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# Railway applications — Track geometry quality —

## Part 1: Characterization of track geometry and track geometry quality

*Applications ferroviaires — Qualité géométrique de la voie —*

*Partie 1: Caractérisation de la géométrie de la voie et de la qualité géométrique de la voie*



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# Foreword

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# Railway applications — Track geometry quality —

# Part 1: Characterization of track geometry and track geometry quality

## 1 Scope

This document defines track geometry parameters and specifies the minimum requirements for track geometry measurements and the evaluation method for track geometry quality.

This document is applicable to 1 435 mm and wider track gauges. The urban/light rail systems, tramways and any track gauge narrower than 1 435 mm are excluded from the scope of this document, however it can be used as a reference.

## 2 Normative references

There are no normative references in this document.

## 3 Terms and definitions, symbols and abbreviations

### 3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

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/

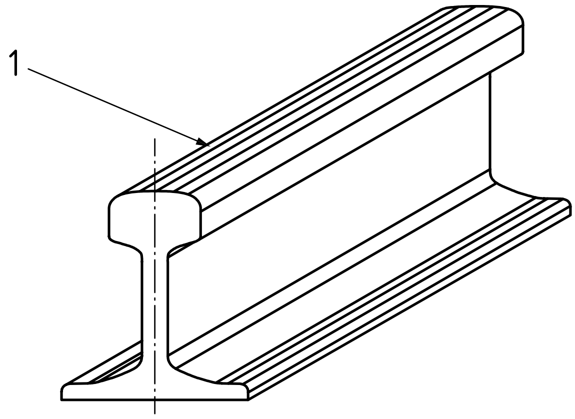
**3.1.1**
**track geometry parameters**
parameters to describe geometrical characteristics of the track, such as track gauge, longitudinal level, alignment, cross level, twist

**3.1.2**
**track geometry quality**
assessment of deviation in the vertical and lateral planes from the average or designed geometrical characteristics of specified parameters which give rise to safety concerns or have a correlation with ride quality

**3.1.3**
**gauge face**
inside face of the running rail head

**3.1.4**
**running table**
upper surface of the head of the rail

Note 1 to entry: See Figure 1.




**Key**

1 running table

**Figure 1 — Running table[1],[2]**

**3.1.5**
**running surface**
curved surface defined by the longitudinal displacement of a straight line perpendicular to the centre-line of the track and tangential to both running tables

Note 1 to entry: See Figure 2.

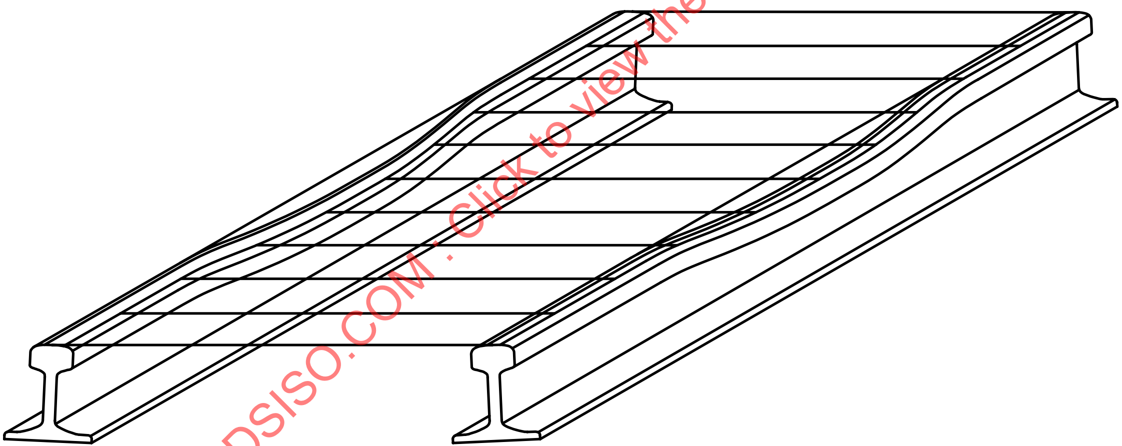


**Figure 2 — Running surface**



**3.1.6**
**uncertainty**
value defining the interval about the result of a measurement expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand[3]

Note 1 to entry: The coverage factor is equal to 2. The uncertainty as defined corresponds to a confidence interval of about 95 % of a normal distribution.

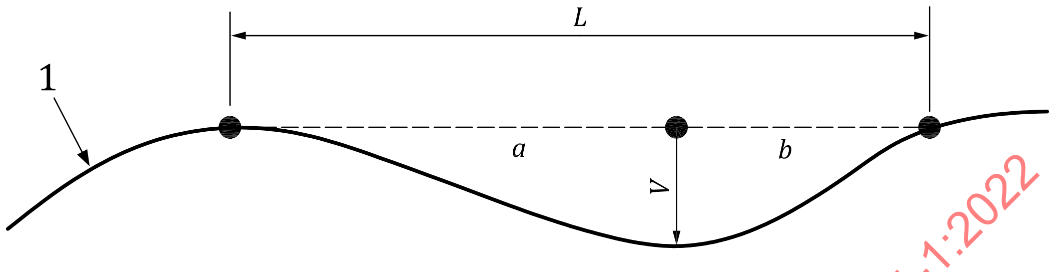
**3.1.7**
**resolution**
smallest change in the value of a quantity to be measured which produces a detectable change in the indication of the measuring instrument

**3.1.8**
**chord length**
length of the straight line (chord) between two points on the same rail

**3.1.9**
**chord measurement system**
system which measures track geometry by perpendicular distance (i.e. offset) from the chord to the chosen rail measurement point within its length

Note 1 to entry: See Figure 3.




**Key**
1 rail
$V$ offset
$L$ chord length
$a$,$b$ divided chord length, $L=a+b$

**Figure 3 — Chord measurement**

Note 2 to entry: It is symmetrical chord measurement when $a=b$, otherwise it is asymmetrical chord measurement.



**3.1.10**
**inertial measurement system**
system which measures track geometry by referring the rail position to an inertial reference, which may be provided by a combination of accelerometers, gyroscopes, and sometimes magnetometers

**3.1.11**
**wavelength range**
space domain covered by the track geometry measurements

**3.1.12**
**sampling distance**
equal distance travelled between each two consecutive measured points

**3.1.13**
**range of measurement**
specific domain described by its limits

**3.1.14**
**isolated defect**
part of the signal exceeding a given limit with at least one sample

## 3.2 Symbols and abbreviations

| Symbol | Designation | Unit |
|---|---|---|
| $G$ | Track gauge | mm |
| $Z_p$ | Limit of the range below the running surface within which the gauge is measured. $Z_p$ is always 14~16 mm for a Vignole rail | mm |
| $Z_{ll1}$ | Deviation in the direction of consecutive running table levels on right hand rail. Used in the measurement of longitudinal level | mm |
| $Z_{ll2}$ | Deviation in the direction of consecutive running table levels on left hand rail. Used in the measurement of longitudinal level | mm |

| Symbol | Designation | Unit |
|---|---|---|
| $Y_{p1}$ | Distance between point P and a reference line on right hand rail. Used in the measurement of alignment | mm |
| $Y_{p2}$ | Distance between point P and a reference line on left hand rail. Used in the measurement of alignment | mm |
| P | Gauge face contact point | |
| $W_1$, $W_2$, $W_3$ | Wavelength ranges which are correlated to line speed and are classified into short, medium and long wavelengths | |
| $C_1$, $C_2$ | Chord length class which are based on line speed and are classified into short and long chord lengths | |
| $V_1$ | Amplitude from the zero line. Used in the measurement of twist | mm/m |
| $V_2$ | Amplitude from the mean value. Used in the measurement of twist | mm/m |
| $\ell$ | Twist base-length | m |
| *X*, *Y*, *Z* | Axes of a track coordinate system | |
| *C* | Filtered cross level which is obtained by high-pass filtering of cross level | mm |
| *CX* | Combined irregularity refers in particular to the combined irregularity of alignment and filtered cross level | mm |
| *T* | Track quality index. The combined standard deviation of track geometric irregularities including left longitudinal level, right longitudinal level, level alignment, right alignment, gauge, cross level and twist | |
| *L* | Chord Length. Length of the straight line between the two points on the same rail | m |
| *K* | Combination coefficient | |

## 4 Description of the track coordinate system

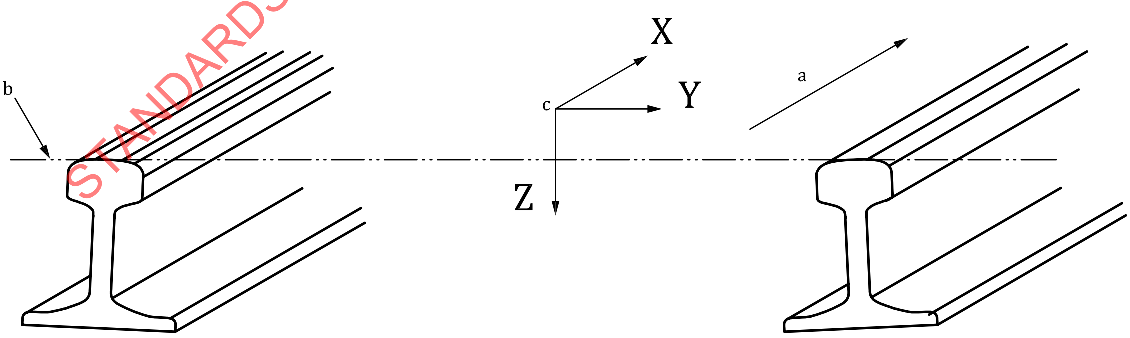
The track geometry quality is described by means of a moving right-hand Cartesian coordinate system centered to the track with clockwise rotation (see Figure 4):

— X-axis: axis represented as an extension of the track towards the direction of running;

— Y-axis: axis parallel to the running surface;

— Z-axis: axis perpendicular to the running surface and pointing downwards.

NOTE This description is for the coordinate system of the measurement vehicle. It is up to the infrastructure manager to define a reference direction of the track.




**Key**

a Running direction.

b Intersection between considered cross section and running surface.

c Track coordinate system.

**Figure 4 — Relationship between the axes of the track coordinate system**



Rail identification (left or right rail) and sign convention of parameter measurement is not in the scope of the standard but should be agreed between parties for the purpose of exchanging data.

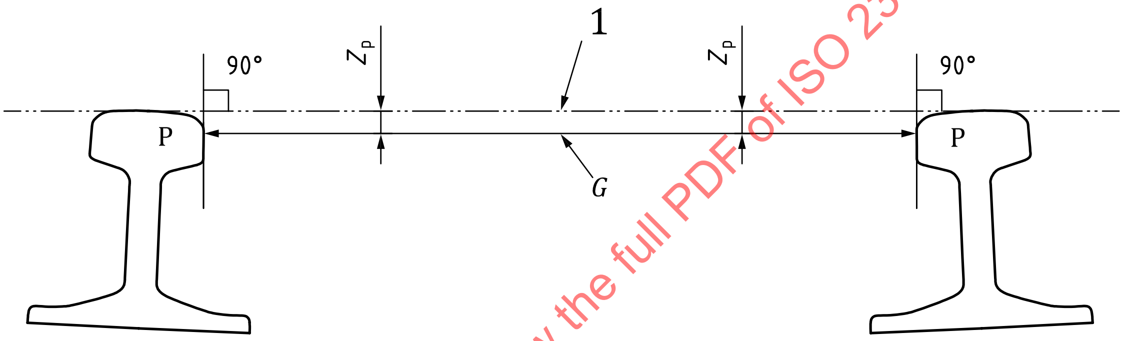
# 5 Definition of track geometry parameters

## 5.1 Track gauge

Track gauge, $G$, is the smallest distance between lines perpendicular to the running surface intersecting each rail head profile at point P in a range from 0 to $Z_p$ below the running surface. In this standard, $Z_p$ is in the range of 14 mm to 16 mm.

NOTE Track gauge limit values depend on the chosen $Z_p$ value. For example, $Z_p$ is 14 mm in Europe and Japan and 16 mm in China and Japan.

In the situation of new unworn rail head, the point P will be at the limit $Z_p$ below the rail head, as shown in Figure 5.

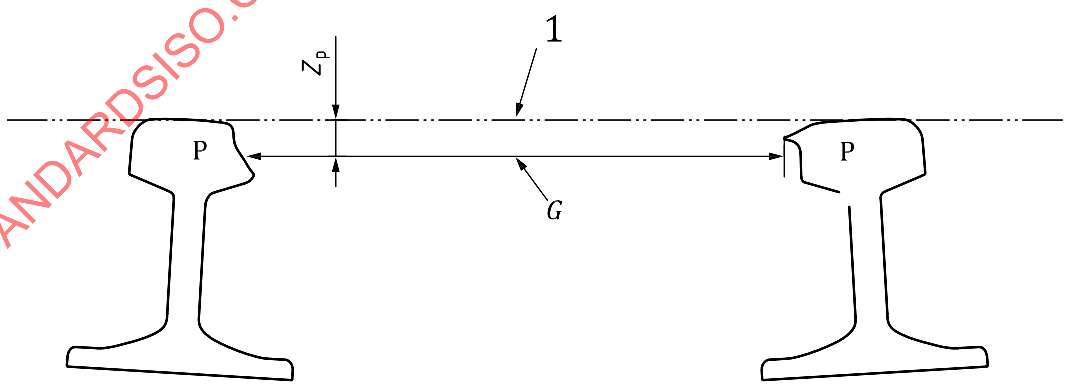



**Key**

1 running surface

**Figure 5 — Track gauge for new rail (example in case rails are tilted)**

In the situation of worn rail head the height of point P for the left rail can be different from the right rail, as shown in Figure 6.




**Key**

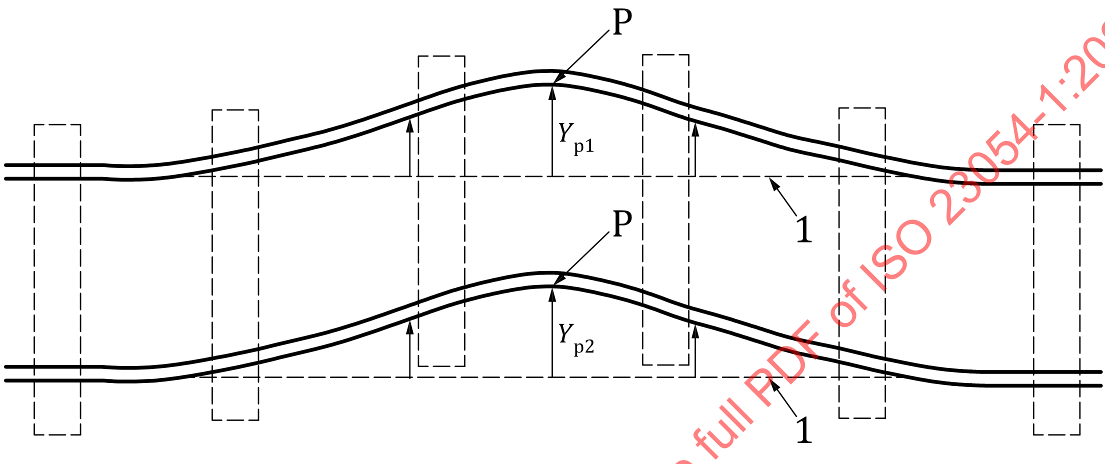
1 running surface

**Figure 6 — Track gauge for worn rail (example in case rails are tilted)**

## 5.2 Alignment

Alignment is the deviation $Y_{p1}$ and $Y_{p2}$ in $Y$-direction of the position of point P (see 5.1) on any rail from the reference line. The reference line can be the design alignment or a smoothed alignment calculated from successive measurements (see Figure 7).

Alignment measurements shall be made with either an inertial measurement system or a chord measurement system (that should preferably be asymmetrical chord), or a combination of both. Those measurement systems will produce results in different domains (space or versine respectively). It is possible to transform the measured signals between domains using a colouring/decolouring/recolouring process.




**Key**

P point P according to 5.1

1 reference line

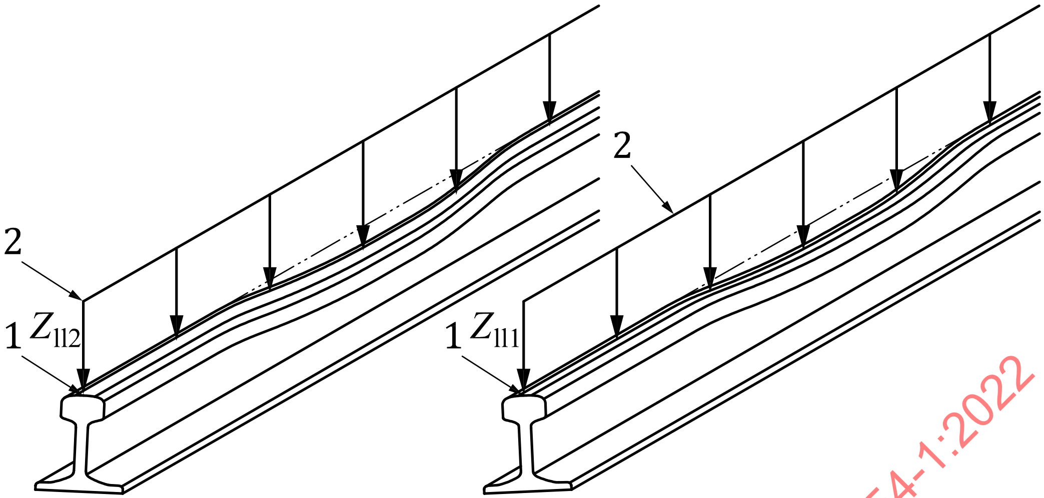
**Figure 7 — Alignment**



## 5.3 Longitudinal level

Longitudinal level is the deviation $Z_{ll1}$ and $Z_{ll2}$ in $Z$-direction of running table levels on any rail from the reference line. The reference line can be the design longitudinal level or a smoothed longitudinal level calculated from successive measurements (see Figure 8).

Longitudinal level measurements shall be made with either inertial measurement system or a chord measurement system (that should preferably be asymmetrical chord), or a combination of both. Those measurement systems will produce results in different domains (space or versine respectively). It is possible to transform the measured signals between domains using a colouring/decolouring/recolouring process.




**Key**

1 running table

2 reference line

**Figure 8 — Longitudinal level**



## 5.4 Cross level

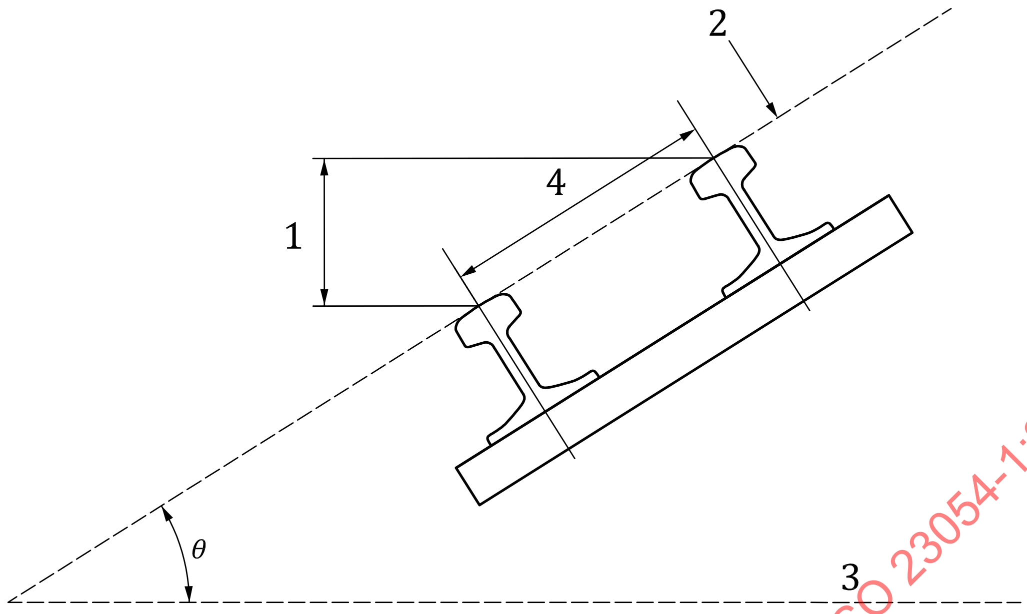
The difference in height of the adjacent running tables computed from the angle between the running surface and a horizontal reference plane. It is expressed as the height of the vertical leg of the right-angled triangle having a hypotenuse that relates to the nominal track gauge as follows (see Figure 9):

— For nominal gauge of 1 435 mm the hypotenuse is 1 500 mm in length.

— For nominal gauges of 1 520 and 1 524 mm the hypotenuse is 1 600 mm in length.

— For nominal gauge of 1 668 mm the hypotenuse is 1 740 mm in length.

Cross level is also called cant or superelevation.




**Key**

1 cross level

2 running surface

3 horizontal reference plane

4 hypotenuse

$\theta$ inclination angle

**Figure 9 — Cross level**



### 5.5 Twist

The algebraic difference between two cross levels divided by their distance apart (base-length $\ell$), typically expressed as mm/m or ‰.

### 5.6 Other parameters

Other parameters contribute to an understanding of vehicle track interaction and ride quality. These other parameters can be obtained by direct measurement or by derived measurement. A representative list of additional analysis and parameters are shown in the Annex A.

## 6 Measurement requirements of track geometry

### 6.1 General

The track geometry is measured by the track geometry measuring systems mounted on track recording vehicles, commercial vehicles, track maintenance machines or manually operated devices. It is intended to:

— measure track geometry parameters;

— measure the longitudinal distance at the sampling distance which should not exceed 0,25 m;

— associate the location to the measured data;

— process the measured data, preferably on site.

The track geometry measuring system shall produce reliable results under normal operating conditions. The measured data can be used for track quality monitoring, assessment, maintenance planning and safety assurance as related to track geometry.

The speed range shall be from standstill to the maximum permissible measuring speed of the vehicle if a chord measurement system is used; if an inertial measurement system is used, a minimum speed may be necessary to measure some parameters.

## 6.2 Measurement conditions

In order to reproduce the dynamic effects of vehicles on the track, all of the geometric parameters should preferably be measured under loaded condition.

NOTE Typically, the loading at the measuring point of the rail is equivalent to a minimum vertical wheel load of 25 kN when considering an average track stiffness of 90 kN/mm per rail (wheel load divided by rail deflection) and a flat bottom (Vignole) rail.

There can be differences in all track geometry parameter values according to whether they are measured under loaded or unloaded, static or dynamic condition. These differences should be taken into account when comparing measurements and when defining limits for assessment of track geometry parameters.

In case of unloaded or static measurement conditions, such conditions shall be documented.

The results of measurements shall be within the specified measurement precision for different speeds and for each direction of recording. If this is not the case, the domain of validity and/or the direction shall be specified.

All parameters shall be measured at the same location within the specified sampling distance.

All principal parameters shall be measured at the same sampling distance. For signal processing and signal analysis reasons, this sampling distance should be determined to be consistent with the wavelength ranges and chord lengths.



## 6.3 Measuring systems and evaluation methods for longitudinal level and alignment

### 6.3.1 Measuring systems

There are two measuring systems for longitudinal level and alignment:

— Inertial measurement system

— Chord measurement system

### 6.3.2 Evaluation methods

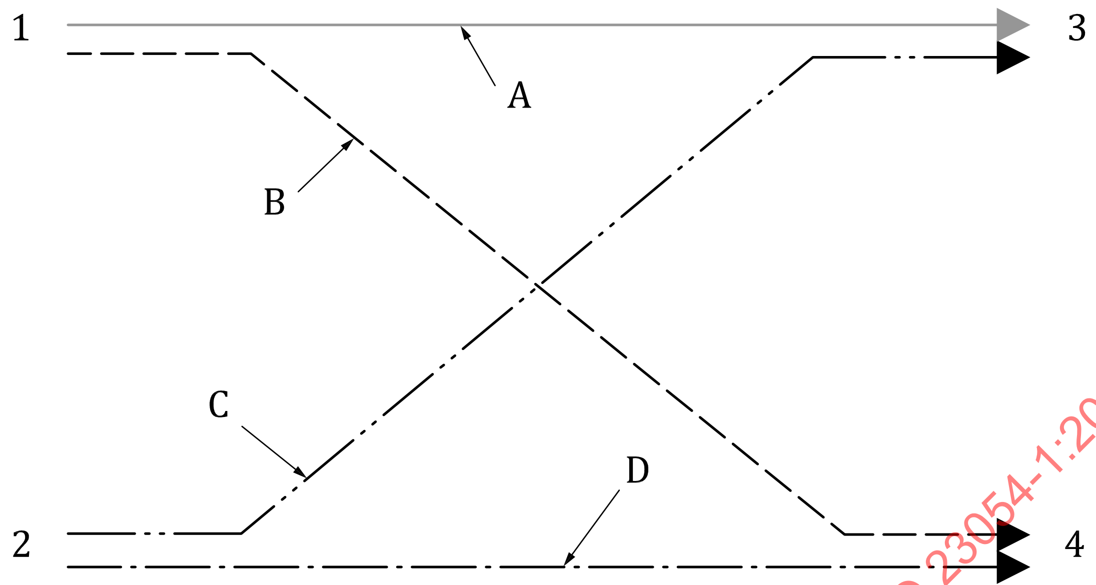
There are two evaluation methods for longitudinal level and alignment:

— Wavelength range method

— Chord based method

### 6.3.3 Relationship of measuring systems and evaluation methods

Measuring systems and evaluation methods have a relationship to convert interactively between them (Figure 10).




**Key**

Measuring system:

1 inertial measurement system

2 chord measurement system

Evaluation method:

3 wavelength range method

4 chord based method

Conversion process:

A indicates filtering procedure to convert track geometry measured by an inertial measurement system for evaluation method of track irregularity by wavelength range method, see Annexes C and D.

B indicates colouring procedure to convert track geometry measured by an inertial measurement system for the evaluation of track irregularity by chord based method.

C indicates decolouring procedure to convert track geometry measured by a chord measurement system for the evaluation of track irregularity by wavelength range method, see Annex E.

D indicates recolouring procedure to convert track geometry measured by a specified chord measurement system for the evaluation method of track irregularity by another chord based method. If the same chord for measurement and assessment is used, the recolouring procedure is not used.

**Figure 10 — Relationship to measuring systems and evaluation methods**



Railway authority and infrastructure manager can adopt any of the above measuring systems and evaluation methods.

### 6.3.4 Wavelength

Wavelengths of interest are correlated to line speed and are classified into short, medium and long wavelengths. The correlation with line speed is that the faster the vehicle travels, the more susceptible the vehicle is to longer wavelength irregularities. To encompass the current state of the art, the short, medium and long wavelengths shall be expressed as a band pass filter that has an upper and lower level to each side of the band.

The wavelength classes are defined in Table 1.

Short wavelength shall consist of a band pass filter with a lower cut-off ≤ 3 m and an upper cut-off from 25 m to 42 m.

Medium wavelength shall consist of a filter with a low pass ≤ 25 m and a high pass at 70 m.

NOTE 1 Medium wavelength, $W_2$ is generally only considered for line speeds between 150 km/h to 250 km/h.

Long wavelength shall consist of a filter with a low pass ≤ 70 m and a high pass from 120 m to 200 m.

NOTE 2 Long wavelength, $W_3$ is generally only considered for line speeds of 250 km/h or greater.

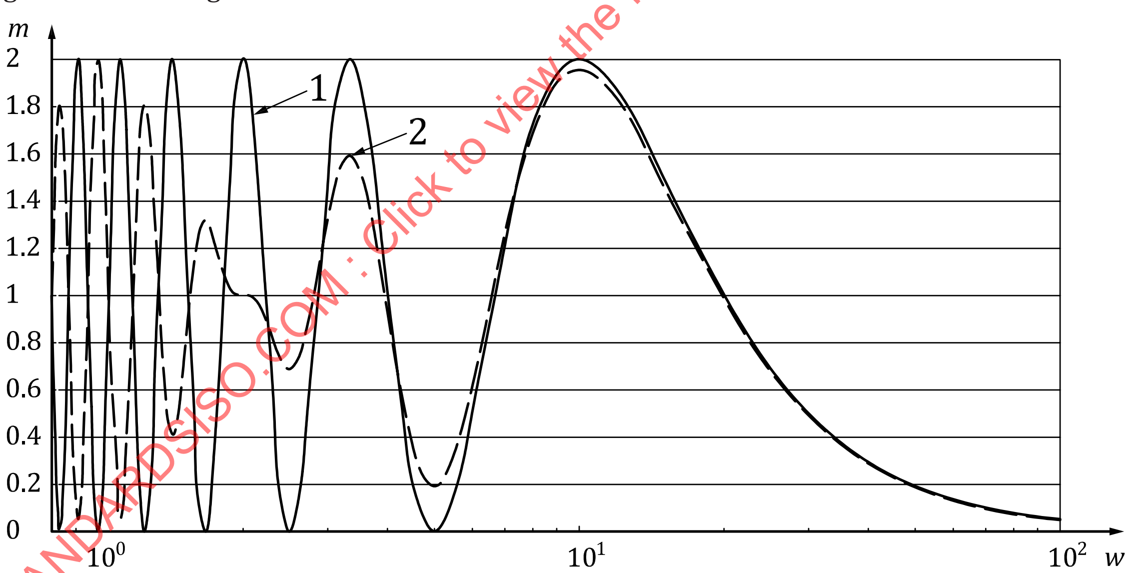
All filters shall conform to Annex C.

**Table 1 — Wavelength class**

| Wavelength class | Lower cut-off wavelength | Upper cut-off wavelength |
|---|---|---|
| $W_1$ | ≤ 3 m | 25-42 m |
| $W_2$ | ≤ 25 m | 70 m |
| $W_3$ | ≤ 70 m | 120-200 m |

### 6.3.5 Chord length

Chord lengths are chosen based on the wavelengths of interest, which are correlated to line speed. Chord lengths are classified into short and long chord lengths. The correlation with line speed is that the faster the vehicle travels, the more susceptible the vehicle is to longer wavelength irregularities. To encompass the current state of the art, the short base chord length shall be between 5 m and 20 m, and the long base chord length shall be not less than 20 m.




**Key**

*m* magnitude of the transfer function

*w* wavelength (m)

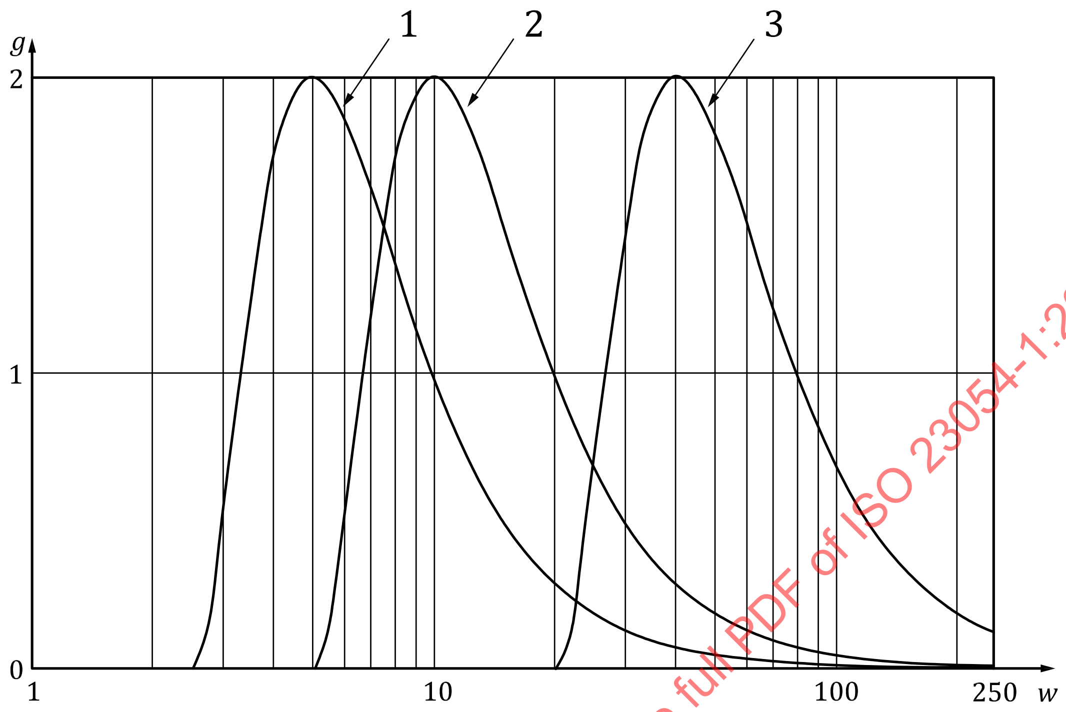
1 transfer function – 5 m/5 m

2 transfer function – 5,5 m/4,5 m

**Figure 11 — Example for transfer function of 10 m chord symmetrical vs. asymmetrical**

The division of the chord in the chord measurement system has a significant effect on the transfer function. Figure 11 shows an example of a symmetrical chord and an asymmetrical chord in 10 m chord.

In case of the symmetrical chord measurement system, the relationship between wavelength and the transfer function is shown in Figure 12. This figure demonstrates the longer the wavelength of interest, the longer the chord length.




**Key**

*g* gain

*w* wavelength (m)

1 5 m chord

2 10 m chord

3 40 m chord

**Figure 12 — The relationship between the wavelength and the transfer function**



The chord length classes are defined in Table 2.

**Table 2 — Chord length class**

| Chord length class | Base chord |
|---|---|
| $C_1$ | 5-20 m |
| $C_2$ | > 20 m |

NOTE Long chord length, $C_2$ is generally only considered for line speeds of 250 km/h or greater.

## 6.4 Resolution and range of measurement

### 6.4.1 Resolution

The resolution shall be ≤ 0,1 mm for track recording vehicles, commercial vehicles.

The resolution shall be ≤ 0,5 mm for track maintenance machines, trolleys or manually operated devices.

The needed resolution will depend on the chord length, i.e. the shorter the chord is, the smaller the resolution should be.

### 6.4.2 Range of measurement

#### 6.4.2.1 Track gauge

The range shall be the nominal gauge -15 mm/+50 mm.

#### 6.4.2.2 Alignment

##### 6.4.2.2.1 Wavelength range method

The requirements are specified in Table 3.

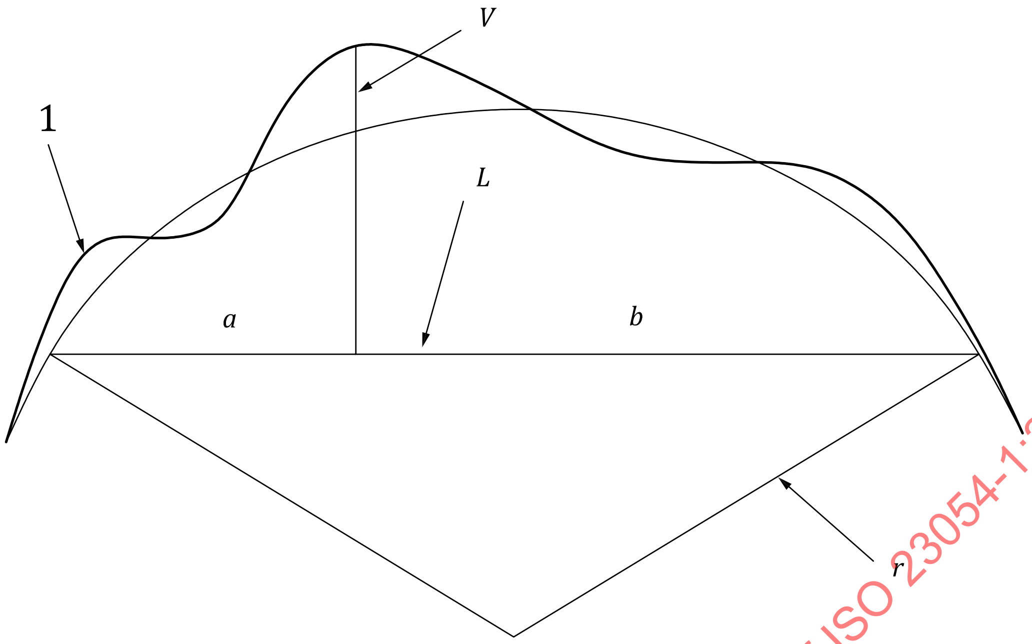
**Table 3 — Alignment: range of measurement (based on wavelength class)**

Dimensions in millimetres

| **Wavelength class** | $W_1$ | $W_2$ | $W_3$ |
|---|---|---|---|
| **Range of measurement** | ±50 | ±100 | ±300 |
| NOTE The high ranges of measurement stated for $W_2$ and $W_3$ are only required if these domains are measured on conventional lines. If $W_2$ and $W_3$ are only measured on high-speed lines, smaller ranges can be applied. | | | |

##### 6.4.2.2.2 Chord based method

Alignment range is determined by Figure 13 as it is dependent upon the choice of measurement chord and associated division.




**Key**

1 rail

*V* offset

*L* chord length

*a*,*b* divided chord length, *L*=*a*+*b*

*r* radius

Note: $M = V_d + X_e \times s$

Where

*M* is the measurement range;

$V_d$ is the designed versine;

$X_e$ is the expected irregularity;

*s* is the safety factor, *s*=1,25.

**Figure 13 — Measurement of base chord**



The requirements are specified in Table 4.

**Table 4 — Alignment: range of measurement (based on chord length class)**

Dimensions in millimetres

| **Chord length class** | $C_1$ | $C_2$ |
|---|---|---|
| **Range of measurement** | ±170 | ±220 |

### 6.4.2.3 Longitudinal level

#### 6.4.2.3.1 Wavelength range method

The requirements are specified in Table 5.

**Table 5 — Longitudinal level: range of measurement (based on wavelength class)**

Dimensions in millimetres

| **Wavelength class** | $W_1$ | $W_2$ | $W_3$ |
|---|---|---|---|
| **Range of measurement** | ±50 | ±100 | ±200 |
| NOTE The high ranges of measurement stated for $W_2$ and $W_3$ are only required if these domains are measured on conventional lines. If $W_2$ and $W_3$ are only measured on high-speed lines, smaller ranges can be applied. | | | |

#### 6.4.2.3.2 Chord based method

This has the same mathematical relationship as 6.4.2.2.2

The requirements are specified in Table 6.

**Table 6 — Longitudinal level: range of measurement (based on chord length class)**

Dimensions in millimetres

| **Chord length class** | $C_1$ | $C_2$ |
|---|---|---|
| **Range of measurement** | ±50 | ±60 |

### 6.4.2.4 Cross level

The range of measurements depends on the maximum design value of cross level, the range shall be ±1,25×maximum design value in mm.

### 6.4.2.5 Twist

The range shall be ±15 mm/m or ±15 ‰.

## 6.5 Output requirement

Measurements shall be recorded as a consecutive set of readings preferably in digital form and shall also be presented graphically. The measurement shall be coordinated with the positional datum.

It should be possible to browse track geometry data and measure the form of waveforms.

# 7 Assessment method of track geometry

## 7.1 General

Generally, two indicators can describe the track geometric quality:

— peak values of isolated defects;

— standard deviation over a defined length, typically 100 m or 200 m;

Different types of limit values can be defined to assess:

— safety

— maintenance

— acceptance of work

## 7.2 Peak values of isolated defects

— Track gauge

Individual defects are represented by the amplitude from the nominal value to the peak value (minimum and maximum peak value).

— Alignment

Individual defects are represented by the amplitude from zero to peak. In case of chord measurement, the design values or reference values produced by filtering are discounted.

— Longitudinal level

Individual defects are represented by the amplitude from zero to peak value. In case of chord measurement, the design values or reference values produced by filtering are discounted.

— Cross level

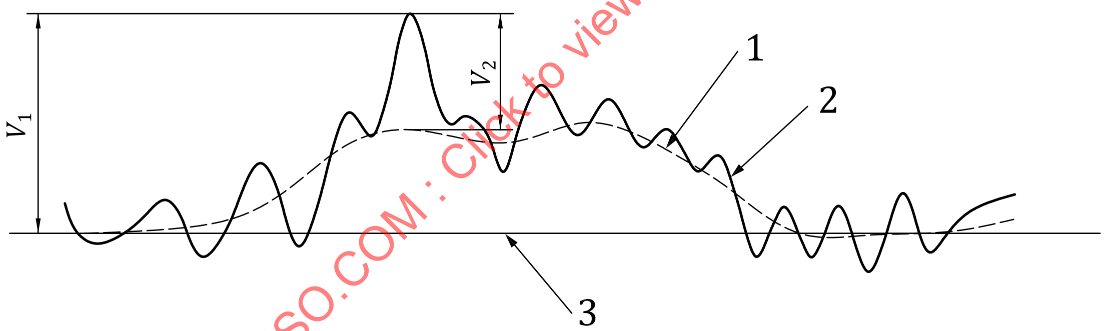
Individual defects are represented by the amplitude from the low pass filtered value to the peak value.

NOTE Usually a chosen sliding mean between 18 m and 40 m is used as a low pass filter.

Alternatively, the measured values (defined as amplitude between zero and peak values) may be compared with the design values.

— Twist

Individual defects are represented by the amplitude from the zero-line to the peak value ($V_1$). For purposes not related to safety the average to peak value can be used ($V_2$) (see Figure 14).




**Key**

1 low pass filtered value (mean value)

2 twist

3 zero line

**Figure 14 — Twist – Analysis method**



## 7.3 Standard deviation

The standard deviation (SD) represents the dispersion of a signal over a given track section, in relation to the mean value of this signal over the considered section as given in Formula (1).

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \bar{x})^2}{N-1}} \quad (1)$$

Where

$N$ is the number of values in the sample;

$x_i$ is the current value of a signal;

$i$ is an index;

$\bar{x}$ is the mean value of a signal;

$\sigma$ is the standard deviation.

Standard deviation is commonly calculated for the following parameters:

- Track gauge;
- Alignment $W_1$ or determined by $C_1$ without design values or reference values produced by filtering.

It may also be calculated for other parameters such as;

- Alignment $W_2$ or determined by $C_2$ with the design values removed;
- Longitudinal level $W_1$ or determined by $C_1$ without design values or reference values produced by filtering;
- Longitudinal level $W_2$ or determined by $C_2$ with the design values removed;
- Cross level;
- Twist.

For longitudinal level and alignment, it is recommended to calculate *SD* separately for each rail. It may also be calculated differently (for example: mean value of both rails, worst or best of either rail or outer rail in curves).

Length of track section used for standard deviation has an impact on the result. If comparable results are expected, only one length should be used. Commonly, for maintenance reasons, standard deviation is calculated over a length of typically 100 m or 200 m. It may be calculated either at fixed distances without overlap or with overlap, as a sliding standard deviation. Calculation of standard deviation is also done over longer distances such as 1 km, an entire line or an entire network.

NOTE 1 Distinction between specific track sections, such as plain lines, stations and switches and crossings, can also be made.

NOTE 2 The quasi-static part of the signals affects the calculation of *SD* for twist, track gauge and cross level.

## 7.4 Others

### 7.4.1 Power spectral density

The power spectral density (PSD) gives the energy of the signal in relation to frequency for a given track geometry parameter measured over a given track section.

For a track geometry parameter $x$, the most commonly used formula to calculate the PSD is given in Formula (2):

$$S_k = 2\overline{X_k}X_k / (Nf_s) \qquad (2)$$

Where

$f_s$ is the spatial sampling frequency;

| | |
|---|---|
| $N$ | is the number of the uniformly sampled points; |
| $X_k = \sum_{j=0}^{N-1} x_j e^{-2\pi ijk/N}$ | is the Fourier transformation of $x$, $j$,$k$=0 to $N$–1; |
| $\overline{X_k}$ | is the complex conjugate of $X_k$; |
| $S_k$ | is the power spectral density of $x$, $k$=0 to $N$–1. |

NOTE 1 In order to be representative, the PSD is calculated:

— over a sufficient length of track, typically 5 km. However, shorter lengths can also be used to analyse changes of the spectral characteristics of track geometry;

— over a section of track with features and quality as homogeneous as possible, e.g. same track layout or same components;

— for a wide range of wavelengths including at least $W_1$ and $W_2$.

NOTE 2 PSD can be of help for characterizing geometric quality over a section of track or a line for:

— vehicle manufacturers to have a better knowledge of the quality of the track on which the vehicles will run;

— infrastructure managers to know which defect wavelengths are present on the track.

One of the main advantages of PSD is that it can show typical peaks corresponding to the existence of repetitive defects such as welds.

As there are other methods for calculating PSD, the method being used should be specified.

### 7.4.2 Track quality index

Track quality index, $T$, is a combined standard deviation (CoSD) and refers to the sum of standard deviations of e.g. left longitudinal level, right longitudinal level, left alignment, right alignment, track gauge, cross level, twist, etc. $T$ is an indicator of irregularity of track section.

$T$ shall be calculated by Formula (3) as follows:

$$T = \left(\sum_{i=1}^{p} w_i \sigma_i^q\right)^{1/q} \tag{3}$$

where

| | |
|---|---|
| $T$ | is the track quality index; |
| $i$ | is the index; |
| $p$ | is the number of track geometry parameters; |
| $w_i$ | is the weight factor; |
| $\sigma_i$ | is the standard deviation of each track geometries; |

$q$=1 or 2.

# Annex A
(informative)

# Additional analysis and parameters

## A.1 Gauge rate

The algebraic difference between two gauges divided by their distance apart (base-length), typically expressed as ‰.

## A.2 Combined irregularity

Combined irregularity, *CX*, refers in particular to the combined irregularity of alignment and filtered cross level.

This parameter covers the eventuality that an irregularity on the cross level function causes unloading in a wheel running along a rail combined with an alignment defect displacing the rail towards the track centre.

Combined irregularity is calculated for each rail by using the Formula (A.1).

$$Xc_i = Yp_i - K*C \quad (A.1)$$

Where

$Xc_i$ is the combined irregularity, $i$=1,2;

$K$ is the combination coefficient;

$Yp_i$ is the distance between point P and a reference line on right hand rail, used in the measurement of alignment, $i$=1,2;

$C$ is the filtered cross level obtained by high-pass filtering of cross level.

## A.3 Cyclic irregularities

Cyclic irregularities are a derailment risk that involves a harmonic response by specific types of railway vehicles. Such vehicles are built with a suspension system that is vulnerable to this phenomenon.

A cyclic isolated defect occurs when a measured parameter has a minimum value that repeats at a set frequency along the track which induces the harmonic response to the vehicle suspension. Energy builds up in the suspension if cycles of input continue, until the vehicle wheelsets unload; leading to derailment.

The peak values of input that trigger the harmonic response at a critical speed can all be within isolated defect limit of longitudinal level or twist. It is the combined fixed wavelength and repetitive nature of these peak values that trigger the harmonic reaction at the critical speed.

Detection is usually made by an algorithm linked to the measured parameter and can span different wavelengths to match known susceptible vehicle types.

There are several different types of cyclic irregularity, some of which are listed as follows:

— Cyclic longitudinal level (or cyclic top);

— Cyclic cross fall (or cyclic twist).

Mitigation of the derailment risk with this type of phenomenon is usually undertaken by a combination of speed restriction to eliminate the harmonic response as well as manual/mechanical intervention.

Isolated defect limits are derived by experimentation/experience.

Cyclic irregularities are more susceptible when combined with other isolated defects such as twist or alignment.

## A.4 Acceleration

Acceleration measurements can be also used to give an indication of track geometry quality and to detect the local track geometry deviations which have an influence on the dynamic behaviour of a vehicle. The specification for the measurement of acceleration is referenced within Annex B.

## A.5 Vehicle response analysis

Vehicle response analysis (VRA) can be used to make objective, quantified statements about the relationship between the track geometry quality and the vehicle's responses at various speeds. Some factors have been taken into consideration such as successions of isolated defects that might generate resonance, combinations of defects at the same location and local track design (e.g. curvature and cross level).

The VRA method is based on the following principles:

— Calculation of vehicle response to the track geometry measured according to this document. The vehicle response is represented by the wheel-rail forces and accelerations of the vehicle running gear and car body;

— Consideration of different vehicle types and speeds, taking into account the worst response of all vehicles considered at every measuring point;

— The output can be referred back to single parameters like longitudinal level, twist and alignment.

When using this method, attention should be paid to the consistency between the wavelength domain of the track geometry and the frequency range of the vehicle response parameters.



# Annex B
(informative)

# Measurement of acceleration

## B.1 Introduction

Acceleration measurements can be used to give an indication of track geometry quality and to detect the local track geometry deviations which have an influence on the dynamic behaviour of a vehicle. These measurements could be used in conjunction with the main parameter measurements described in the standard. However, acceleration measurements are sensitive to the dynamic behaviour of the vehicle and other factors such as climatic conditions, actual position of the vehicle in the train and wheel rail interaction.



## B.2 Measurement method

Measurements can be taken at various locations on the car body and/or bogie depending upon the particular assessment required.

— A1 – vertical axle box acceleration for the detection of rail surface defects (e.g. corrugation) and isolated geometrical defects.

— A2 – transverse bogie acceleration for the detection of short wavelength track geometry defects (alignment or cross level).

— A3 – transverse and vertical car body acceleration for the detection of defects that have an influence on riding comfort.

## B.3 Frequency range

| | | |
|---|---|---|
| — | A1 – vertical axle box acceleration | 0 to 1 000 Hz |
| — | A2 – bogie acceleration | 0 to 100 Hz |
| — | A3 – car body acceleration | 0 to 50 Hz |

## B.4 Range of measurement

| | | |
|---|---|---|
| — | A1 – vertical axle box acceleration | ±1 000 m/s$^2$ |
| — | A2 – bogie acceleration | ±50 m/s$^2$ |
| — | A3 – car body acceleration | ±20 m/s$^2$ |

## B.5 Sampling frequency

The sampling frequency should be at least 5 times the cut-off frequency applied to the signal e.g. ≥ 5 000 Hz for axle box acceleration (i.e. 5 × 1 000 Hz).

## B.6 Measurement conditions

- A1– (vertical axle box acceleration) the measuring speed should be adapted to the used sensors and the analysis method.
- A2 and A3 – (bogie and car body acceleration) measurement should be made at the operating speed for the line within a tolerance of ±10 %.

## B.7 Analysis method

- A1 – (vertical axle box acceleration):
  - Calculation and analysis of mean to peak and/or peak to peak values in the given frequency range which are linked to dynamic wheel-rail forces and to isolated defects;
  - Calculation of standard deviation of signal over a specified distance and a given frequency range. This can be used for assessing corrugation and/or density of short geometric defects of the rail;
  - Double integration of the signal in a given frequency range in order to obtain a representation of short defects of track geometry. This method can be also used for calculating longitudinal level.
- A2 and A3 – (bogie and car body acceleration) isolated defects are represented by the amplitude from the mean value to the peak value or from zero to the peak value as defined by the infrastructure manager.

## B.8 Output requirements

Results should be presented in graphical form. An analogue or digital recording of raw data can also be made to enable further analysis of measurements. It is recommended to provide the speed together with the accelerations.

The infrastructure manager should define the exact output requirements.

## B.9 Output presentation

- A1 – (vertical axle box acceleration):
  - presented as the standard deviation over a given duration or a given length for a specified wavelength range;
  - presented in a graphical format when mean/peak to peak analysis or double integration is performed.
- A2 and A3 – (bogie and car body acceleration) presented as isolated defects that exceed a prescribed threshold.



# Annex C
(normative)

# Filter requirements

## C.1 General requirements

Filters are applied to a measurement signal to obtain $W_1$, $W_2$ or $W_3$.

To permit comparison of data from different measuring systems (of different manufacturers), filters should be standardized.

The filters are required to have linear phase and a damping of -3 dB at the cut-off frequency. Tolerance bands for the transfer functions (magnitude responses) in the wavelength ranges $W_1$ and $W_2$ are given as follow. Due to the lack of experience, no tolerance bands and requirements for the slope are given for $W_3$. It is recommended that the transfer functions remain within these tolerance bands.

Diagrams of the filter transfer functions (including the tolerance band limits in case of $W_1$ and $W_2$) shall be provided together with the measurement output data.

## C.2 Tolerance bands for filter transfer functions

### C.2.1 Introduction

The cut-off frequency is the frequency where the damping of magnitude is -3 dB. The filters shall have a slope of 24 dB/octave and a 4th order Butterworth characteristic. The filters shall have linear phase.

### C.2.2 Filter for $W_1$, $W_2$ and $W_3$

The cut-off frequencies of $W_1$, $W_2$ and $W_3$ are as follows:

$$\text{with } f = \frac{1}{w} \qquad \text{(C.1)}$$

where $w$ is wavelength.

$W_1$ has the following cut-off frequencies:

— $0{,}04\ \text{m}^{-1} \geq f_{low} \geq 0{,}023\ 8\ \text{m}^{-1}$ (25 m ≤ wavelength ≤ 42 m)

— $f_{high} \geq 0{,}333\ 3\ \text{m}^{-1}$ (wavelength ≤ 3 m)

$W_2$ has the following cut-off frequencies:

— $f_{low} = 0{,}014\ 3\ \text{m}^{-1}$ (wavelength = 70 m)

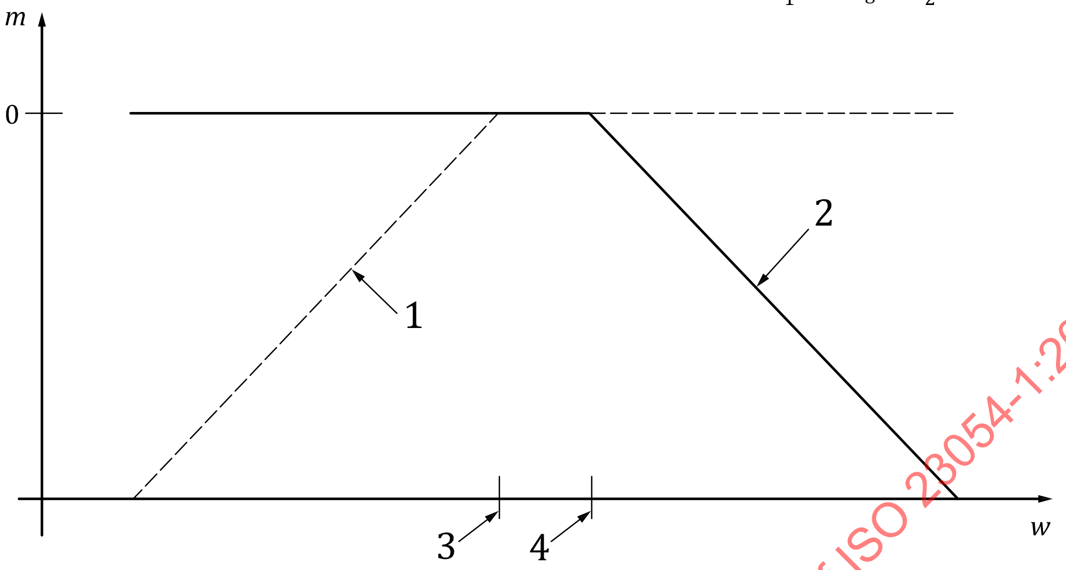
— $f_{high} \geq 0{,}04\ \text{m}^{-1}$ (wavelength ≤ 25 m)

$W_3$ has the following cut-off frequencies:

— $0{,}008\ 3\ \text{m}^{-1} \geq f_{low} \geq 0{,}005\ \text{m}^{-1}$ (120 m ≤ wavelength ≤ 200 m)

— $f_{high} \geq 0{,}014\ 3\ \text{m}^{-1}$ (wavelength ≤ 70 m)

The cut-off frequencies of the wavelength $W_1$ and $W_2$ and also $W_2$ and $W_3$ should overlap to avoid a gap in the total wavelength range. See Figure C.1 based on Example: $f_{\text{low}-W_1} < f_{\text{high}-W_2}$ .




**Key**

*m* magnitude [dB]

*w* wavelength [=1/frequency]

1 transfer function filter $W_2$

2 transfer function filter $W_1$

3 $f_{\text{high}-W_2}$

4 $f_{\text{low}-W_1}$

**Figure C.1 — Example of frequency overlap**



## C.3 Guideline for filter design

In case it is necessary to design a custom bandpass filter for any wavelength range between 3 m and 70 m the guideline for tolerance bands provided in this clause shall be considered.

For a generic bandpass filter with cut-off frequencies $f_{\text{low}}$ and $f_{\text{high}}$ at −3 dB, the following wavelength ranges can be identified:

— passband is the wavelength range from $f_{\text{low}}$ to $f_{\text{high}}$;

— stopband is the wavelength range where the filter response is within −50 dB;

— transition band is the wavelength range between passband and stopband.

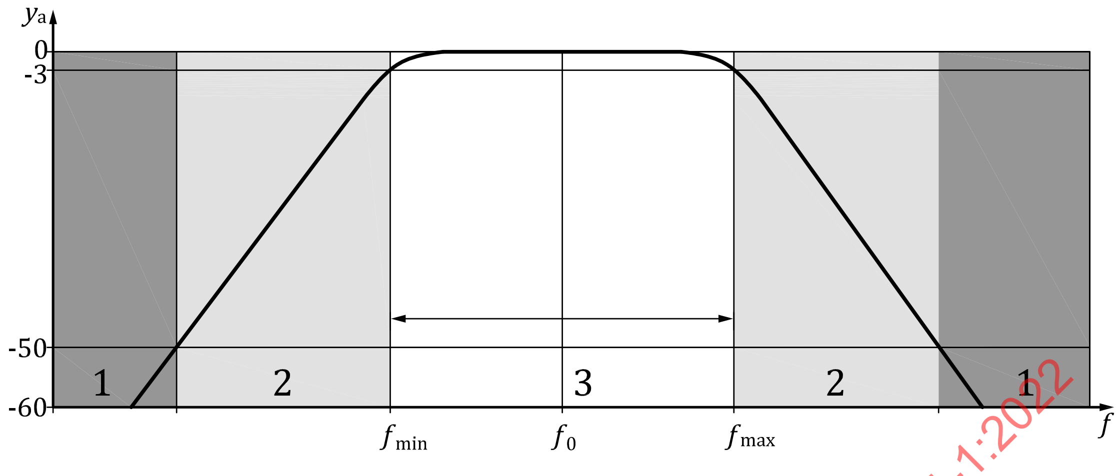
The following indexes are also defined:

— centre frequency $f_0$ is the geometric mean value of $f_{\text{low}}$ and $f_{\text{high}}$;

— bandwidth (BW) is the difference between $f_{\text{high}}$ and $f_{\text{low}}$;

— quality factor (or $Q$ factor) is calculated as $\frac{f_0}{\text{BW}}$.

See Figure C.2.




**Key**

$f$ frequency [1/m]

$y_a$ amplitude [dB]

1 stopband

2 transition band

3 passband

**Figure C.2 — Bandpass filter**



Given the centre frequency and $Q$ factor of a filter, the cut-off frequencies are obtained with Formulae (C.2) and (C.3):

$$f_{\text{low}}(Q) = f_0 \left( \sqrt{1 + \frac{1}{4Q^2}} - \frac{1}{2Q} \right) \quad \text{(C.2)}$$

$$f_{\text{high}}(Q) = f_0 \left( \sqrt{1 + \frac{1}{4Q^2}} + \frac{1}{2Q} \right) \quad \text{(C.3)}$$

The frequencies have been chosen by multiplying $Q$ with multiplicands as given in Table C.1.

Table C.1 is given in a generic way in order to allow using the tolerance band for arbitrary frequency bands.

**Table C.1 — Tolerance band**

| $f$ [1/m] | Lower limit [dB] | Upper limit [dB] | Tolerance [dB] (upper-lower) | Remark |
|---|---|---|---|---|
| $f \leq f_{\text{low}}(Q/5,4)$ | - Inf | −50 | Inf | stopband |
| $f = f_{\text{low}}(Q/5)$ | −57,0 | −47,0 | 10 | transition band |
| $f = f_{\text{low}}(Q/4,5)$ | −53,4 | −43,4 | 10 | transition band |
| $f = f_{\text{low}}(Q/4)$ | −49,3 | −39,3 | 10 | transition band |
| $f = f_{\text{low}}(Q/3,5)$ | −44,7 | −34,7 | 10 | transition band |
| $f = f_{\text{low}}(Q/3)$ | −39,4 | −29,4 | 10 | transition band |
| $f = f_{\text{low}}(Q/2,5)$ | −33,2 | −23,2 | 10 | transition band |
| $f = f_{\text{low}}(Q/2)$ | −25,8 | −15,8 | 10 | transition band |
| $f = f_{\text{low}}(Q/1,5)$ | −17,0 | −7,0 | 10 | transition band |
| $f = f_{low}(Q/1,4)$ | −14,5 | −5,5 | 9 | transition band |
| $f = f_{\text{low}}(Q/1,3)$ | −12,7 | −4,7 | 8 | transition band |

**Table C.1** *(continued)*

| $f$ [1/m] | Lower limit [dB] | Upper limit [dB] | Tolerance [dB] (upper-lower) | Remark |
|---|---|---|---|---|
| $f = f_{low}(Q/1{,}2)$ | −10,3 | −3,3 | 7 | transition band |
| $f = f_{low}(Q/1{,}1)$ | −7,8 | −2,8 | 5 | transition band |
| $f = f_{low}(Q/1{,}05)$ | −5,7 | −2,7 | 3 | transition band |
| $f = f_{low}(Q)$ | **−3,3** | **−2,7** | **0,6** | **CUT OFF** |
| $f = f_{low}(Q/0{,}95)$ | −3,2 | −1,2 | 2 | pass band |
| $f = f_{low}(Q/0{,}9)$ | −2,7 | −0,7 | 2 | pass band |
| $f = f_{low}(Q/0{,}8)$ | −1,7 | −0,1 | 1,6 | pass band |
| $f = f_{low}(Q/0{,}7)$ | −1,0 | 0,0 | 1 | pass band |
| $f = f_{low}(Q/0{,}6)$ | −0,7 | 0,0 | 0,7 | pass band |
| $f = f_{low}(Q/0{,}55)$ | −0,6 | 0,0 | 0,6 | pass band |
| $f = f_{low}(Q/0{,}5)$ | −0,5 | 0,0 | 0,5 | pass band |
| $f = f_{low}(Q/0{,}45)$ | −0,4 | 0,1 | 0,5 | pass band |
| $\mathrm{f} = \mathrm{f}_{low}(Q/0{,}4)$ | −0,3 | 0,2 | 0,5 | pass band |
| $f = f_{low}(Q/0{,}35)$ | −0,2 | 0,2 | 0,4 | pass band |
| $f = f_{high}(Q/0{,}35)$ | −0,2 | 0,2 | 0,4 | pass band |
| $f = f_{high}(Q/0{,}4)$ | −0,3 | 0,2 | 0,5 | pass band |
| $f = f_{high}(Q/0{,}45)$ | −0,4 | 0,1 | 0,5 | pass band |
| $f = f_{high}(Q/0{,}5)$ | −0,5 | 0,0 | 0,5 | pass band |
| $f = f_{high}(Q/0{,}55)$ | −0,6 | 0,0 | 0,6 | pass band |
| $f = f_{high}(Q/0{,}6)$ | −0,7 | 0,0 | 0,7 | pass band |
| $f = f_{high}(Q/0{,}7)$ | −1,0 | 0,0 | 1 | pass band |
| $f = f_{high}(Q/0{,}8)$ | −1,7 | −0,1 | 1,6 | pass band |
| $f = f_{high}(Q/0{,}9)$ | −2,7 | −0,7 | 2 | pass band |
| $f = f_{high}(Q/0{,}95)$ | −3,2 | −1,2 | 2 | pass band |
| $f = f_{high}(Q)$ | **−3,3** | **−2,7** | **0,6** | **CUT OFF** |
| $f = f_{high}(Q/1{,}05)$ | −5,7 | −2,7 | 3 | transition band |
| $f = f_{high}(Q/1{,}1)$ | −7,8 | −2,8 | 5 | transition band |
| $f = f_{high}(Q/1{,}2)$ | −10,3 | −3,3 | 7 | transition band |
| $f = f_{high}(Q/1{,}3)$ | −12,7 | −4,7 | 8 | transition band |
| $f = f_{high}(Q/1{,}4)$ | −14,5 | −5,5 | 9 | transition band |
| $f = f_{high}(Q/1{,}5)$ | −17,0 | −7,0 | 10 | transition band |
| $f = f_{high}(Q/2)$ | −25,8 | −15,8 | 10 | transition band |
| $f = f_{high}(Q/2{,}5)$ | −33,2 | −23,2 | 10 | transition band |
| $f = f_{high}(Q/3{,}0)$ | −39,4 | −29,4 | 10 | transition band |
| $f = f_{high}(Q/3{,}5)$ | −44,7 | −34,7 | 10 | transition band |
| $f = f_{high}(Q/4)$ | −49,3 | −39,3 | 10 | transition band |
| $f = f_{high}(Q/4{,}5)$ | −53,4 | −43,4 | 10 | transition band |
| $f = f_{high}(Q/5)$ | −57,0 | −47,0 | 10 | transition band |
| $f \geq f_{high}(Q/5{,}4)$ | - Inf | −50 | Inf | stopband |