Technical Specification

# ISO/TS 14837-34

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# Mechanical vibration — Ground-borne noise and vibration arising from rail systems —

## Part 34: Characterizing irregularity of the running surfaces with respect to vibration excitation

*Vibrations mécaniques — Vibrations et bruits initiés au sol dus à des lignes ferroviaires —*

*Partie 34: Caractérisation des irrégularités de surface de roulement associées à l'exitation vibratoire*



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# Introduction

The mechanisms of excitation of ground-borne noise and vibration from railway systems are listed in ISO 14837-1:2005, 4.2.2, which identifies five excitation mechanisms acting at the wheel-rail interface. These mechanisms include

a) moving loads (quasistatic) excitation,

b) excitation caused by wheel or rail roughness,

c) parametric excitation,

d) wheel or rail defects, and

e) discontinuities of the track.

This document is concerned with excitation by roughness. The aim of this document is to

f) define the term roughness used in connection with the source of ground vibration from railways,

g) provide guidance regarding the procedures that can be used for roughness excitation measurement and analysis, and

h) provide guidance regarding the equipment that can be used to measure roughness excitation.

The term acoustic roughness is already defined by common use and in EN 15610. The mechanism by which acoustic roughness generates vibration, leading to noise in the range $f$ = 50 Hz to $f$ = 6 kHz, is essentially the same as that which is a source of ground vibration in the frequency ranges of approximately $f$ = 1 Hz to $f$ = 80 Hz and approximately $f$ = 20 Hz to $f$ = 250 Hz, that leads to ground-borne or structure-borne noise. This document therefore draws upon the established definitions, methods of measurement and methods of analysis for acoustic roughness to provide guidance for the measurement and analysis of the roughness pertaining to ground-borne vibration and ground-borne noise.

# Mechanical vibration — Ground-borne noise and vibration arising from rail systems —

# Part 34: Characterizing irregularity of the running surfaces with respect to vibration excitation



## 1 Scope

This document specifies methods for measuring and analysing irregularities of running surfaces for use in the prediction and assessment of ground-borne noise and vibration arising from railway systems. This document

a) defines the data that can be described as rail or wheel roughness and that can be used to quantify a source term for the generation of the dynamic forces that can lead to ground-borne vibration from railway vehicles,

b) gives guidance regarding the types of equipment that can be used to measure roughness as a variation of height along the running direction of the rail surface or wheel parameter,

c) gives guidance regarding the methods that can be used to obtain an estimate of the roughness wavelength spectrum from measurement records taken over a length of rail head or wheel perimeter, and

d) gives guidance regarding the presentation of a roughness spectrum representing the condition of a length of rail or of a wheel related to its ability to generate vibration.

This document does not

e) give guidance regarding the characterization of localized geometrical features (e.g. switches, crossings, rail squats, occasional rail joints and localized geometrical defects of the running surface). These features are likely to produce dynamic forces that are not linear with their amplitude because of the change of geometry at the wheel-rail contact. Hence these features are not characterized by methods of analysis defined within this document. Annex A provides further information regarding the characterization of localized geometrical features,

f) give guidance regarding the specification or testing of roughness measurement equipment that can be used. Annex B provides an overview of measuring equipment,

g) give guidance regarding the measurement or analysis of track quality for any other purpose than the assessment of ground-borne vibration,

h) present any example of roughness spectra intended to represent typical roughness. Roughness levels vary greatly between track sites and any examples used in this document have not been selected on any other basis than their usefulness for the purpose of demonstrating the principles of analysis,

i) promote any particular make, model or manufacturer of measurement equipment, and

j) recommend or promote software for the implementation of the analysis procedure.

## 2 Normative references

There are no normative references in this document.

## 3 Terms and definitions

For the purposes of this document, the following terms and definitions apply. For an explanation of roughness-related terms, see Clause 4.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

**3.1**
**running surface**
part of the wheel tread or the rail head, along which the wheel-rail contact passes during rolling

Note 1 to entry: In the case of the rail this is the bright band of the surface of the rail head that contains all the running positions of the wheel-rail contact.

[SOURCE: EN 15610:2019, 3.9]

**3.2**
**roughness**
variation in height of the rail or wheel running surface associated with a particular noise or vibration phenomenon

**3.3**
**roughness spectrum**
amplitude of the roughness expressed as a function of the roughness wavelength $\lambda$

[SOURCE: EN 15610:2019, 3.2, modified — "acoustic" has been deleted in the term and the definition.]

**3.4**
**roughness level**
$L_r$
level expressed in decibels, given by the following formula:

$$L_r = 10 \cdot \log_{10} \frac{r_{\mathrm{RMS}}^2}{r_0^2}$$

where

$L_r$ is the roughness level in dB;

$r_{\mathrm{RMS}}$ is the root mean square roughness in µm; and

$r_0$ is the reference roughness with $r_0$ = 1 µm

Note 1 to entry: This definition applies to values measured either in the form of a roughness wavelength spectrum or for a specific roughness wavelength band.

[SOURCE: EN 15610:2019, 3.3, modified — "acoustic" has been deleted in the term and the definition and Note 1 to entry has been replaced.]

**3.5**
**roughness wavelength**
$\lambda$
ratio expressed in m given by the following formula:

$$\lambda = v / f$$

where

$f$ is the frequency in Hz

$v$ is the train speed in m/s

# 4 Characterizing roughness related to vibration excitation

## 4.1 Roughness and noise or vibration phenomena

Roughness is the variation in the height of the rail or wheel running surface. Therefore,

a) acoustic roughness is the roughness associated with the excitation of rolling noise,

b) ground-borne noise roughness is roughness associated with the excitation of ground-borne or structure-borne noise, and

c) ground-borne vibration roughness is roughness associated with the excitation of low-frequency ground vibration.

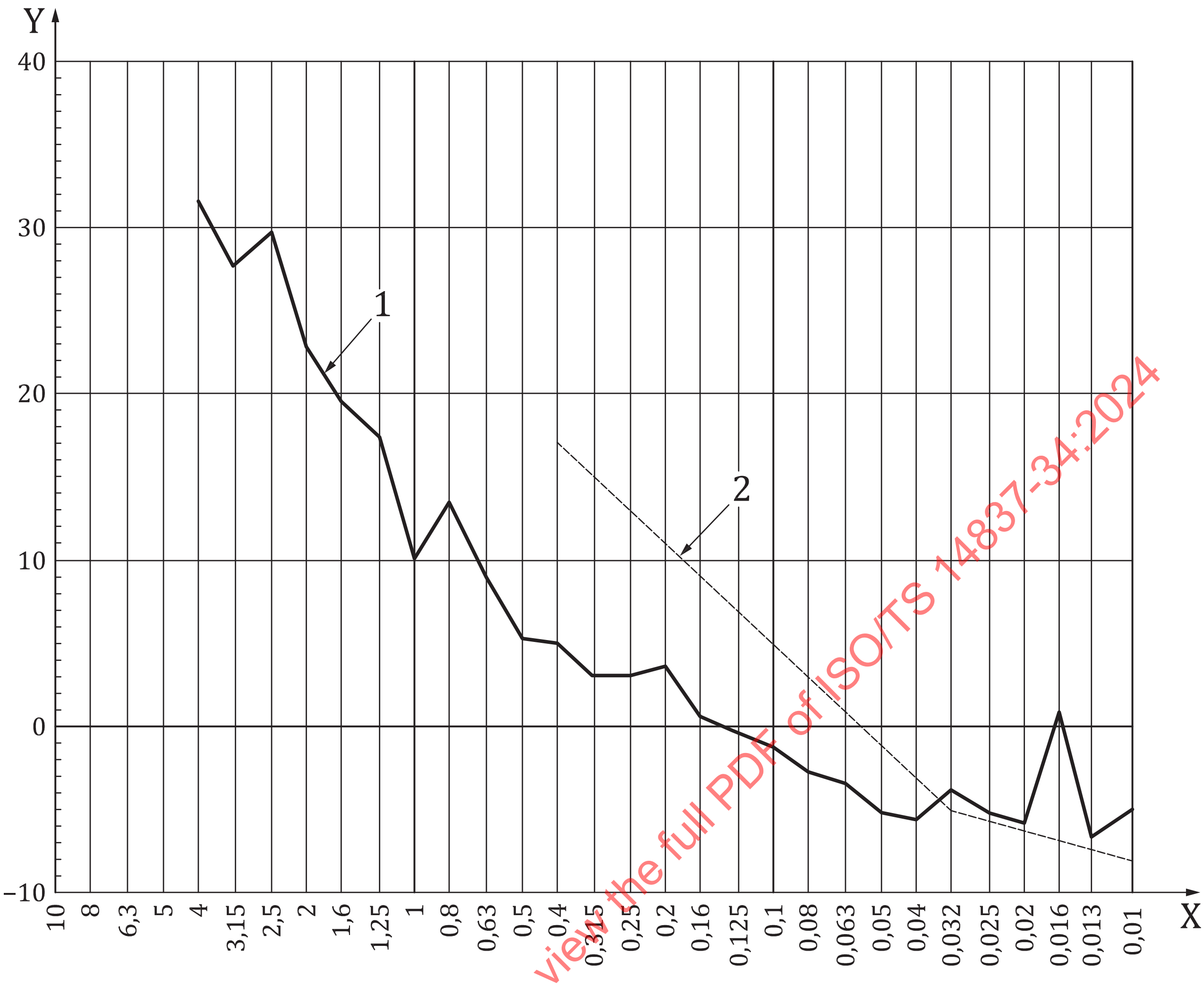
The vehicle-track interaction equation for the excitation of force by vertical profile irregularities in the height of the rail and/or wheel running surfaces is the same for 4.1 a), b) and c). Only the roughness wavelength range changes.

## 4.2 Roughness spectrum

The roughness spectrum is an estimation of the statistical properties of the roughness record over the length of measurement. A roughness spectrum represents the general geometrical condition of the running surface and does not represent the geometry of localized features (e.g. a crossing nose, rail joint, dipped joint or certain kinds of track or rail or wheel defect) that do not occur with sufficient frequency in a measurement record to be part of its statistical summary of the condition of the track or running surface.

## 4.3 Roughness level

Figure 1 shows an example of a measured roughness spectrum. It is presented in accordance with the requirements of EN 15610 but with the roughness wavelength range extended to $\lambda$ = 4 m to include the roughness associated with the excitation of low-frequency ground vibration and ground-borne noise. The presentation is given in logarithmically scaled one-third-octave bands, with the roughness level as a function of the roughness wavelength, in decreasing order. The default upper limit for a test section specified in ISO 3095:—, Figure 5 is shown as a reference. This limit is specified to $\lambda$ = 0,4 m. For the range $\lambda$ = 0,032 m to $\lambda$ = 0,4 m the limit increases at a rate of 20 dB/decade.




**Key**

X roughness wavelength $\lambda$ in m, logarithmically scaled

Y roughness level $L_r$ in dB in one-third octave bands

1 measured roughness spectrum

2 ISO 3095:—, Figure 5 upper limit

**Figure 1 — Example of a roughness spectrum presented in accordance with the guidance given in EN 15610**



## 4.4 Roughness wavelength range

Table 1 illustrates the relationship between roughness wavelength, train speed and the resulting excitation frequency. The shaded cells indicate the range of roughness wavelengths defined as acoustic roughness in EN 15610. Roughness wavelengths that lead to low-frequency ground-borne vibration (approximately $f$ = 1 Hz to $f$ = 80 Hz) or ground-borne and structure-borne noise (approximately $f$ = 20 Hz to $f$ = 250 Hz) require a roughness definition which includes data to longer roughness wavelengths than for acoustic roughness.

At short roughness wavelengths (e.g. $\lambda$ < 1 m), roughness is defined by the wear patterns of the running surfaces of the wheels and the rails. At long roughness wavelengths (e.g. $\lambda$ ≥ 1 m) roughness is defined by the vertical alignment of the track. Long roughness wavelengths are therefore affected by the construction quality, the construction method and the condition of the track substructure and ballast.

Long roughness wavelengths are not usually relevant for low-frequency ground-borne noise unless the train is travelling at high speed (e.g. $v$ > 160 km/h in Table 1). Long roughness wavelengths are relevant to low-frequency ground-borne vibration for all train speeds.

The maximum roughness wavelength for the running surfaces of wheels is limited by the wheel circumference.

**Table 1 — Relationship between excitation frequency, train speed and roughness wavelength**

| Frequency, $f$ | Roughness wavelength, $\lambda$, in metres for a given train speed, $v$ | | | |
|---|---|---|---|---|
| Hz | 40 km/h (11,11 m/s) | 80 km/h (22,22 m/s) | 160 km/h (44,44 m/s) | 315 km/h (87,5 m/s) |
| 1 | 11,11 | 22,22 | 44,44 | 87,50 |
| 2 | 5,56 | 11,11 | 22,22 | 43,75 |
| 4 | 2,78 | 5,56 | 11,11 | 21,88 |
| 8 | 1,39 | 2,78 | 5,56 | 10,94 |
| 16 | 0,69 | 1,39 | 2,78 | 5,47 |
| 31,5 | 0,35 | 0,71 | 1,41 | 2,78 |
| 63 | 0,18 | 0,35 | 0,71 | 1,39 |
| 125 | 0,09 | 0,18 | 0,36 | 0,70 |
| 250 | 0,04 | 0,09 | 0,18 | 0,35 |
| NOTE Grey shaded cells indicate the wavelength range of “acoustic roughness” as defined in EN 15610. | | | | |

## 4.5 Characterization of roughness

Roughness spectra (see Figure 1), summarize the variation in roughness of a running surface with regard to its roughness wavelength and severity. Localised peaks are apparent, such as those arising from fastening spacing and from reprofiling operations (e.g. rail grinding). If a limit such as that from ISO 3095:—, Figure 5 is also shown, this demonstrates, for example, that the irregularities shown are of a relatively small amplitude throughout the roughness wavelength range relevant to both air-borne and ground-borne noise and vibration (see Table 1).

For some purposes, investigating variations in the measured roughness spectrum from a limit line (such as the one shown in ISO 3095:—, Figure 5) can be useful. For example the investigation can highlight and give the correct weight to areas of periodicity throughout the roughness wavelength range of interest.

Spectra (see Figure 1) are not used for rail reprofiling or track maintenance. For these purposes the roughness wavelength range of interest is divided into intervals that are significantly larger than one-third octave bands. For example, in EN 13231-2 the ranges of interest are $\lambda$ = 10 mm to $\lambda$ = 30 mm, $\lambda$ = 30 mm to $\lambda$ = 100 mm, $\lambda$ = 100 mm to $\lambda$ = 300 mm and $\lambda$ = 300 mm to $\lambda$ = 1 000 mm whereas in EN 13848-1 the ranges are $\lambda$ = 3 m to $\lambda$ = 25 m, $\lambda$ = 25 m to $\lambda$ = 70 m and $\lambda$ = 70 m to $\lambda$ = 150 m. Different methods of presenting the measurements are considered in EN 13231-2 and EN 13848-1 (e.g. peak-to-peak and root-mean-square (RMS) amplitudes). Measurements undertaken in accordance with the requirements of EN 13231-2 and EN 13848-1 are appropriate for the purposes which the maintenance is being undertaken and the equipment that is being used to monitor the work and its quality.

The most detailed presentation of roughness is as measured displacement as a function of distance along the track. If such a presentation method is used to represent roughness wavelengths pertinent to ISO 3095 as well as roughness wavelengths relevant to ground-borne noise and vibration, the required resolution of displacement measurements is approximately 0,01 µm.

# 5 Principles of measurement and analysis

EN 15610 describes the measurement and analysis of acoustic roughness and sets principles of measurement and analysis that can be applied to roughness associated with the generation of low-frequency ground-borne vibration and ground-borne noise. EN 15610 should be referred to in order to understand the principles to be used in the measurement and analysis of acoustic roughness.

EN 15610 defines roughness as a one-third-octave spectrum versus roughness wavelength range from $\lambda$ = 3 mm (for different train speeds) to $\lambda$ = 0,25 m. Acoustic roughness is the origin of rolling noise between $f$ = 50 Hz and $f$ = 6 kHz. ISO 3095 refers to the requirements in EN 15610 for the measurement and analysis of roughness and compares the measured spectrum against a limit of up to $\lambda$ = 0,4 m. The requirements of EN 15610 were tested before being finalized. This was achieved by having different teams applying its requirements to two track sections and comparing their test results. The results from both teams are reported in CEN/TR 15874 which gives further insight into the analysis of roughness data.

Some of the principles of measurement and analysis of acoustic roughness are universal and shall be applied to measurement and analysis of roughness for ground-borne noise and vibration. Other principles in EN 15610 are neither necessary nor practical for ground-borne noise and vibration applications.

The universal roughness measurement principles described in EN 15610 include:

a) the ratio of the measured sample record length to the longest roughness wavelength being recorded should be greater than 60. To obtain a roughness spectrum for $\lambda$ = 2 m, the sample record should be a minimum of 120 m for the statistical variance limit to be met. For very long roughness wavelengths relevant to low frequency ground vibration from high speed trains (e.g. $\lambda$ > 10 m) it can be difficult to meet the statistical variance limit due to the long sample record that would be required;

b) the appropriate lateral sample record (number of measurement lines and their spacing across the running surface) which is dependent on the width of the running surface;

c) the analysis methods that can be used are Fast Fourier Transforms (FFT) and digital filtering. Both are acceptable for roughness wavelengths associated with ground vibration and ground-borne noise. However, digital filtering is more appropriate for the sample record lengths that are usually required for roughness wavelengths relevant to ground-borne noise and vibration; and

d) presentation as one-third-octave roughness spectrum in dB with a reference of 1 μm to characterize the full sample record (i.e. not including local geometrical features).

Aspects of EN 15610, which are not always necessary for the calculation of ground vibration or ground-borne noise, include:

— processing to remove pits and spikes from the sample record. These features in the sample record only affect roughness wavelengths with $\lambda$ < 50 mm. Hence they are out of the range of interest for low-frequency ground vibration or ground-borne noise;

— keeping a log of all defects being edited from the record. This is not practical on such long records and automated removal of defects shall be allowed.

Other requirements for characterizing the irregularity of the running surfaces with respect to vibration excitation include:

e) any roughness spectrum shall be qualified by the data processing used;

f) reporting of roughness data shall clearly state:

   1) the type of measurement device used;

   2) the sampling period;

   3) the type of averaging used;

   4) the length of the record; and

   5) the valid roughness wavelength range of the data.

g) in cases where roughness is to be measured for a site-specific purpose (e.g. the local prediction of likely levels of ground-borne noise in a proposed new building near to the site concerned), the roughness amplitude can vary along the length of rail on which the roughness profile is measured. This causes uncertainty because the roughness local to the site can be different to the roughness evaluated for the full length of the record. In such cases it is desirable to record and retain the actual roughness profile in the space domain to facilitate post processing in order to take full account of this effect. Annex C provides further information regarding processing of roughness information in site-specific cases.

The principles of measurement and analysis described in this clause are intended to provide a means of characterising the roughness of a track which is not loaded by a train. The loaded geometry of the track, resulting from track stiffness variation, can theoretically act as a separate vibration excitation mechanism which is not characterised by the principles described in this document and is explained in EN 13848-2. Excitation from the loaded geometry of the track is only important for ground-borne noise and vibration generation when the geometrical roughness of the track is comparable to, or lower than, the loaded geometry.

# Annex A
(informative)

# Characterization of localized geometrical features

The general excitation mechanisms for vibration and ground-borne noise are described in ISO 14837-1:2005, 4.2.2 and in Reference [9]. Ground-borne noise and vibration are clearly excited by local features in the track as switches, crossings, rail joints, welds, rail squats and wheel irregularities (e.g. wheelflats). These inputs can be non-linear and more difficult to characterise than excitation arising from smaller scale roughness considered in Clause 4 and Clause 5. An early and comprehensive reference in this area characterises such noise as impact noise as distinct from rolling noise[10] and concluded in particular that at a rail joint, the height difference, and not the width of the gap is the controlling parameter in generating impact noise. An update to this work is given in Reference [11].

The contribution of wheelflats and joints to noise is considered in References [12] and [13].

EXAMPLE The sound power level over the full frequency range $f$ = 63 Hz to $f$ = 4 kHz is a full 10 dB to 20 dB higher over the speed range $v$ = 30 km/h to $v$ = 120 km/h from a 2 mm deep wheelflat than from a typical tread-braked wheel. While the frequency range $f$ = 63 Hz to $f$ = 4 kHz is pertinent to air-borne noise, the frequency ranges of $f$ = 1 Hz to $f$ = 80 Hz and $f$ = 20 Hz to $f$ = 250 Hz, that are pertinent to ground-borne vibration and noise respectively, are only partially covered.

Impact noise frequencies significant for ground-borne noise and vibration are considered in References [14] and [15]. It is demonstrated in Reference [14] that the magnitude of ground-borne vibration arising from wheelflats are significantly greater than those arising from common levels of vertical track irregularity. Based on extensive field measurements, it is concluded in References [16] and [17] that the maximum vibration levels are induced mainly by freight locomotives. For several freight locomotives, a high variance in measured vibration levels up to 20 dB was observed, indicating a significant scatter in wheel tread conditions (sometimes referred to as wheel out-of-roundness). It is clear from Reference [15] that a crossing excites noise across the full frequency spectrum $f$ = 1 Hz to $f$ = 250 Hz that is significant for ground-borne noise and vibration.

Modelling and measurement of vibration at switches and crossings is considered in References [18] and [19], primarily with regard to the contact forces that are significant in the deterioration and maintenance of these expensive track components. In Reference [19], it is shown by measurement that the effect of a rail profile correction at the frog is beneficial in the frequency range $f$ < 50 Hz, leading to a reduction of about 10 dB in soil vibration. However, for higher frequencies the benefit is not as pronounced, becoming practically negligible for $f$ > 100 Hz.

# Annex B
(informative)

# Measuring equipment

## B.1 Rail roughness measuring equipment

A variety of equipment is available to measure irregularities on railway rails. Several types of equipment are used on rail reprofiling trains and measuring vehicles. There already exist several European and International Standards describing the requirements for the measurements to be taken and the equipment to be used for different roughness wavelength ranges. For example:

a) Requirements for equipment to measure track geometry at roughness wavelengths in the range $\lambda$ = 3 m to $\lambda$ = 200 m are considered in EN 13848-1.

b) EN 13231-2 sets out the technical requirements and the measurements to be made for the acceptance of work to re-profile both longitudinally and transversely the heads of railway rails. The roughness wavelength range of interest for EN 13231-2 is $\lambda$ = 10 mm to $\lambda$ = 1 000 mm. A validation procedure is proposed for equipment to be used for these measurements.

c) EN 15610 specifies the requirements of a system that can be used to measure acoustic roughness in the roughness wavelength range $\lambda \leq$ 0,25 m in one-third-octave bands. It does not present a method of assessing whether equipment is satisfactory for that purpose.

Essentially two types of measuring equipment exist and can give a continuous measurement of the longitudinal profile of a rail: chord-based systems and inertial systems. Axlebox accelerometer systems (see B.2) are a versatile and widely used method of measuring track condition when the track is loaded. Examples exist of both chord-based and inertial systems for both ground-borne noise and vibration wavelength measurements (typical for track geometry requirements, see EN 13848-1) and acoustic wavelength measurements (typical for rail reprofiling, see EN 13231-2). In Reference [20], a comparison is made between chord and inertia based systems for measuring rail head irregularities.

For acoustic roughness measurements (see EN 15610), both static straight-edge devices and inertial equipment have been used. It is not practical to measure the sample record length required for railway induced ground-borne noise and vibration roughness wavelengths using straight-edge measurement equipment described in EN 15610.

It is recognised in EN 13848-1 that if a measurement is made using a system based on a moving chord, the measured signals are distorted in magnitude and phase. Depending on the position of transducers within the chord, some roughness wavelengths cannot be measured by the chord-based system. In any case, a procedure is required in order to correct for the distortions that do exist. This is the case regardless of the type of transducer that is used to measure the rail distortion from the datum provided by the chord.

Regardless of the equipment used, the accuracy and repeatability of the measurement equipment used to measure irregularities in amplitude and over the roughness wavelength range, that are significant for generation of ground-borne noise and vibration, shall be qualified. Inertial systems have been demonstrated to give not only extremely repeatable but also, as far as this is possible to demonstrate, accurate measurements over the entire roughness wavelength of interest for both air-borne and ground-borne noise and vibration[21][22].

## B.2 Axlebox accelerometer systems

The first axlebox accelerometer system was an analogue device developed by British rail research in the 1980s and used routinely for several years in the UK to detect corrugation[20]. Axlebox accelerometer systems have subsequently been and are being used to

a) measure corrugation[24][25],

b) monitor welds and general track condition and thereby help programme maintenance[25][26][27][28],

c) monitor discrete defects, including turnouts, crossings, studs, squats and thermit welds[29][30][31],

d) monitor joints, including insulated joints[31][33], and

e) investigate vehicle/track/soil interaction[34] and the effects of track support stiffness[35].

Axlebox accelerometer system output depends critically on the dynamic behaviour of vehicle and track, and in particular the transfer function between the wheel/rail irregularity and axlebox acceleration[25][36]. The transfer function between roughness and acceleration can be variable at frequencies pertinent to ground-borne noise and vibration. This variation occurs because of the dynamic behaviour of the track itself, which is a function of the track support stiffness and of the track form and vehicle suspension. Accurate measurement of ground-borne noise and vibration wavelengths requires the complex behaviour of the track and vehicle suspension to be fully understood and accounted for in the measurements taken[37].

Axlebox accelerometer systems give measurements of irregularity that are repeatable and reproducible on a consistent trackform and for acoustic frequencies[36] as at these frequencies (above those of interest to ground-borne noise and vibration), movement of the wheel and rail is extremely small because of their high inertia and the axlebox acceleration is directly proportional to the wheel/rail irregularity.

If the contributions of the wheel and rail to the overall irregularity are to be considered independently, a method is required to separate their effects. One method is to measure the wheel surface irregularity and subtract this from the irregularity measured with the axlebox system[37][38].

## B.3 Wheel roughness measuring equipment

Most if not all types of equipment that are available to measure irregularities on railway wheels are based on the same principle. The instrument comprises one or more displacement transducers that are located in a firm base that is held, commonly with a magnet, to the rail. The distance around the periphery of the wheel is measured using a tachometer wheel that is in contact with and rotates with the train wheel.

The wheelset is jacked up slightly so as to be clear of the rail. The transducers are moved to be in contact with and approximately normal to the wheel surface and the wheel is then rotated by hand. Continuous measurements of radial irregularities are made with the transducers while the distance around the wheel is measured using the tachometer in contact with it. An example of measurements taken in this way are presented in Reference [39]. Some results for different rolling stock are shown in Reference [16] and for freight locomotives and wagons in Reference [17].

Wheel impact detection systems have been used for many years to detect irregularities on wheels in service, which can significantly increase track damage and in particular rail breaks. Such irregularities can also cause substantial ground-borne noise and vibration. Nevertheless, the purpose of these systems is to alert users to a problem rather than to give a continuous measurement of wheel irregularity. The main technologies that are used in these systems are accelerometers and strain-gauged rails. An overview of the technologies is given in Reference [40] and some results are shown in Reference [17].

## B.4 Loaded and unloaded measurement systems

It is stated in Reference [27] that one important aspect of controlling vibration levels is the availability of systems that accurately measure and monitor vertical track (and rail) irregularities to facilitate maintenance management. Such systems measure irregularities in roughness wavelengths relevant to ground-borne vibration and noise. Measurement systems can measure the unloaded or the loaded irregularity of the track.

B.1 describes unloaded measurements. B.2 describes loaded measurement systems. More loaded and unloaded measurement systems are discussed in Reference [27].

It is further stated in Reference [27] that none of the available systems measure the complete roughness wavelength range relevant for ground-borne vibration and noise. For example, at a freight train speed of $v = 80$ km/h, the relevant roughness wavelengths are between $\lambda = 0,1$ m to $\lambda = 10$ m. In common practice and according to existing standards, track recording coaches (TRC) are used to assess loaded track geometry (longitudinal roughness level) with $\lambda > 3$ m (sometimes $\lambda > 1$ m), whereas hand-held accelerometer-based trolleys and mechanical displacement probes measure unloaded rail irregularities $\lambda < 0,5$ m. To cover the complete roughness wavelength range, a combination of measurement methods is required.

It is important to combine loaded and unloaded measurement methods (e.g. axlebox accelerometer systems simultaneously measure rail corrugation and loaded track geometry). But when under sleeper pads are used then the loaded case will show differences (e.g. up to 15 dB lower roughness levels from $f = 63$ Hz to $f = 400$ Hz because of the lower stiffness of the track[41]) of the unloaded measurement system. This is the case because the unloaded measurement is independent of track stiffness and therefore shows no reduction in roughness from $f = 63$ Hz to $f = 400$ Hz.

B.3 describes an unloaded system that can be used to measure wheel out-of-roundness. It is obvious that a certain out-of-roundness against a round wheel shows different vibration amplification for different track systems (e.g. see Reference [17]). This is due to the fact that the excitation mechanisms can change according to differences in the dynamic properties of the track system.