Rail Corrugation Measurements for Rolling Stock Type Testing and Noise Control

Andrea Bracciali[1], Paolo Folgarait[2]

[1]*Dipartimento di Meccanica e Tecnologie Industriali - Università di Firenze*
via Santa Marta, 3 - 50139 Firenze
e-mail: bracciali@ing.unifi.it

[2] *Lucchini Centro Ricerche e Sviluppo S.r.l.*
v.le della Resistenza, 2 - 57025 Piombino
e-mail: p.folgarait@lucchini.com

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Abstract

The longitudinal wear of the running surface of the rails, known as corrugation or roughness, has a fundamental importance in the generation of rolling noise. The use of specific devices is necessary to obtain the best results in terms of repeatability of the corrugation measurements.

In this paper the causes of errors in corrugation measurements are reviewed and critically discussed, including the instrument resolution, the limited length of the measurements and the corrugation spectrum calculation procedures starting from measured data.

The actual International Standard draft prEN ISO 3095 is critically reviewed especially with respect to the measuring procedure and to the obtained corrugation spectrum precision; as long recordings can be done with some equipments, an original procedure is proposed to identify the best measurement section for noise rolling stock type testing purposes.

1. CORRUGATION MEASUREMENTS PRACTICE

1.1 Introduction

Rail corrugation phenomena are widely known and experienced by almost all railway administrations, independently on the type of traffic and the extent of the network.

The theories that justify the grow of corrugation are quite complicated and not univocally accepted, even if the role of wheelset and track dynamic behaviour and the mechanics of materials involved are clear.

The corrugation becomes unacceptable when it leads to particularly high and annoying levels of noise and vibration. As an additional and even most important factor, the safety of critical components can be impaired if the corrugation level is not reduced. To such a goal, grinding is the only known remedy to restore the initial straightness of the rail surface. The use of grinding strategies to reduce rail corrugation before it generates unacceptable consequences is shown in another paper presented at this workshop [1].

From a metrology point of view, several cases must be analysed to include all the possibilities:

- rail corrugation survey, ranging from quite good track to very corrugated track;
- rail corrugation measurements for trackwork acceptance after grinding;
- rail corrugation measurements to qualify a site as a candidate to perform rolling stock noise type tests.

Each of these problems has different needs and requires different approaches. While for rail corrugation survey it is important to look at the peak-to-peak amplitudes, at least in some frequency ranges, to identify the need to perform grinding, the acceptance of trackwork is normally done on the basis of an exceedence analysis [2]. In any case an instrument with the capability of long measurements is needed; in the first case an indirect corrugation measurement is done through the measurement at a speed in the order of 80÷100 km/h of the vertical acceleration in the axlebox of a measuring coach whose wheel roughness is accurately controlled (normally the wheelset on which the instrumented axlebox is mounted is unbraked); in the second case the speed is much less important, as grinding trains productivity is normally below 1 km/h, depending on the level of corrugation and of lateral wear that must be restored, and a portable instrument (trolley) that works at walking speed is largely sufficient [3]. The amplitude of corrugations to be detected ranges from several hundred microns for heavily corrugated rails to a few microns for just ground track.

The third case, i.e. the corrugation measurements to verify the usability of a candidate site for noise type tests on new rolling stock is more critical. The corrugation amplitude can be, as shown later, well below the 1 μm conventional limit and the international standard drafts require a certain limit spectrum to be respected [4]. It is important to remind that the measurement of highly corrugated rails is a task that all equipments normally pass quite brilliantly, while the measurements on quite smooth track is subjected to a large scatter [5].

The interest of the scientific community to this problem is proven by the large participation to international workshops and conferences in which the topic is discussed (see, for example, [6] and the series of IWRN [7]).

1.2 Corrugation measuring principle

As a deviation from a theoretical perfectly straight line, corrugations measurements are always subjected to an average shift that is normally minimised by removing the mean value from the measurement made.

The measurement of the longitudinal profile can be done via contact or contactless transducer. For the latter technology, based of laser transducers, the measurements precision is still under discussion especially for measurements on particularly smooth track. The response of an optical system can moreover be affected by local lighting conditions (sun) that are unimportant for contact measurements.

Contact measurements can be done by direct measurement of longitudinal profile with a displacement transducer, in absolute analogy to what is done in any mechanical workshop with roughness metres. The problems that arise from this procedure are the following:

- the wavelengths of interest are much longer than those used in current mechanics, requiring a particularly long, heavy and expensive guide and, as a champion, an ultra-precise calibrating stone to get the reference profile to be subtracted from the measured profile;
- as a consequence of this, it is very uncomfortable to measure long rail sections, also because the several segments, normally shorter than or equal to 1.2 m, must be jointed and this introduces a further source of uncertainty and errors;
- if no additional numerical filtering is done, the sensor is very sensitive to local imperfections that are not normally felt by the wheel-rail contact patch filter (see the works on pits & spike filtering in [6]);
- the whole equipment can be bulk and heavy, and can hardly be handled by one person and to travel as a hand baggage in aeroplanes.

Contact measurements can also be done by measuring the vertical acceleration of a sliding ball running on the rail surface. The slider is mounted, as far as possible, freely suspended in the vertical direction and leans on the rail surface. A trolley is normally pushed along the track by an operator and the sensor, that is a servoaccelerometer with high sensitivity, measures the longitudinal imperfections. Also this procedure has some drawbacks:

- the sensitivity of the servoaccelerometer is normally designed for the operation in a defined speed of operation. The walking speed can differ from operator to operator and this can introduce unexpected errors in the measurement;
- the desired output from the equipment, i.e. a rail longitudinal profile (displacement w.r.t. a zero mean level) must be obtained through a double analogue/digital integration, with all the problems related to this process.

1.3 Requirements of the standards

The most demanding application of a rail roughness measuring equipment is certainly that of noise-related measurements.

The most recent draft of the International Standard on external noise measurements for test type of new or existing rolling stock requires that to be accepted for this purpose an existing track must fulfil a complex requirement [4, app. D] (figure 1). The section is approved if the measured spectrum satisfy the criteria briefly reported in figure 2. The diagram spans the 0.01÷0.63 m wavelength range, but in the Standard text it is said that only the 0.01÷0.10 m range must be checked.

Also the Technical Specifications for Interoperability for High Speed rolling stock give a limit defined by the equation $L = 4 - 6\log_{10}(\lambda_0/\lambda)$, where λ_0 is set to 1 m and λ ranges from 0.005 to 0.200 m (see figure 6).

The roughness level is defined as

$$L_r = 20\log_{10}\left(\frac{r}{r_0}\right) \quad (1)$$

where r is the RMS value of the roughness in a certain wavelength range and r_0 is the reference RMS value (=1 μm).

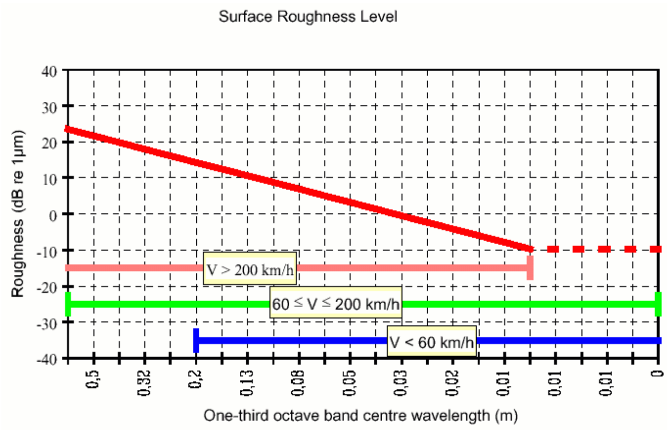

Figure 1. Roughness spectrum limit as a function of speed [4]

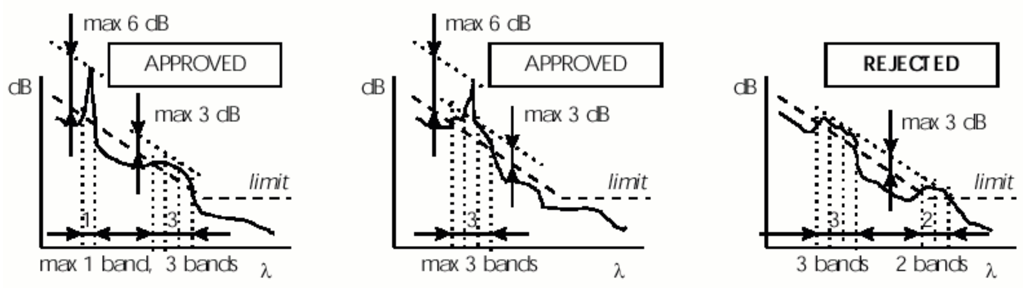

Figure 2. Acceptability of the roughness of a track section [4]

It can be seen that the lower value of the curve in figure 1 is -10 dB = 0.316 µm RMS. The basic principle of any measurement is that, roughly speaking, the measuring instrument must be more precise of the quantity to be measured of at least one order of magnitude. This requires that the instrument must be capable to give a good estimation of a roughness energy of *at least* 0.0316 µm.

It is quite common to reach misleading conclusion when neglecting the discretisation error. Nowadays signal processing techniques are mainly (not to say exclusively) conducted with digital computers. Any instrument gives therefore results with a certain number of digits; for example the Müller BBM RM1200E gives profiles with a discretisation of Δr=0.2 µm [6], while the former versions of Stuart Grassie's CAT gave profiles with Δr=1 µm. It is trivial, but worth to say, that it is not sufficient to "artificially" increase the number of digits to increase the instrument precision, that must be calibrated by using a certified equipment like, for example, the Co-ordinate Measuring Machine (CMM) described in [2]. It must be also said that it does not appear straightforward to find a calibration equipment so accurate especially for the use of trolleys, while for standing equipment an ultra-precise calibrating stone can be used.

2. THE INFLUENCE OF THE SIGNAL PROCESSING PROCEDURE

Let's suppose that a certain profile has been measured in the space domain and that its composition in terms of wavelengths PSD is needed. Two options can be considered:

- an analysis in the frequency domain through a first FFT analysis, with the appropriate windowing and averaging procedures, followed by a "grouping" of the obtained narrow bands to get the constant percentage band spectra (1/3 octave) required by the standard [8];
- an analysis in the space domain through digital filtering (eventually with zero-phase non-causal filters) followed by a simple RMS calculation procedures.

In any case the calculation procedure can hide some limitations of the instrumentation. Looking at figure 3, where a recording example from RM1200E equipment is shown together with the spectra obtained with FFT after pits & spike removal, it can be seen that at the smallest wavelength an RMS level of -20 dB is obtained. This level is equivalent to 0.1 µm: how can this be measured if the *resolution* of the equipment is 0.2 µm? The secret is the numerical processing: as it is performed typically in Matlab (that works with double precision real numbers), the typical stair appearance of discretised signals become a fairly continuous pattern artificially increasing the resolution. It is important to underline that the problem is not intrinsic in the FFT procedure used to obtain the results shown in figure 3 but in any software operation: as an example, figure 4 shows a digital filtering obtained from CAT earlier versions (resolution = 1 µm) where the filtered data are smooth while original data are only roughly discretised.

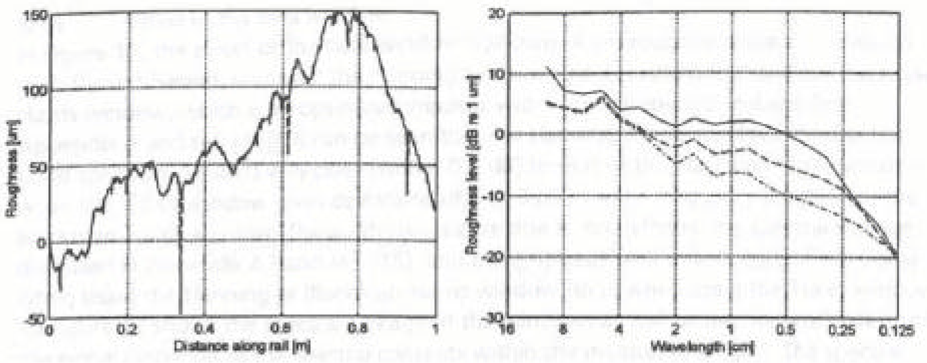

Figure 3. An example of RM1200E data processing with pits & spike removing followed by FFT analysis [6].

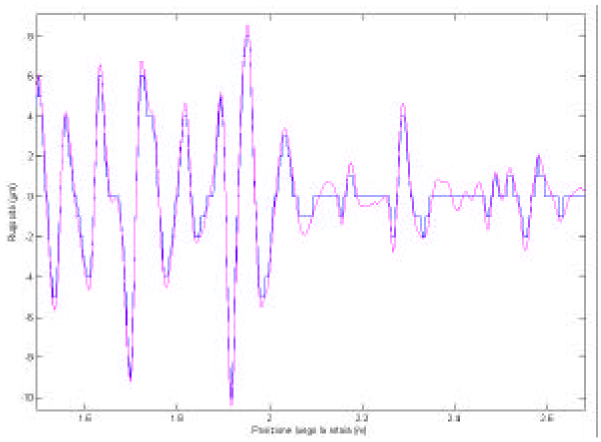

Figure 4. Comparison of original data and filtered data obtained with CAT software.

3. LIMITS GIVEN BY THE INSTRUMENTATION RESOLUTION

3.1 The discretisation error

The pattern (energy distribution) of power spectral densities obtained from real profiles can be also significantly different from that indicated as the limit spectrum in [4]. In the following, the hypothesis that the process can be approximated as a Gaussian white noise at least in each frequency range is made.

In order to identify correctly the effect of the limited resolution Δ of a generic instrument on the estimated RMS of a signal with an RMS amplitude of *A*, some numerical calculations have been performed in order to test the response to two completely different input signals:

- one cycle of a pure sine wave (we remind that in this case RMS = amplitude/$\sqrt{2}$ for an arbitrary integer number of cycles);
- a 10.000 samples random white noise normalised to have any wanted RMS value.

The hypothesis is that each band is independent from the others, and that therefore any conclusion that is reached with a random signal can be applied to the band limited signal in 1/3 octave bands.

The numerical procedure generates the signals with a high amplitude (RMS=100) and discretises the signal with an arbitrary resolution, that for convenience is assumed to be Δ=1. By decreasing the RMS amplitude of the signals it has been possible to observe the influence of the ratio of the RMS amplitude A and the instrument resolution Δ on the estimated RMS value compared to the real RMS value. Figure 5 summarises the obtained results. From this emerges that the reliability of the estimated RMS value depends also on the type of signal, being the sine signal the worst case. This can be explained by the fact that the white noise signal is less constant compared to sine and some peak can be correctly estimated while a sine wave is all discretised with the same discretisation error. Only values of $A/\Delta > 1$ or, better, $A/\Delta > 2$ give reasonable errors.

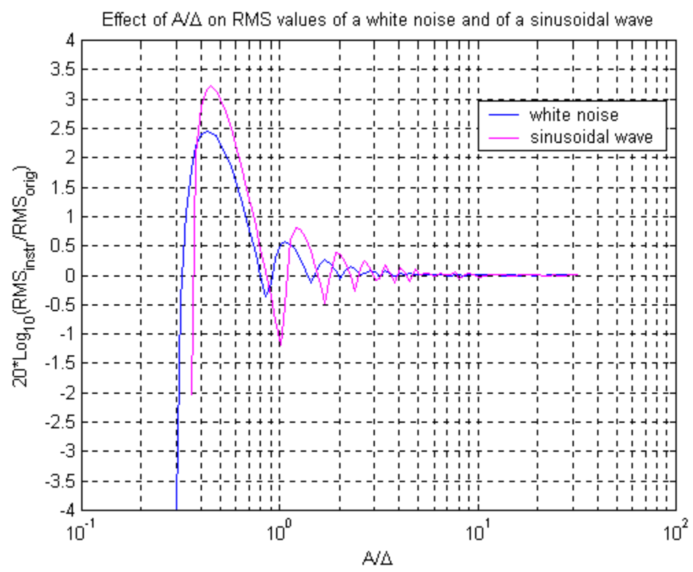

Figure 5. Errors in the RMS estimation of a given signal as a function of *A/*Δ.

The analysis of the response of different equipments is shown in figure 6. Four equipments have been compared:

(1) the 1 µm discretisation original CAT
(2) the 0.2 µm discretisation Müller BBM RM1200E [6]
(3) the 0.1 µm discretisation TPD equipment to measure wheel corrugation [6] (used here only as an example of different resolution equipment)
(4) the 0.01 µm discretisation offered by the CAT after a software modification.

Apparently, instruments (2,3,4) satisfy the standard requirements but, as shown in the next paragraph, the real corrugation amplitudes can be much lower than the limits.

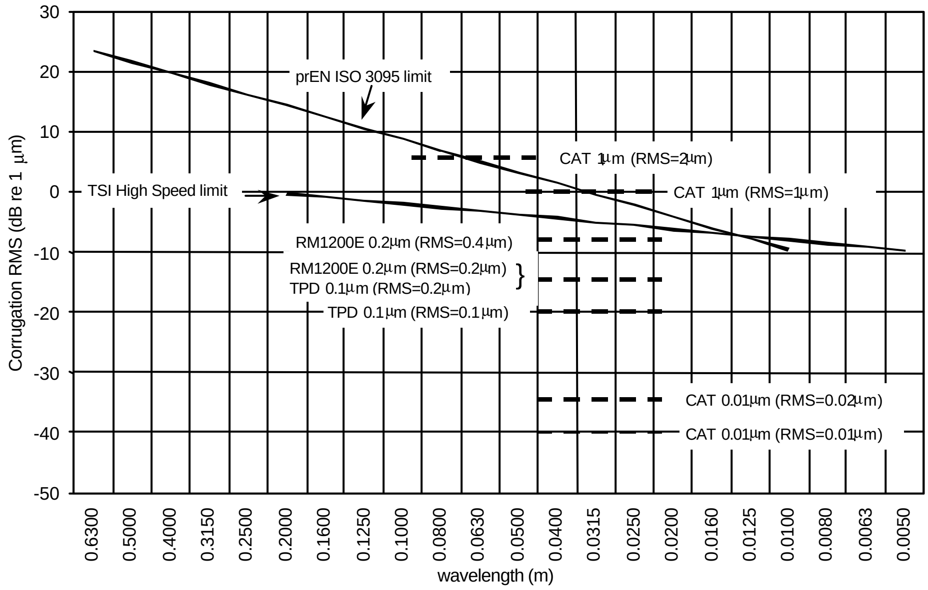

Figure 6. Resolution offered by different equipments compared to Standard requirements.

3.2 Analysis of some measured data with the improved resolution CAT

As shown, only an instruments with a resolution better than approximately 0.1 μm can give a reasonable estimation of the limit spectrum, but nothing can be said in general about the behaviour of the equipment with real rail corrugation amplitude.

To observe the behaviour of the CAT instrument at shorter wavelengths and at smaller levels, an improved version of the software was released. The original 1 μm resolution of the instrument was set to this value because the instrument was originally used to check the corrugation of the rail head surface after grinding, where the amplitude in the 30-100 mm wavelength range in normally in the order of several microns. To speed up statistics and data processing for extremely long distances, the software was designed to work on integer data, but nowadays this necessity is less stringent given the possibilities of actual portable computers; the need to look at sub-micron amplitudes required that this limitation were removed. The software has therefore been re-written to output the data with 0.01 μm resolution without changing any other HW/SW feature of the equipment.

The real problem remains, as already mentioned, how to correctly certify the precision of a trolley with a so high resolution. An indirect answer to this question is given by the results obtained, after having modified the CAT's software, from some measurements that have been performed in the frame of the European project HIPERTRACK on a railway track in the station of Incoronata, Foggia, Italy during December 2001 [9]. The line has two tracks, called even (northbound) and odd (southbound); each rail for each track has been measured four times for a length of 40 m. The average PSD diagrams shown are an average on this distance.

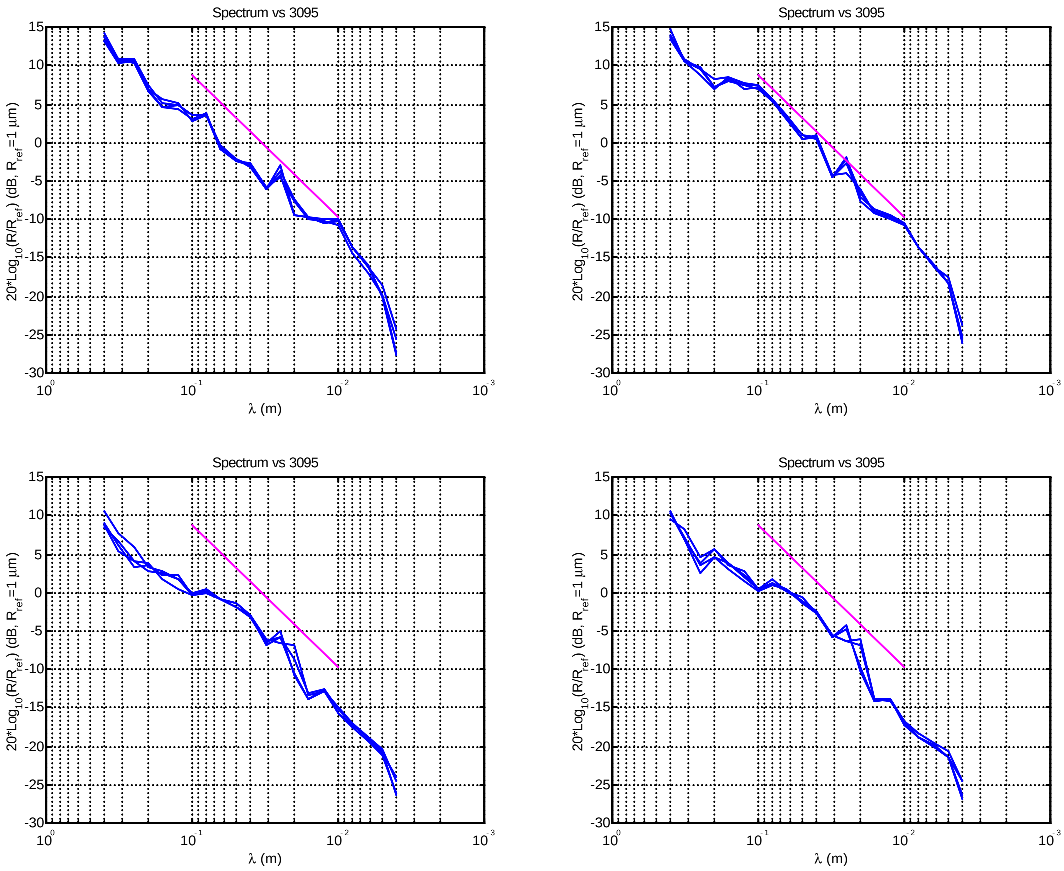

Figure 7. Corrugation spectra obtained with modified CAT (resolution =0.01 μm = -40 dB) in Incoronata. Even track - left rail (top left), Even track - right rail (top right), Odd track - left rail (bottom left), Odd track - right rail (bottom right)

The results in figure 7 show two different tracks with similar corrugation levels between left and right rails. The following considerations can be made:

- the spectra from several runs (4 for each rail) are particularly repeatable and consistent;
- the even track, ground around 6 months before the measurements, is more corrugated than the (older) odd track, which is particularly smooth and whose corrugation spectra are notably below the ISO 3095 "limit spectrum";

- the results at the shorter wavelengths are different for the different tracks, proving that these results are not given by noise (that should be present in the same way in all the measurements, all made in a couple of hours) but are real data;
- all the results are well above the -40 dB theoretical limit offered by the 0.01 µm resolution of the CAT, indicating that further significant digits would be useless.

For comparison, two diagrams from some previous measurements are shown in figures 8 and 9.

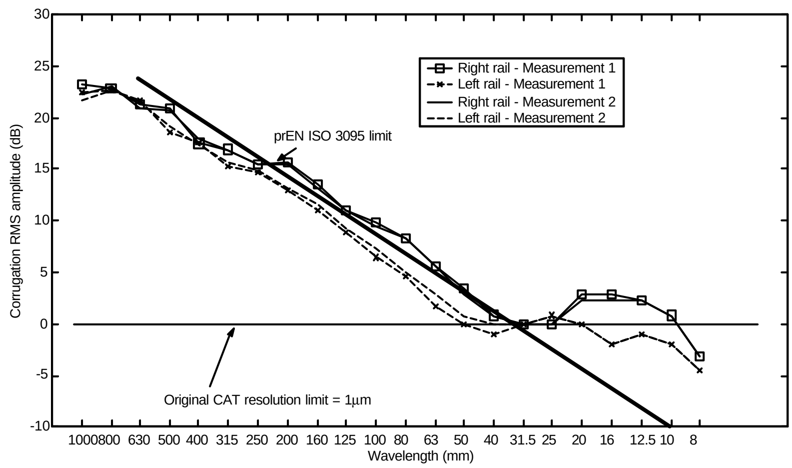

Figure 8. Corrugation spectra obtained with original CAT (resolution =1 µm). The processing has been done with the original CAT software working with integer data representation. It is evident the “strange” behaviour at the wavelengths where the amplitudes should be lower than the instrument resolution.

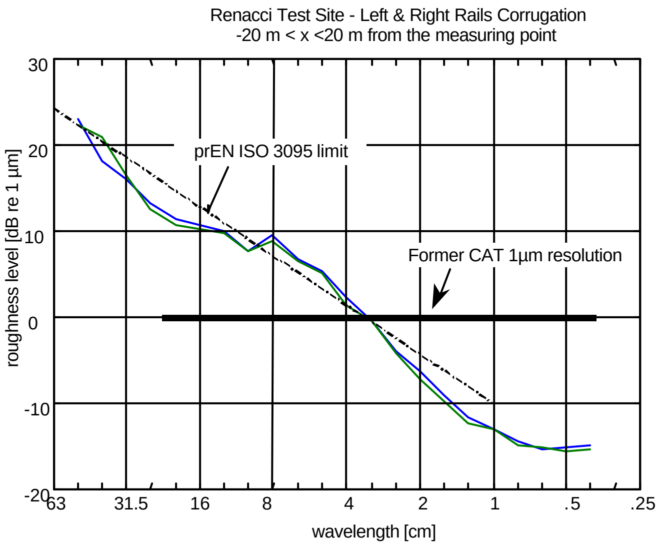

Figure 9. Corrugation spectra obtained with original CAT (resolution =1 µm) in Renacci, Italy. The processing has been done with the RAS package [8] that gives results with higher resolution than that offered by the equipment only for numerical reasons on FFT calculations.

4. UNCERTAINTIES DUE TO LIMITED MEASURING LENGTH

The various equipments can have limitations on the measured length. In the following an analysis of the errors introduced by limited measuring length is shown. As already indicated, the use of digital filters and FFT procedures are analogous, but the error analysis is easier working in the space (time) domain by using the theory of errors applied to digital filters.

It is worth to remind that to have a correct estimation of the output of a digital band-pass filter of amplitude B when the input is a pure sine wave it is necessary that [10]

$$BT = K \geq 1 \tag{2}$$

where T is the time of acquisition.

Working in the space domain, B_s is the filter amplitude in terms of difference of the inverse wavelengths and T becomes L, i.e. the length of the measurement. For the more general case of a random input, the approximate ratio ε between the filter output RMS standard deviation σ and its RMS mean value μ is given by

$$\frac{\sigma}{\mu} = \varepsilon = \frac{1}{2\sqrt{B_S L}} = \frac{1}{2\sqrt{K}} \qquad \text{(for } K>10\text{)} \tag{3}$$

or, expressed in dB with some minor approximation,

$$\varepsilon_{dB} = 20\log_{10}\left(\frac{\mu \pm \sigma}{\mu}\right) = 20\log_{10}(1 \pm \varepsilon) = 20\,\frac{\ln(1 \pm \varepsilon)}{\ln 10} = 8.69\ln(1 \pm \varepsilon) \tag{4}$$

Supposing to use $B_s L = K$ values such that $\varepsilon \ll 1$, eqn. 4 simplifies to

$$\varepsilon_{dB,app} = 8.69(\pm\varepsilon) = \pm\frac{8.69}{2\sqrt{K}} = \pm\frac{4.35}{\sqrt{K}} \tag{5}$$

It is worth to note that the corrugation signal is neither a pink noise nor a white random Gaussian noise as the constant percentage band PSD decreases at smaller wavelength centres (i.e. increasing the frequency), but its random nature approximately remains in each band that can be considered, as usual, independent from the others.

Two approaches can be followed when making the measurements: an approach by keeping K (and therefore the error ε) constant by changing the length of measurement for each band or, more commonly, by keeping L constant obtaining therefore a different error ε in each wavelength range. To compare the two approaches some calculations are shown in table 1 for the following cases:

- a measurement with L=1.2 m independently from the wavelength, for which the value of K and the error ε is computed in percentage and in dB for each 1/3 octave wavelength band;
- a similar analysis for L=100 m;
- a measurement with K=20, for which the required length in each wavelength band is calculated while the errors remain (obviously) constant.

It is clear that the errors in the L=1.2 m case are unacceptable even for wavelengths λ_c=0.1 m (the relative statistical error is 30% of the average RMS) while the L=100 m gives reasonable results in the whole selected wavelength range. From the analysis of this table it should appear clearly that the measurement of short segments can lead to erroneous conclusions. The use of equipment capable to measure only up to 1 m or 1.5 m allows to obtain longer records only by pasting several records, but this procedure can be slowly and tricky, as the joining phase is not trivial and the results can differ depending on the operators. In this respect, the use of a virtually unlimited length measurement is decisively superior.

λ_c [m]	f_s [m^{-1}]	B_s [m^{-1}]	$K_{L=1.2\text{ m}}$	$\varepsilon_{L=1.2\text{ m}}$ [%]	$\varepsilon_{L=1.2\text{ m}}$ [dB]	$K_{L=100\text{ m}}$	$\varepsilon_{\%L=100\text{ m}}$ [%]	$\varepsilon_{L=100\text{ m}}$ [dB]	$L_{K=20}$ [m]	$\varepsilon_{K=20}$ [%]	$\varepsilon_{K=20}$ [dB]
0.1000	10	2.32	2.78	30.0	2.61	232	3.29	0.286	8.64	11.2	0.973
0.0800	12.5	2.89	3.47	26.8	2.33	289	2.94	0.256	6.91	11.2	0.973
0.0630	15.9	3.68	4.41	23.8	2.07	368	2.61	0.227	5.44	11.2	0.973
0.0500	20	4.63	5.56	21.2	1.85	463	2.32	0.202	4.32	11.2	0.973
0.0400	25	5.79	6.95	19.0	1.65	579	2.08	0.181	3.45	11.2	0.973
0.0315	31.7	7.35	8.82	16.8	1.46	735	1.84	0.160	2.72	11.2	0.973
0.0250	40	9.26	11.1	15.0	1.30	926	1.64	0.143	2.16	11.2	0.973
0.0200	50	11.6	13.9	13.4	1.17	1160	1.47	0.128	1.73	11.2	0.973
0.0160	62.5	14.5	17.4	12.0	1.04	1450	1.31	0.114	1.38	11.2	0.973
0.0125	80	18.5	22.2	10.6	0.923	1850	1.16	0.101	1.08	11.2	0.973
0.0100	100	23.2	27.8	9.49	0.825	2320	1.04	0.0904	0.864	11.2	0.973

Table 1. Statistical errors for the 1/3 octaves centred in the wavelength range 0.01-0.1 m.

5. ANALYSIS OF THE ACTUAL prEN ISO 3095 DRAFT STANDARD

5.1 Introduction

The actual release of the draft International Standard [4] requires that the corrugation is measured in 6 cross sections at distances 0, ±*r* and ±2*r* from the reference section, where *r* is the microphone distance from the track axis. Both rails has to be measured, in each section, with one or three parallel lines depending on the amplitude of the so-called "running band", that is the dim stripe where the wheels and the rail normally touch each other. As for running bands greater than 10 mm three lines are requested, this will be the normal case for not particularly new lines where the traffic is mixed (wheels tread will be worn in different ways, widening the contact area on the rail). Each line is long at least 1 m (figure 10).

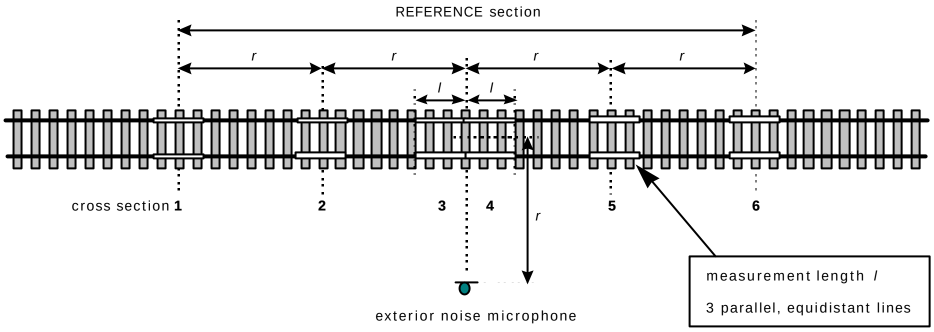

Figure 10. Rail corrugation measuring scheme [4]

The Parallel Inquiry phase of the Standard draft ended in June, 2001, and many comment were given by several railway administrations. The comments have been particularly heavy, leading to several negative votes. The following is a short list of these negative comments:

- as the goal of the Standard is to open the market to different corrugation measuring equipment suppliers, the limitation in the length appears as a constraint against existing equipments capable to measure continuously;
- the measurement of 36 lines seems too heavy to be reasonably practicable with short times and costs;
- the use of short rail sections leads to a low statistical reliability of the results obtained with respect to the rail corrugation of the whole track length;
- the fact that a test site can be rejected for a single line at 50 m from the microphone, eventually on the opposite rail, is a large limitation;
- no reference is given to a Standard that defines the procedures to assess the precision if the instrument;
- the use of three parallel lines is useful as an input to sound emission simulation softwares but it is useless to verify the possibility to use a candidate site.

5.2 A proposal on how to choose the best test site

As already seen, one of the objections made to the actual draft [4] is that all the sections have the same influence on the definition of the quality of the track and that even a small error in one section can lead to the rejection of the potential site. While it is certainly true that the rail corrugation is statistically distributed, it is quite impossible to ensure *a priori* that all the 12 sections indicated in [4] have no local defects.

By using a continuous measurements it is possible:

- to weigh in the proper way the contributions from rail sections at different distance from the microphone, by using the basic laws of acoustics, reducing therefore the contribution of local defects if they are far away from the microphone;
- to define statistical indicators that properly enhance the effect of defects, considering that high local defects can lead to impact noise that must be absolutely avoided;
- to measure a track longer than that strictly needed for the track qualification (for example 400 m instead of just 100 m) and to automate the choice of the best microphone location on the basis not of minimum absolute corrugation but on the most uniform corrugation amplitude and spectra.

It is known that the noise (sound pressure level p) measured at a distance d from a spherical source of power W is given by

$$p^2 = \frac{\rho c W}{4\pi d^2} \tag{6}$$

Even if the real emission figure (monopole or dipole) and the details of the source are not known, a possible weighting function for the measured corrugation profile can be chosen as

$$w(x) \propto \frac{r^2}{d^2} \tag{7}$$

Supposing to have a quite long measurement and that the microphone can be placed in several positions within a certain range, it is possible to select some of these positions and to apply the weighting function (7) to simulate the various contributions to noise of the different track portions.

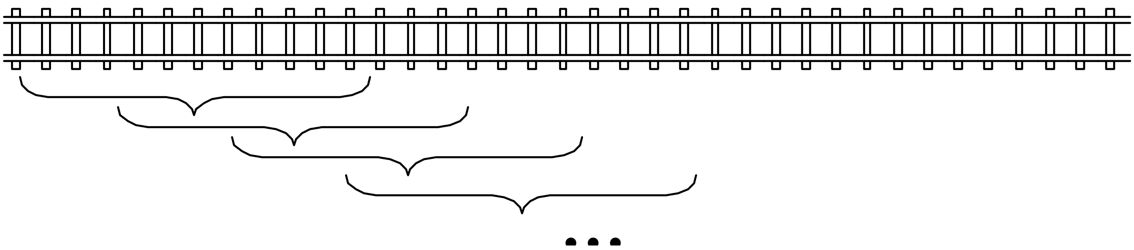

Figure 11. Example of segments definitions. In the developed software the segments have length = 100 m and an overlap of 90 % (distance between consecutive microphone positions = 10 m).

The effect of local imperfections can be evaluated by using the *kurtosis* of the considered signal that is defined, for continuous signals in the time domain and sampled discrete signals, respectively as

$$kurtosis(X) = \frac{E\left[x^4\right]}{\sigma^4} = \frac{1}{\sigma^4}\int_{-\infty}^{+\infty} x^4 p(x)\mathrm{d}x = \frac{1}{\sigma^4 T}\int_0^T x^4 \mathrm{d}t \quad ; \quad kurtosis(X) = \frac{\frac{1}{n}\sum_{i=1}^{n}(x_i-\mu)^4}{\left(\frac{1}{n}\sum_{i=1}^{n}(x_i-\mu)^2\right)^2} \qquad (8')(8'')$$

where μ is the average value (normally removed) and σ is the standard deviation. The kurtosis, that is the fourth statistical moment of a given signal, is widely used in machinery diagnostics, particularly for rolling element bearings. Because the fourth power is involved, the value of kurtosis is weighted towards the values in the tails of the probability density distribution – i.e. it is related to the spread in the distribution. The value of kurtosis for a Gaussian distribution is 3. A higher kurtosis value indicates that there is a larger spread of higher signal values that would generally be the case for a Gaussian distribution. The kurtosis of a signal is very useful for detecting the presence of an impulse within the signal [10].

The result of the application of the (8”) is a single figure that can be easily computed for each microphone position and that can help to identify the *most regular* section in a certain possible measuring range.

As an example of the results obtained with the proposed method, the analysis of a 400 m long track section is shown in figure 12 and 13. The stretch has been divided in 31 segment long 100 m each and overlapped for the 90% (the distance between two adjacent microphone positions is 10 m). The figures show the overall computation and some details of the worst and the best sections. Section 28 has the most regular signal in a weighted sense, meaning that the noise measured in that position will be the most uniform.

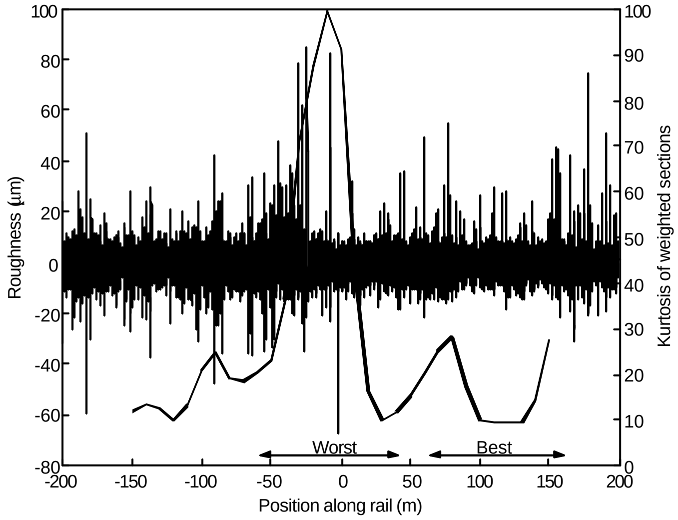

Figure 12. Raw corrugation signal and calculated kurtosis for each microphone position.

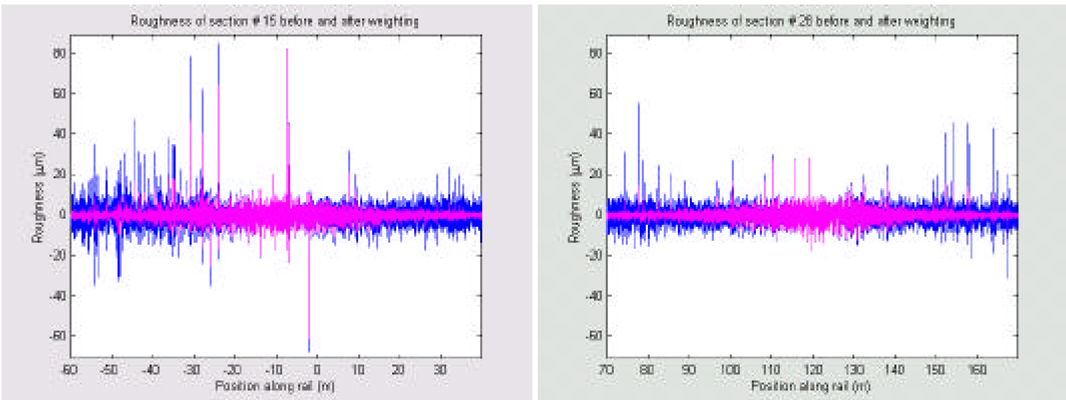

Figure 13. Details of original and weighted corrugation signals for sections 15 (worst) and 28 (best).

6. CONCLUSIONS AND FURTHER DEVELOPMENTS

In this paper the measurement of rail corrugation has been critically reviewed by analysing the equipment capabilities, the data processing procedures and the actual international standards requirements.

Some simulations have been done showing how the effect of the limited measuring length of some commercial equipment can lead to unacceptable statistical errors. In this respect, it is the authors' opinion that the use of virtually unlimited recording length instrumentation can lead to dramatic improvement in terms of the quality of the measurements.

By using a standard signal processing analysis, a new procedure has been introduced that allows the determination of the best section in which a microphone can be placed to obtain the most uniform and less disturbed readings.

This work will be continued by investigating different indicators beyond kurtosis and by repeating tests with different equipments thanks to the co-operation with other corrugation measuring equipment users. Another activity will concern the motorization of the trolley with a variable speed DC motor to study the influence of the running speed on the corrugation measurement precision.

The topic of rail corrugation measurements is still open to research and to contributions; it is hoped that the concepts introduced here can origin a deep discussion to enhance the actual procedures and to improve the International Standards in this field.

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