a different behaviour was observed between the left and the right rail;
- the left rail starts with a higher roughness, which reduces after one month everywhere except for the 10÷20 mm wavelength range. After some intermediate opposite behaviours, roughness remains constant or slightly decreases below 31.5 mm, while tends to grow in the 31.5÷315 mm wavelength range approaching dangerously and passing in the 100÷250 mm wavelength range the TSI limit. Focusing the attention in this area, the track needs grinding operation;
- the right rail starts with a lower roughness below 80 mm, while above 100 mm the roughness is greater than for the left rail. Peculiar is the behaviour at 125 mm, with an extremely high initial peak which dramatically reduces after one month. Considering only the measurements 2 to 11, the trend of roughness growth appears slower than for left rail below 80 mm, with average values of 2 to 3 dB of increase during this period. Above 125 mm roughness substantially does not change, remaining well above the TSI limit. Again, this area would require a further rail grinding;
- roughness growth is slow but significant, meaning that the track must be monitored, maybe at larger interval than those used in this work (three times a year should be sufficient also to reduce data scatter), because after one or two years there may be the need to grind the rails again. Better results may perhaps be obtained with a finer initial grinding, as the right rail tends to worsen more slowly than the left rail in those bands where it started with a lower roughness, showing some non linear behaviour of roughness growth;
- data from noise measurements campaigns separated by several months must be considered with particular care as they may differ by some dB in some frequency band (obviously linked to the train pass-by speed). Generally speaking, roughness measurements should be repeated before any noise measuring campaign.

6. Conclusions

Thanks to the use of long roughness measurement it was possible to observe the time behaviour of the rail roughness on a high speed track.

The use of techniques developed for these kind of measurements allowed the determination of the growth of number of local defects in a 120 m long track section. Discarding defective sections and taking into account only contiguous sections which resulted to be non defective in *all* measurements, it was also possible to estimate the growth of roughness spectra with a much greater precision than with fixed length equipment.



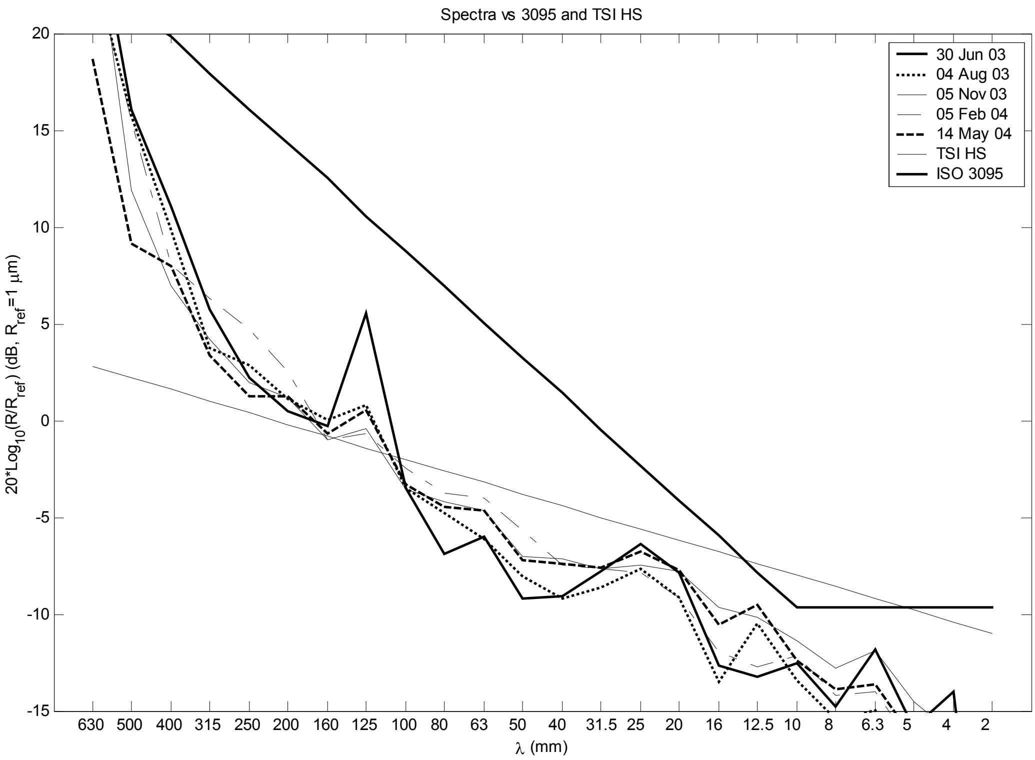


Figure 8. Spectral analysis of *leftcentre* (above, meas # 1,2,5,8,12, sections 410 to 567) and *rightcentre* (below, meas # 1,2,5,8,11, section 721 to 913) traces compared to ISO 3095 and TSI HS limits..

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