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Part 1: *Characterization of track geometry*

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Bahnanwendungen - Oberbau - Gleislagequalität - Teil 1: Beschreibung der Gleisgeometrie

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European foreword

This document (EN 13848-1:2019) has been prepared by Technical Committee CEN/TC 256 “Railway applications”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by September 2019, and conflicting national standards shall be withdrawn at the latest by September 2019.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 13848-1:2003+A1:2008.

The main changes with respect to the previous edition are listed below:

— Uncertainty and resolution values are exported to the relevant other parts (EN 13848-2, -3 and -4);

— Addition of *D0* domain;

— New Annex A on decolouring;

— Improvement of Annex B on mainly cyclic top and dip angle;

— New Annex C and D on filtering;

— New Annex F on simulation.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive 2008/57/EC.

For relationship with EU Directive 2008/57/EC, see informative Annex ZA, which is an integral part of this document.

This European Standard is one of the EN 13848 series, *Railway applications — Track — Track geometry quality*, as listed below:

— *Part 1: Characterization of track geometry*;

— *Part 2: Measuring systems — Track recording vehicles*;

— *Part 3: Measuring systems — Track construction and maintenance machines*;

— *Part 4: Measuring systems — Manual and lightweight devices*;

— *Part 5: Geometric quality levels — Plain line, switches and crossings*;

— *Part 6: Characterisation of track geometry quality*.

According to the CEN-CENELEC Internal Regulations, the national standards organisations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

1 Scope

This document gives definitions for the principal track geometry parameters and specifies minimum requirements for measurement and the analysis methods. The aim is to allow the comparability of the output of different measuring systems.

This document does not apply to Urban Rail Systems.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 13848-2, *Railway applications — Track — Track geometry quality — Part 2: Measuring systems — Track recording vehicles*

EN 13848-3, *Railway applications — Track — Track geometry quality — Part 3: Measuring systems — Track construction and maintenance machines*

EN 13848-4, *Railway applications — Track — Track geometry quality — Part 4: Measuring systems — Manual and lightweight devices*

EN 13848-5:2017, *Railway applications — Track — Track geometry quality — Part 5: Geometric quality levels — Plain line, switches and crossings*

3 Terms and definitions

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

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

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

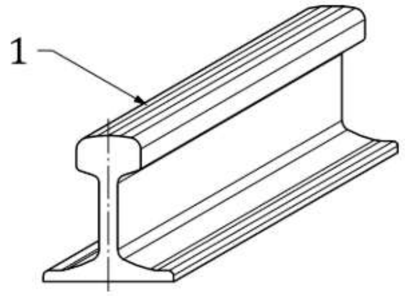
NOTE Refer also to the symbols and definitions described in Clause 4.

3.1
track geometry quality
assessment of excursions in the vertical and lateral planes from the mean or designed geometrical characteristics of specified parameters which give rise to safety concerns or have a correlation with ride quality

3.2
gauge face
inside face of the running rail head

3.3
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

3.4
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.

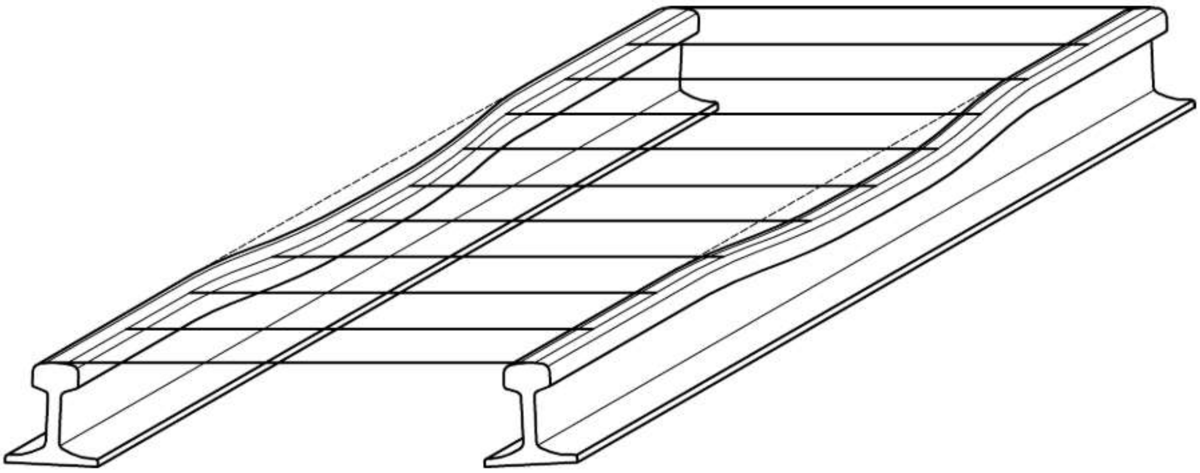


Figure 2 — Running surface

3.5
uncertainty
quantity defining an interval about a result of a measurement expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand [refer to ISO 21748]

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.

Note 2 to entry: The value applicable for track recording vehicles is described in EN 13848-2. For other measurement devices specific values may apply according to EN 13848-3 and EN 13848-4.

3.6
resolution
smallest change in the value of a quantity to be measured which produces a detectable change in the indication of the measuring instrument

Note 1 to entry: The value applicable for track recording vehicles is described in EN 13848-2. For other measurement devices specific values may apply according to EN 13848-3 and EN 13848-4.

3.7
wavelength range
space domain taken by the parameters' components

3.8
sampling distance
travelled distance between any two consecutive measurement points

3.9
range of measurement
specific domain described by its limits

3.10
isolated defect
part of the signal exceeding a given limit such as *IAL*, *IL* or *AL* with at least one sample for a sampling distance of 0,25 m

Note 1 to entry: The length of the exceedance is given by the number of samples exceeding the limit [refer to EN 13848-5:2017].

4 Symbols and abbreviations

For the purposes of this document, symbols and abbreviated terms applied are specified in Table 1.

Table 1 — Symbols

No.	Symbol	Designation	Unit
1	G	Track gauge	mm
2	Z_p	Limit of the range below the running surface within which the gauge is measured. Z_p is always 14 mm for a Vignole rail	mm
3	Z_{ll1}	Deviation in the direction of consecutive running table levels on right hand rail. Used in the measurement of Longitudinal Level	mm
4	Z_{ll2}	Deviation in the direction of consecutive running table levels on left hand rail. Used in the measurement of Longitudinal Level	mm
5	Y_{p1}	Distance between point P and a reference line on right hand rail. Used in the measurement of Alignment	mm
6	Y_{p2}	Distance between point P and a reference line on left hand rail. Used in the measurement of Alignment	mm
7	P	Gauge face contact point	
8	$D0$, $D1$, $D2$, $D3$	Wavelength ranges	m
9	λ	Wavelength	m
10	$V1$	Amplitude from the zero line. Used in the measurement of Twist	mm/m
11	$V2$	Amplitude from the mean value. Used in the measurement of Twist	mm/m
12	ℓ	Twist base-length	m
13	X, Y, Z	Axes of a track coordinate system	

5 Description of the track coordinate system

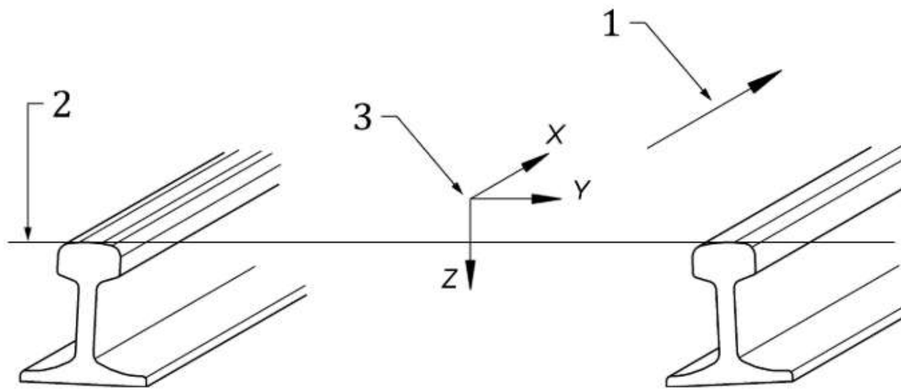
The track geometry quality is described by means of a moving right-hand Cartesian coordinate system centred to the track with clockwise rotation (refer to Figure 3):

— 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

1 running direction

2 intersection between considered cross section and running surface

3 track coordinate system

Figure 3 — Relationship between the axes of the track coordinate system

Rail identification (left or right rail) is not in the scope of the document, but is to be defined for the purpose of exchanging data.

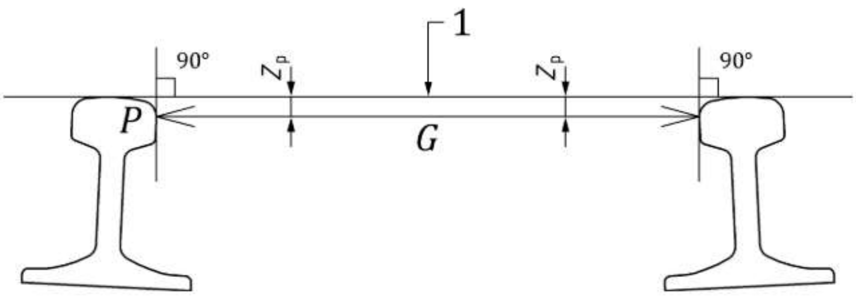
6 Principal track geometric parameters

6.1 Track gauge

6.1.1 General

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 always 14 mm.

In the situation of new unworn rail head the point P will be at the limit Z_p below the railhead, see Figure 4.

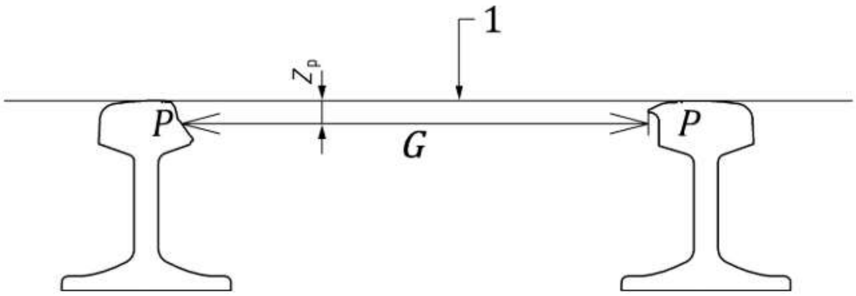


Key

1 running surface

Figure 4 — Track gauge for new rail

In the situation of worn rail head the height of point P for the left rail can be different from the right rail, see Figure 5.



Key

1 running surface

Figure 5 — Track gauge for worn rail

6.1.2 Measurement method

Track gauge can be measured using a contact system or a non-contact system.

6.1.3 Wavelength range

Not applicable.

6.1.4 Resolution

The values of resolution depend on the type of measuring system and are given in the corresponding parts of the standard EN 13848-2, EN 13848-3 and EN 13848-4.

6.1.5 Measurement uncertainty

The values of uncertainty depend on the type of measuring system and are given in the corresponding parts of the standard EN 13848-2, EN 13848-3 and EN 13848-4.

6.1.6 Range of measurement

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

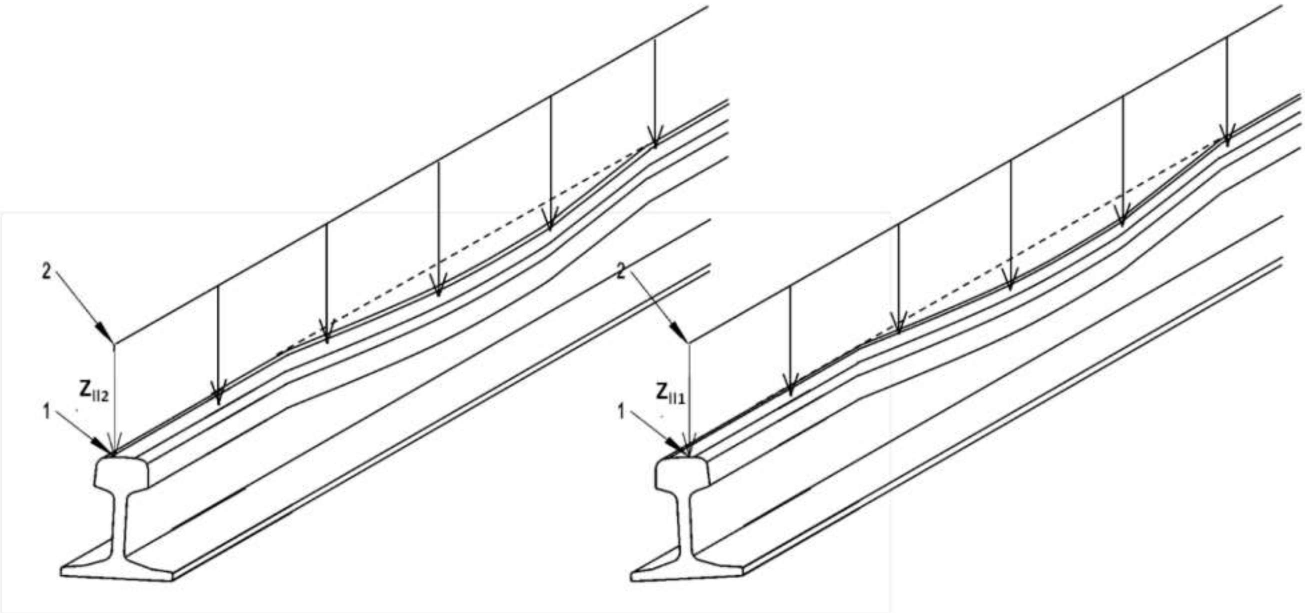
6.1.7 Analysis method

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

6.2 Longitudinal level

6.2.1 General

Longitudinal level is the deviation z_{ll} in z-direction of running table levels on any rail from the smoothed vertical position (reference line) expressed in defined wavelength ranges. The smoothing is applied over a length that covers the wavelength range of interest (minimum two times the upper limit of the wavelength range of interest). The reference line and the longitudinal level are calculated from successive measurements (refer to Figure 6).



Key

1 running table

2 reference line

Figure 6 — Longitudinal level

6.2.2 Measurement method

Longitudinal level measurements shall be made with either an inertial system or a versine system (that should preferably be asymmetric) or by a combination of both methods. If the versine method of measurement is used, a decolouring of the measured signals is necessary in order to eliminate the influence of the transfer function of the versine system (see Annex A).

NOTE In the case of limited analysis length, the longitudinal level can be evaluated also from geodetic measurements.

6.2.3 Wavelength range

Three ranges expressed in wavelengths (λ) shall be considered:

— *D1*: 3 m < λ ≤ 25 m;

— *D2*: 25 m < λ ≤ 70 m;

— *D3*: 70 m < λ ≤ 150 m, used for measuring long wavelength defects. Generally this range should only be considered for line speeds greater than 230 km/h.

NOTE Other wavelengths longer than 70 m can also be taken into consideration by the vertical curvature parameter (refer to Annex B); however, this does not give an equivalent assessment of *D3* domain.

In order to detect short wavelength defects, which can generate high dynamic forces, an optional wavelength range can be considered:

$$D0: 1\ \text{m} < \lambda \leq 5\ \text{m} \quad (1)$$

When measuring in the *D0* domain, the sampling distance should be reduced to 0,1 m. Due to the lack of experience in this domain no additional requirements are given presently.

The filters used for calculating *D0*, *D1*, *D2* and *D3* shall comply with the requirements of Annex C.

6.2.4 Resolution

The values of resolution depend on the type of measuring system and are given in the corresponding parts of the standard EN 13848-2, EN 13848-3 and EN 13848-4.

6.2.5 Measurement uncertainty

The values of uncertainty depend on the type of measuring system and are given in the corresponding parts of the standard EN 13848-2, EN 13848-3 and EN 13848-4.

6.2.6 Range of measurement

The requirements are specified in Table 2.

Table 2 — Longitudinal level: range of measurement

Dimensions in millimetres

Wavelength range	***D1***	***D2***	***D3***
Range of measurement	±50	±100	±200
NOTE The high ranges of measurement stated for *D2* and *D3* are only required if these domains are measured on conventional lines. If *D2* and *D3* are only measured on high-speed lines, smaller ranges can be applied.			

6.2.7 Analysis method

Individual defects are represented by the amplitude from zero to the peak value.

6.3 Cross level

6.3.1 General

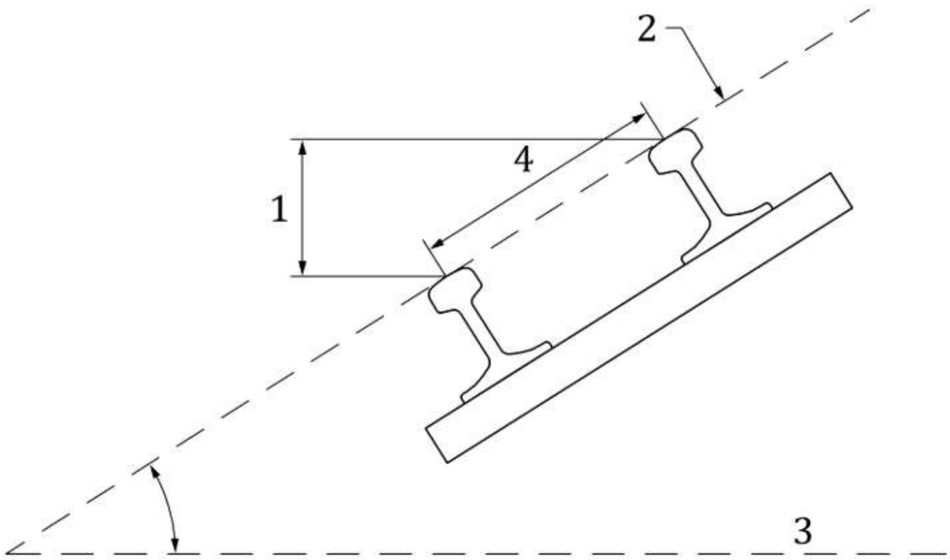
The difference in height of the adjacent running tables computed from the angle between the running surface and a horizontal reference plane. It is expressed as the height of the vertical leg of the right-angled triangle having a hypotenuse that relates to the nominal track gauge plus the width of the rail head rounded to the nearest 10 mm (refer to Figure 7).

Cross level is also called cant or superelevation.

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

For nominal gauges of 1 520 mm 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.



Key

1 cross level

2 running surface

3 horizontal reference plane

4 hypotenuse

Figure 7 — Cross level

6.3.2 Measurement method

Cross level is determined by measuring either the angle between the running surface and the horizontal reference plane or the difference in height between the two running tables.

6.3.3 Wavelength range

Not applicable.

6.3.4 Resolution

The values of resolution depend on the type of measuring system and are given in the corresponding parts of the standard EN 13848-2, EN 13848-3 and EN 13848-4.

6.3.5 Measurement uncertainty

The values of uncertainty depend on the type of measuring system and are given in the corresponding parts of the standard EN 13848-2, EN 13848-3 and EN 13848-4.

6.3.6 Range of measurement

The range of measurements shall be ± 225 mm.

6.3.7 Analysis method

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

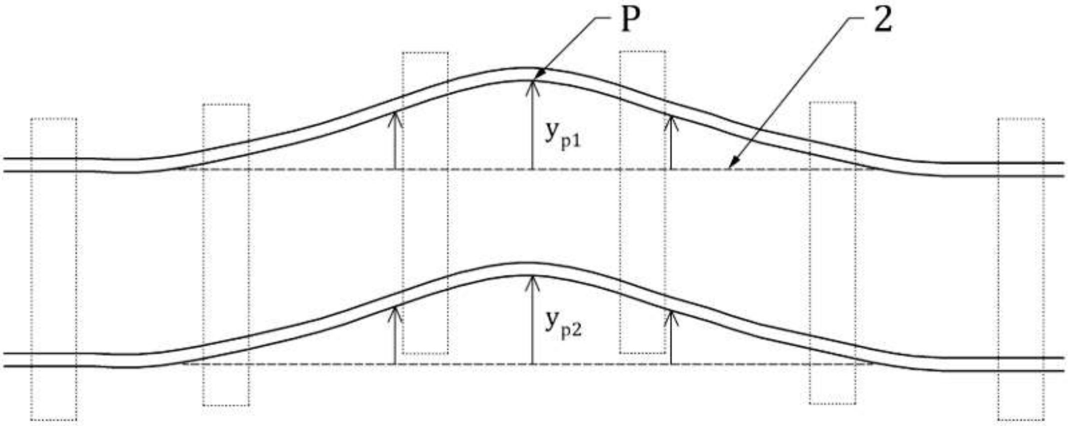
NOTE Usually a sliding mean over 40 m is used as a low pass filter.

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

6.4 Alignment

6.4.1 General

Alignment is the deviation y_p in y-direction of the position of point P (refer to 6.1.1) on any rail from the smoothed lateral position (reference line) expressed in defined wavelength ranges. The smoothing is applied over a length that covers the wavelength range of interest (minimum two times the upper limit of the wavelength range of interest). The reference line and the alignment are calculated from successive measurements (refer to Figure 8).



Key

P point P according to 6.1.1

2 reference line

Figure 8 — Alignment

6.4.2 Measurement method

Alignment measurements shall be made with either an inertial system or a versine system (that should preferably be asymmetric) or by a combination of both methods.

If the versine method of measurement is used, a decolouring of the measured signals is necessary in order to eliminate the influence of the transfer function of the versine system.

6.4.3 Wavelength range

Three ranges expressed in wavelengths (λ) shall be considered:

— *D1*: 3 m < λ ≤ 25 m;

— *D2*: 25 m < λ ≤ 70 m;

— *D3*: 70 m < λ ≤ 200 m, used for measuring long wavelength defects. Generally this range should only be considered for line speeds greater than 230 km/h.

In order to detect short wavelength defects, which can generate high dynamic forces, an optional wavelength range can be considered:

— *D0*: 1 m < λ ≤ 5 m.

When measuring in the domain *D0*, the sampling distance should be reduced to 0,1 m. Due to the lack of experience in this domain no additional requirements are given presently.

The filters used for calculating *D0*, *D1*, *D2* and *D3* shall comply with the requirements of Annex C.

Wavelengths over 70 m can also be taken in consideration by the horizontal curvature parameter (refer to Annex B).

6.4.4 Resolution

The values of resolution depend on the type of measuring system and are given in the corresponding parts of the standard EN 13848-2, EN 13848-3 and EN 13848-4.

6.4.5 Measurement uncertainty

The values of uncertainty depend on the type of measuring system and are given in the corresponding parts of the standard EN 13848-2, EN 13848-3 and EN 13848-4.

6.4.6 Range of measurement

The requirements are specified in Table 3.

Table 3 — Alignment: range of measurement

Dimensions in millimetres

Wavelength range	*D1*	*D2*	*D3*
Range of measurement	±50	±100	±300
NOTE The high ranges of measurement stated for *D2* and *D3* are only required if these domains are measured on conventional lines. If *D2* and *D3* are only measured on high-speed lines, smaller ranges can be applied.			

6.4.7 Analysis method

Individual defects are represented by the amplitude from zero to peak.

6.5 Twist

6.5.1 General

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

6.5.2 Measurement method

Twist measurements is either computed from consecutive measurements of cross level or taken simultaneously at a fixed distance e.g. at a distance equivalent to the wheel-base.

6.5.3 Wavelength range

Not applicable.

6.5.4 Resolution

The values of resolution depend on the type of measuring system and are given in the corresponding parts of the standard EN 13848-2, EN 13848-3 and EN 13848-4.

6.5.5 Measurement uncertainty

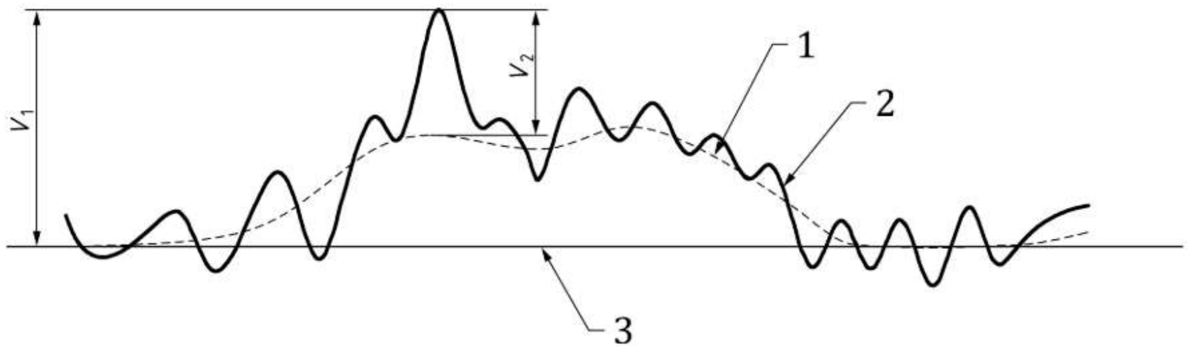
The values of uncertainty depend on the type of measuring system and are given in the corresponding parts of the standard EN 13848-2, EN 13848-3 and EN 13848-4.

6.5.6 Range of measurement

The range shall be ± 15 mm/m.

6.5.7 Analysis methods

Individual defects are represented by the amplitude from the zero-line to the peak value (V_1). For purposes not related to safety the mean to peak value can be used (V_2) (refer to Figure 9).



Key

1 low pass filtered value (mean)

2 twist

3 zero line

Figure 9 — Twist – Analysis method

7 Measurement conditions

In order to reproduce the dynamic effects of vehicles, all of the geometric parameters should preferably be measured on a loaded track, in which case, the applied loading at the measuring point of the rail shall be equivalent to a minimum vertical wheel load of 25 kN when considering a mean track stiffness of 90 kN/mm per rail (wheel load divided by rail deflection) and a rail profile 60E1.

There can be differences in all track geometry parameter values according to whether they are measured in loaded or unloaded, or static or dynamic conditions. These differences should be taken into account when comparing measurements made under different conditions.

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 of travel shall be specified.

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

All principal parameters shall be measured at the same sampling distance. For signal processing and signal analysis reasons this sampling distance should not exceed 0,25 m.

The localization uncertainty of all discrete measurements shall be within ± 10 m.

The uncertainty of the sampling distance shall be within 1 ‰.

Annex A
(informative)

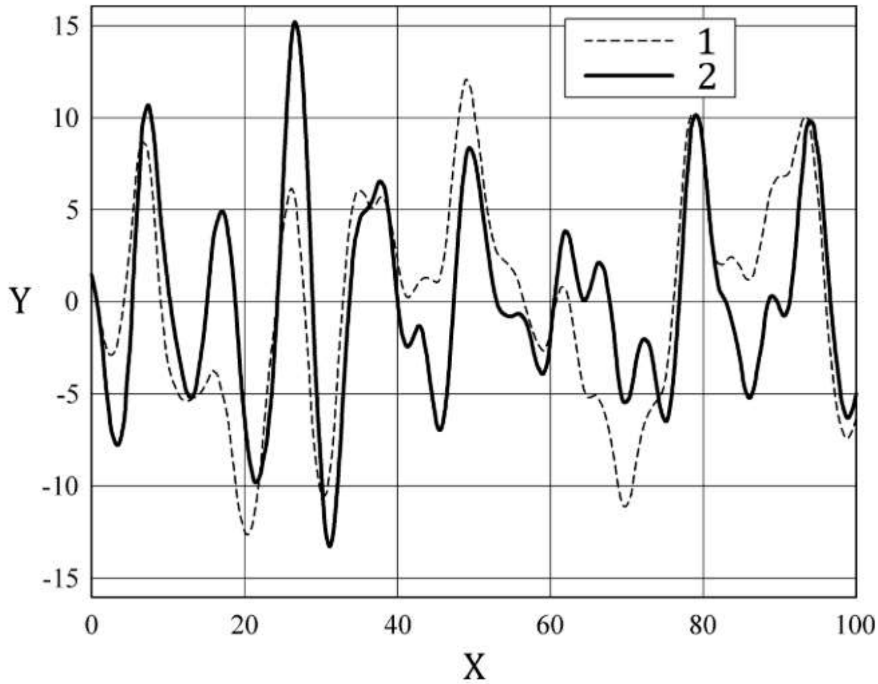
Decolouring process

A.1 Definition of decolouring

If track geometry is recorded with a chord measurement system, the measured signals (versine) of longitudinal level and alignment are distorted in magnitude and phase. The process of compensating these distortions of the signals is called "decolouring", i.e. removing the "colour" due to the chord measurement.

For example, decolouring of a chord measurement is required if the track geometry is assessed according to the EN 13848 series or if used for simulation purposes.

The distortion depends on the chord length and on the chord division. In the case of an asymmetric chord division, it also depends on the running direction of the measurement car. As an example for the distortion, Figure A.1 shows a comparison between chord measurement and the corresponding decoloured signal along a short track section.



Key

1 decoloured signal

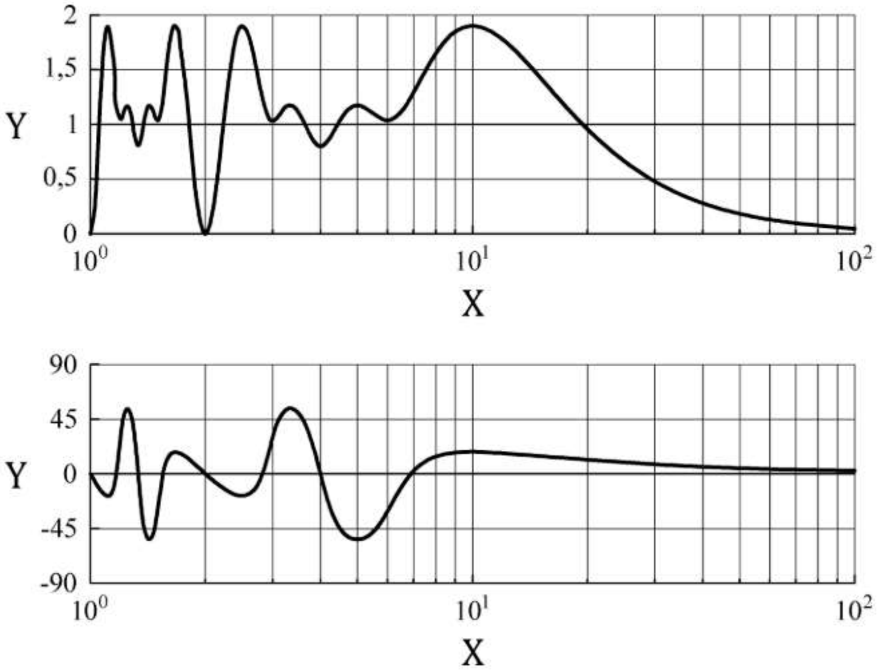
2 chord measurement

X distance [m]

Y amplitude [mm]

Figure A.1 — Example of distortion due to chord measurement

The distortion can be described with the help of the transfer function. The magnitude of the transfer function represents the amplification factor as a function of the wavelength. The magnitude lies between 0 and 2. As an example, Figure A.2 shows the transfer function of a 10 m chord measurement system with a chord division of 4 m and 6 m. A magnitude of zero, seen at 2 m wavelength, means that this wavelength is not recorded at all and cannot be restored. Long waves are also strongly diminished; the maximum wavelength which can be reasonably restored in this case is about 30 m to 50 m. Generally, small values of the magnitude of the transfer function mean a disadvantageous signal-to-noise ratio, where decolouring is likely to malfunction.



Key

X wavelength |m]

Y magnitude [-] and phase [°]

Figure A.2 — Example of transfer function of chord measurement (chord division: 4 m/6 m)

A.2 Decolouring method

There are a number of methods for decolouring. A selection of references to literature is given below.

— Haigermoser A. *Dynotrain Deliverable D2.6 — Final report on track geometry. Tech. rep.* Dynotrain Consortium, 2013

— Wolter, Klaus Ulrich: European Patent: Reconstruction of original signals from relative measurements, EP 1543439 A1, DB Netz AG, June 2005

— Aknin, Patrice; Chollet, Hugues: A new approach for the modelling of track geometry recording vehicles and the deconvolution of versine measurements. Vehicle System Dynamics Supplement 33 (1999), pp. 59-70

— Mauer, Lutz: Determination of Track Irregularities and Stiffness Parameters with Inverse Transfer Functions of Track Recording Vehicles. Vehicle System Dynamics Supplement 24 (1995), pp. 117-132

A.3 Verification of a decolouring process

A.3.1 Introduction

The verification of a decolouring process can be done in two ways:

— using test signals;

— through verifications on recorded track geometry data.

The signals used in these procedures should cover the full wavelength range of interest.

A.3.2 Verification with test signals

The off-line verification as shown in Figure A.3 is possible if a test signal containing undistorted (i.e. not affected by transfer functions of chord measuring systems) track geometry with all relevant wavelengths is available.

The test signal can be either a simulated signal or a real measure coming from a measuring system (inertial or geodetic).

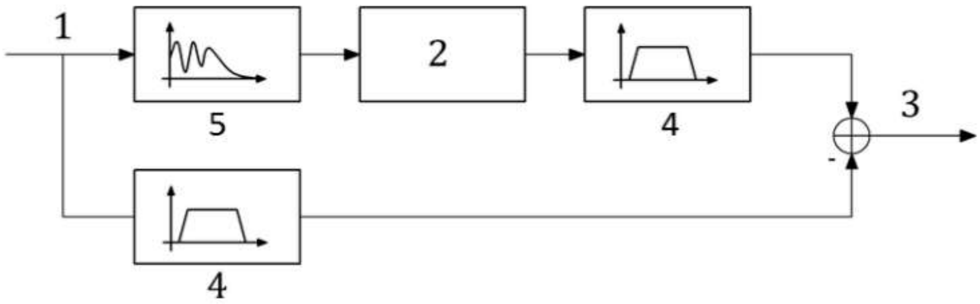
For example, verification of decolouring in *D1* and *D2* can be done through the following steps:

1) Filtering of the test signal in *D1* and *D2* with a filter according to the definition in Annex C;

2) Calculating the versine of the test signal considering the given chord length and division;

3) Applying the decolouring and filtering in *D1* and *D2* to the versine;

4) Comparing the signals obtained at point 1 and point 3.



Key

1 test signal

2 decolouring

3 decolouring error

4 bandpass filter with zero phase

5 application of versine

Figure A.3 — Verification of decolouring with a test signal

The comparison of signals at point 4 can be done in the space domain and in the frequency domain by computing the transfer function and coherence function between the output signals of points 1 and 3.

For other wavelength ranges a similar process can be applied.

A.3.3 Verification with recorded track geometry data

Verification from recorded data are useful if the decolouring algorithm is not known, or a test signal is not available. In this case the cross check between track gauge and difference of decoloured and filtered alignment or between cross level and difference of decoloured and filtered longitudinal level is suggested.

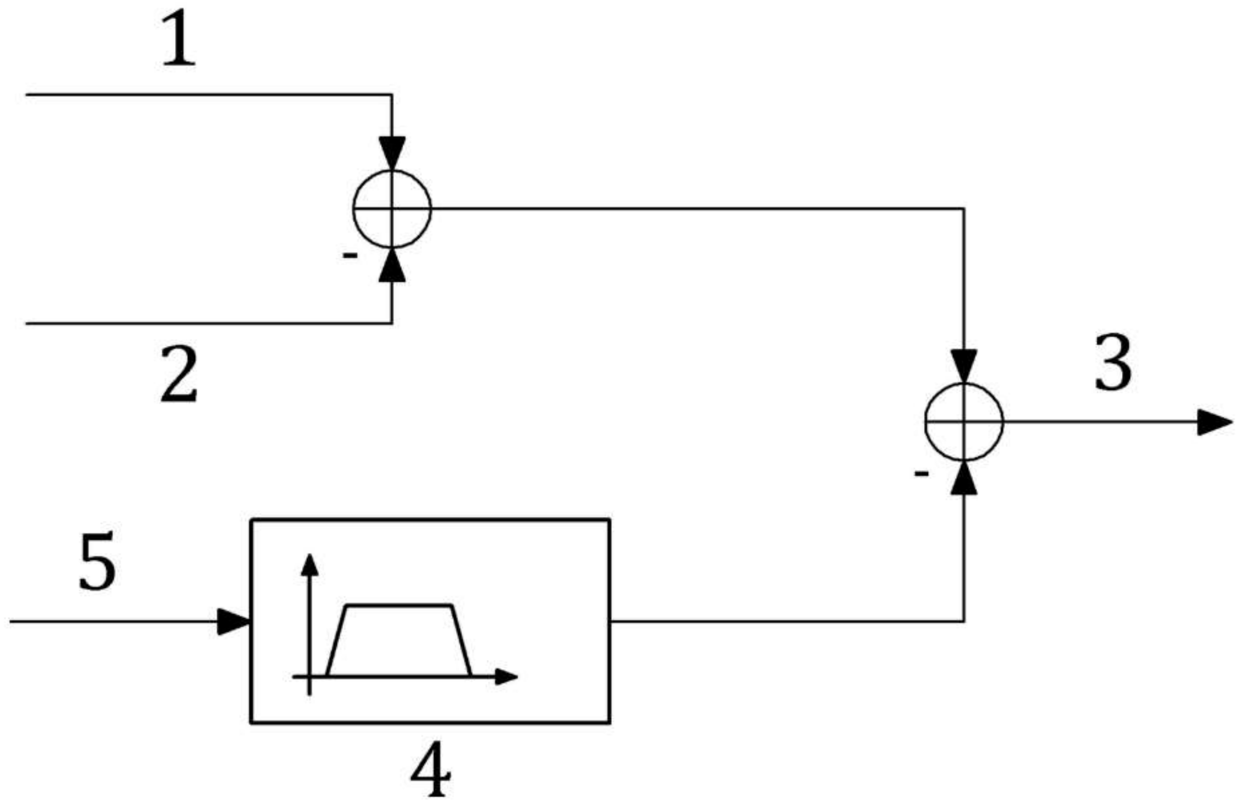
In order to verify the compensation of the amplitude and phase of the transfer function the cross check shall be applied in the space domain.

Cross check between the track gauge and the difference between the alignment of the left and the right rail should be preferred. This is due to the higher accuracy of the track gauge measurement with respect to the cross level.

The verification is done according to the following steps:

1) Filtering of track gauge with a filter according to Annex C;

2) Comparison between the filtered track gauge and the difference between the alignment of the left and the right rail in the same wavelength range. Figure A.4 below gives an example for *D1*.



Key

1 left alignment *D1*

2 right alignment *D1*

3 cross check

4 zero phase

5 track gauge

Figure A.4 —Verification of decolouring with recorded data

The comparison of signals at point 2 can be done in the space domain and in the frequency domain by computing the transfer function and coherence function between the output signals of points 1 and 2.

Annex B
(informative)

Other parameters

B.1 Introduction

The principal track geometric parameters are described in the relevant part of this standard. However, 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. Other supportive data may be necessary in order to facilitate calculation of the derived measurements. A representative list of other parameters is shown in the following.

B.2 Parameters obtained by direct measurement

The following parameters can be measured directly:

— Horizontal curvature (1/m);

— Vertical curvature (1/m);

— Gradient (mm/m);

— Acceleration (m/s^2) (refer to Annex E).

B.3 Parameters obtained by derived measurement to establish in-service values

B.3.1 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 (e.g. longitudinal level at *D1*) has a 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 wheel sets unload; leading to derailment.

The peak values of input that trigger the harmonic response can all be below Intervention Limit IL (EN 13848-5:2017). It is the combined fixed wavelength and repetitive nature of these values that trigger the harmonic reaction.

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 below:

— 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.

All Alert (AL), Intervention (IL) and Immediate action limits (IAL) are derived by experimentation/experience.

Cyclic irregularities are more susceptible when combined with other isolated defects such as Twist or Alignment.

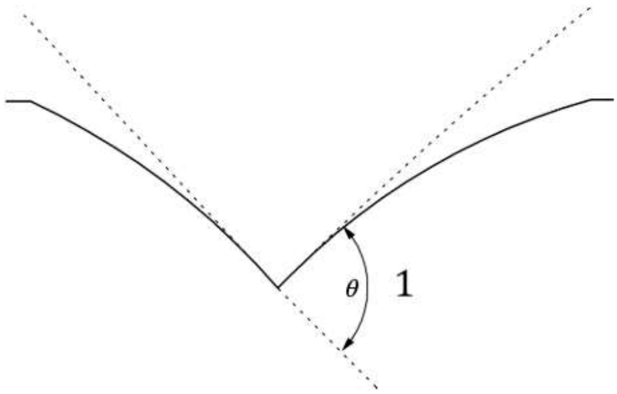
B.3.2 Dip angle

A 'Dip Angle' as defined in Figure B.1 gives pre-indication of a potential rail end break. Detection of dip angles therefore enables early intervention to such a derailment risk, especially in jointed track.

Dip angles are measured over a very short wavelength (*D0*) and derived from an algorithm that calculates the derivative of longitudinal level to determine the localized 'gradient' and hence the 'Dip Angle' θ measured in milliradians. The higher the dip angle the more impact force the rail end will experience with passing traffic.

AL, IL and IAL values are then set, with corresponding intervention time scales and potential speed restrictions.

Rail ends are not rigid and hence the value of the measured dip angle can change dependent upon the speed, load and direction of travel of the measuring vehicle.



Key

1 dip angle

Figure B.1 — Dip angle

B.3.3 Other parameters

The following track design parameters are defined in EN 13803 [3]. Deviations from the design values may be assessed by track measurements:

— Rate of change of gradient;

— Cant deficiency;

— Rate of change of cant deficiency;

— Cant deficiency variation;

— Rate of change of cant;

— Cant gradient;

— Cant variation.

In addition, the evaluation of ride comfort and running dynamics according to EN 14363 or EN 12299 may be used to assess track geometry.

B.3.4 Rail measurements

Increasingly the role of rail head shape, in contributing to ride quality, is being recognized by the incorporation of rail head shape measuring equipment in the track recording vehicle. The following parameters can be measured or calculated with such equipment:

— Rail headwear (mm);

— Side wear (mm);

— Head profile;

— Gauge corner profile;

— Rail inclination;

— Rail corrugation (mm);

— Equivalent conicity.

B.3.5 Supporting data

— Line speed;

— Localization;

— Track features (switches, tunnels, bridges, etc.).

Annex C
(normative)

Filter requirements

C.1 General requirements

In order to ensure a correct application of the track quality levels given in EN 13848-5:2017, and in order to compare data of different measuring systems (of different manufacturers), a standardization of the filters for the different wavelength domains of longitudinal level and alignment is necessary.

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 *D1* and *D2* are given in C.2 below. Due to the lack of experience no tolerance bands and requirements for the slope are given for *D3* and *D0*. It is recommended that the transfer functions remain within these tolerance bands. However, e.g. in order to maintain data history it might be necessary to choose a transfer function which is partly outside of the tolerance band. If the transfer function is below the lower limit given in the tables below, the limit values of part 5 shall be adapted accordingly (see also D.5). If the transfer function is above the upper limit, the output values will be increased. Since this is on the safe side, no further action is required for the safety assessment.

Diagrams of the filter transfer functions (including the tolerance band limits in case of *D1* and *D2*) shall be provided together with the measurement output data.

C.2 Tolerance bands for filter transfer functions

C.2.1 Introduction

The tables in the following clauses give the tolerance bands for the transfer functions in *D1* and *D2*, respectively.

C.2.2 Filter for *D1*

D1 has the following cut-off frequencies:

— f_{low} = 0,04 m^{-1} (wavelength 25 m)

— f_{high} = 0,333 3 m^{-1} (wavelength 3 m)

Table C.1 defines the boundaries for the transfer function.

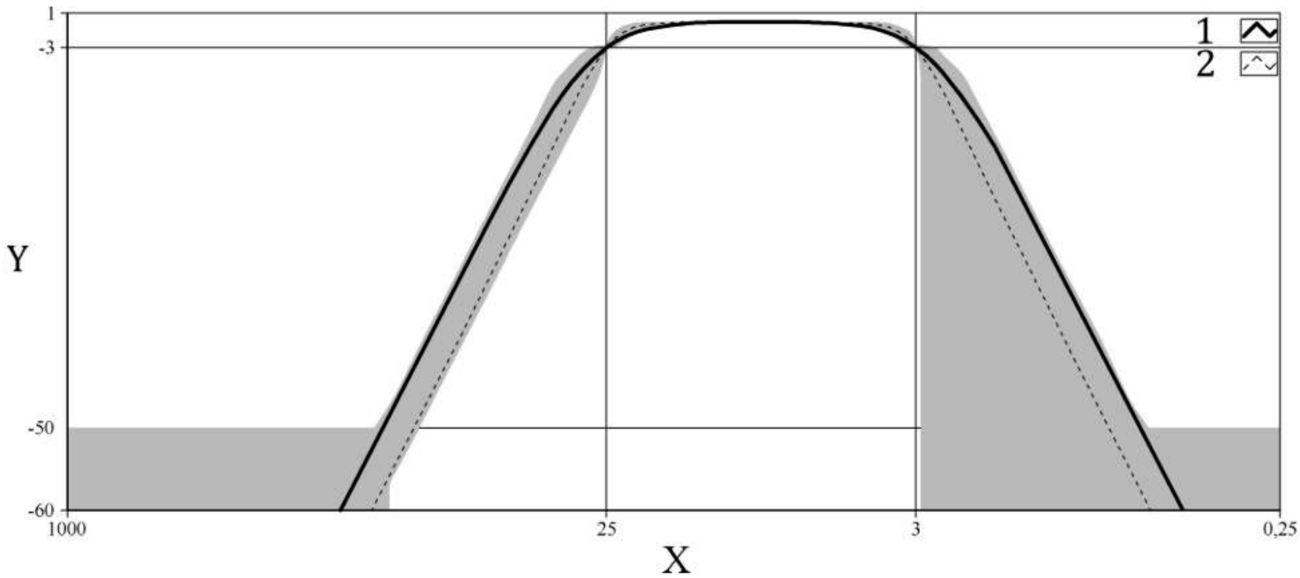
Table C.1 — Boundaries for transfer function in *D1*

λ [m]	*f* [1/m]	Lower limit (dB)	Upper limit (dB)	Tolerance (upper-lower)	Remark
≤ 0,62	≥ 1,602 6	-Inf	−50,0	Inf	stopband
0,68	1,475 7	-Inf	−47,1	Inf	transition band
0,75	1,330 0	-Inf	−43,5	Inf	transition band
0,84	1,184 6	-Inf	−39,4	Inf	transition band
0,96	1,039 5	-Inf	−34,8	Inf	transition band
1,12	0,894 9	-Inf	−29,5	Inf	transition band

λ [m]	***f* [1/m]**	**Lower limit (dB)**	**Upper limit (dB)**	**Tolerance (upper-lower)**	**Remark**
1,33	0,751 1	-Inf	−23,3	Inf	transition band
1,64	0,608 6	-Inf	−15,9	Inf	transition band
2,13	0,468 5	-Inf	−7,0	Inf	transition band
2,27	0,440 9	-Inf	−5,6	Inf	transition band
2,42	0,413 6	-Inf	−4,7	Inf	transition band
2,59	0,386 5	-Inf	−3,3	Inf	transition band
2,78	0,359 7	-Inf	−2,9	Inf	transition band
2,89	0,346 5	-Inf	−2,8	Inf	transition band
3,00	**0,333 3**	**-3,3**	**-2,7**	**0,6**	**CUT OFF**
3,12	0,320 3	−3,2	−1,2	2,0	pass band
3,25	0,307 4	−2,7	−0,7	2,0	pass band
3,55	0,282 0	−1,7	−0,1	1,6	pass band
3,89	0,257 2	−1,0	0,0	1,0	pass band
4,29	0,233 2	−0,7	0,0	0,7	pass band
4,51	0,221 5	−0,5	0,0	0,5	pass band
4,76	0,210 1	−0,4	0,0	0,4	pass band
5,03	0,199 0	−0,3	0,1	0,4	pass band
5,31	0,188 2	−0,2	0,1	0,3	pass band
5,63	0,177 7	−0,1	0,1	0,2	pass band
13,33	0,075 0	−0,1	0,1	0,2	pass band
14,11	0,070 9	−0,2	0,1	0,3	pass band
14,93	0,067 0	−0,3	0,1	0,4	pass band
15,76	0,063 5	−0,4	0,0	0,4	pass band
16,61	0,060 2	−0,5	0,0	0,5	pass band
17,49	0,057 2	−0,7	0,0	0,7	pass band
19,29	0,051 8	−1,0	0,0	1,0	pass band
21,15	0,047 3	−1,7	−0,1	1,6	pass band
23,05	0,043 4	−2,7	−0,7	2,0	pass band
24,02	0,041 6	−3,2	−1,2	2,0	pass band
25,00	**0,040 0**	**-3,3**	**-2,7**	**0,6**	**CUT OFF**
25,99	0,038 5	−5,8	−2,8	3,0	transition band
26,98	0,037 1	−7,9	−2,9	5,0	transition band
28,99	0,034 5	−10,3	−3,3	7,0	transition band

λ [m]	f [1/m]	Lower limit (dB)	Upper limit (dB)	Tolerance (upper-lower)	Remark
31,02	0,032 2	−12,7	−4,7	8,0	transition band
33,07	0,030 2	−14,6	−5,6	9,0	transition band
35,13	0,028 5	−17,0	−7,0	10,0	transition band
45,64	0,021 9	−25,9	−15,9	10,0	transition band
56,33	0,017 8	−33,3	−23,3	10,0	transition band
67,12	0,014 9	−39,5	−29,5	10,0	transition band
77,96	0,012 8	−44,8	−34,8	10,0	transition band
88,84	0,011 3	−49,4	−39,4	10,0	transition band
99,75	0,010 0	−53,5	−43,5	10,0	transition band
110,68	0,009	−57,1	−47,1	10,0	transition band
≥ 120,19	≤ 0,008 3	-Inf	−50,0	Inf	stopband

For *D1*, the lower limit for spatial frequencies over f_{high} (wavelength 3 m) is set to –Inf.



Key

1 cascade of 2nd order Butterworth

2 4th order Butterworth

X wavelength [m]

Y amplitude [dB]

Figure C.1 — *D1* filter boundaries and two possible transfer functions

In Figure C.1, filter 1 is a cascaded 2nd order Butterworth filter and filter 2 is a 4th order Butterworth filter (see D.3).

C.2.3 Filter for *D2*

D2 has the following cut-off frequencies:

— f_{low} = 0,0143 m⁻¹ (wavelength 70 m)

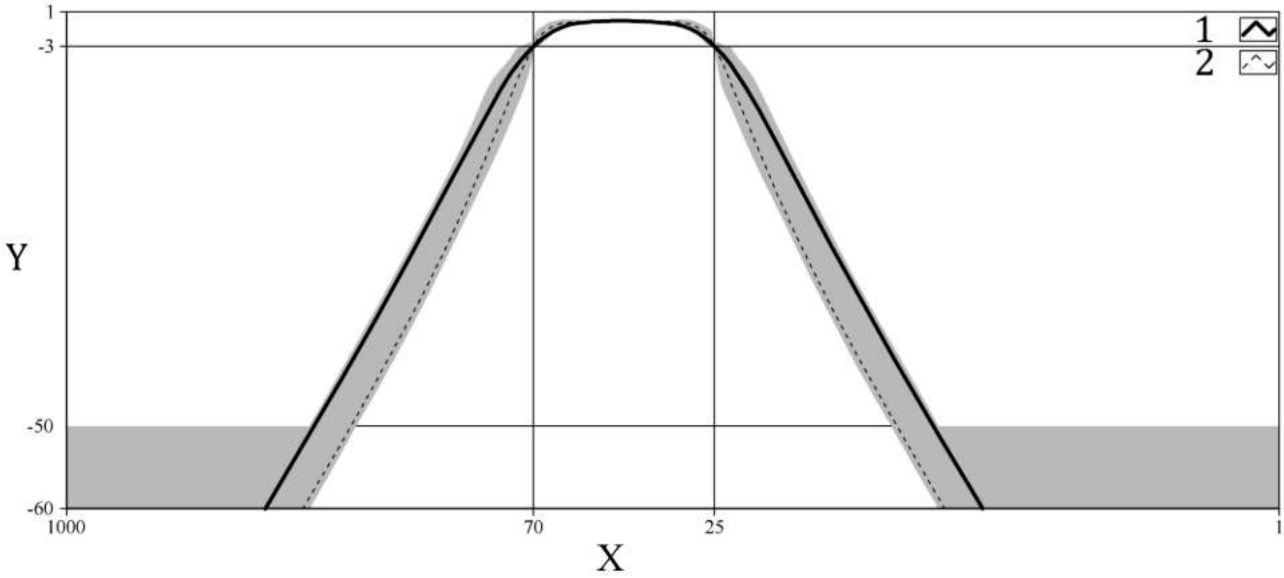
— f_{high} = 0,04 m⁻¹ (wavelength 25 m)

Table C.2 defines the boundaries for the transfer function.

Table C.2 — Boundaries for transfer function *D2*

λ [m]	*f* [1/m]	Lower limit [dB]	Upper limit [dB]	Tolerance (upper-lower)	Remark
≤ 6,96	≥ 0,143 7	- Inf	−50	Inf	stopband
7,53	0,132 9	−57,0	−47,0	10,0	transition band
8,30	0,120 5	−53,4	−43,4	10,0	transition band
9,25	0,108 1	−49,3	−39,3	10,0	transition band
10,42	0,096 0	−44,7	−34,7	10,0	transition band
11,91	0,084 0	−39,4	−29,4	10,0	transition band
13,85	0,072 2	−33,2	−23,2	10,0	transition band
16,44	0,060 8	−25,8	−15,8	10,0	transition band
20,00	0,050	−17,0	−7,0	10,0	transition band
20,87	0,047 9	−14,5	−5,5	9,0	transition band
21,79	0,045 9	−12,7	−4,7	8,0	transition band
22,79	0,043 9	−10,3	−3,3	7,0	transition band
23,86	0,041 9	−7,8	−2,8	5,0	transition band
24,42	0,041 0	−5,7	−2,7	3,0	transition band
25,00	**0,040 0**	**-3,3**	**-2,7**	**0,6**	**CUT OFF**
25,60	0,039 1	−3,2	−1,2	2,0	pass band
26,23	0,038 1	−2,7	−0,7	2,0	pass band
27,54	0,036 3	−1,7	−0,1	1,6	pass band
28,95	0,034 5	−1,0	0,0	1,0	pass band
30,46	0,032 8	−0,7	0,0	0,7	pass band
31,25	0,032 0	−0,5	0,0	0,5	pass band
32,07	0,031 2	−0,4	0,0	0,4	pass band
32,92	0,030 4	−0,3	0,1	0,4	pass band
33,79	0,029 6	−0,2	0,1	0,3	pass band
34,69	0,028 8	−0,1	0,1	0,2	pass band
50,44	0,019 8	−0,1	0,1	0,2	pass band
51,79	0,019 3	−0,2	0,1	0,3	pass band

λ [m]	f [1/m]	Lower limit [dB]	Upper limit [dB]	Tolerance (upper-lower)	Remark
53,17	0,018 8	−0,3	0,1	0,4	pass band
54,57	0,018 3	−0,4	0,0	0,4	pass band
56,00	0,017 9	−0,5	0,0	0,5	pass band
57,46	0,017 4	−0,7	0,0	0,7	pass band
60,45	0,016 5	−1,0	0,0	1,0	pass band
63,54	0,015 7	−1,7	−0,1	1,6	pass band
66,72	0,015 0	−2,7	−0,7	2,0	pass band
68,35	0,014 6	−3,2	−1,2	2,0	pass band
70,00	**0,014 3**	**-3,3**	**-2,7**	**0,6**	**CUT OFF**
71,67	0,014 0	−5,7	−2,7	3,0	transition band
73,36	0,013 6	−7,8	−2,8	5,0	transition band
76,79	0,013 0	−10,3	−3,3	7,0	transition band
80,30	0,012 5	−12,7	−4,7	8,0	transition band
83,86	0,011 9	−14,5	−5,5	9,0	transition band
87,50	0,011 4	−17,0	−7,0	10,0	transition band
106,44	0,009 4	−25,8	−15,8	10,0	transition band
126,36	0,007 9	−33,2	−23,2	10,0	transition band
146,91	0,006 8	−39,4	−29,4	10,0	transition band
167,93	0,006 0	−44,7	−34,7	10,0	transition band
189,25	0,005 3	−49,3	−39,3	10,0	transition band
210,79	0,004 7	−53,4	−43,4	10,0	transition band
232,50	0,004 3	−57,0	−47,0	10,0	transition band
≥ 250	≤ 0,004	- Inf	−50,0	Inf	stopband



Key

1 cascade of 2nd order Butterworth

2 4th order Butterworth

X wavelength [m]

Y amplitude [dB]

Figure C.2 — *D2* filter boundaries and two possible transfer functions

In Figure C.2, filter 1 is a cascaded 2nd order Butterworth filter and filter 2 is a 4th order Butterworth filter (see D.3).

Annex D
(informative)

Background to filtering

D.1 Selection of tolerance bands

The tolerance band for *D1* provided in Annex C has been chosen in such a way that the transfer functions of a 4th order Butterworth filter and of a cascaded 2nd order Butterworth filter (see D.2) are the basis for the limits at the long wavelength side. At the short wavelength side, the amplitudes of track irregularities are much smaller, so that they do not give a significant contribution to the total amplitudes. Therefore, the tolerance band was widely relaxed at this side.

The tolerance band for *D2* has been chosen in such a way that the transfer functions of a 4th order Butterworth filter and of a cascaded 2nd order Butterworth filter (see D.2) define the limits at both the long and short wavelength side. For *D2*, the tolerance band is symmetric, since the amplitude of track irregularities with wavelengths located in any of the upper or lower transition band can be significant.

D.2 Guideline for custom filters

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 can be considered.

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

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

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

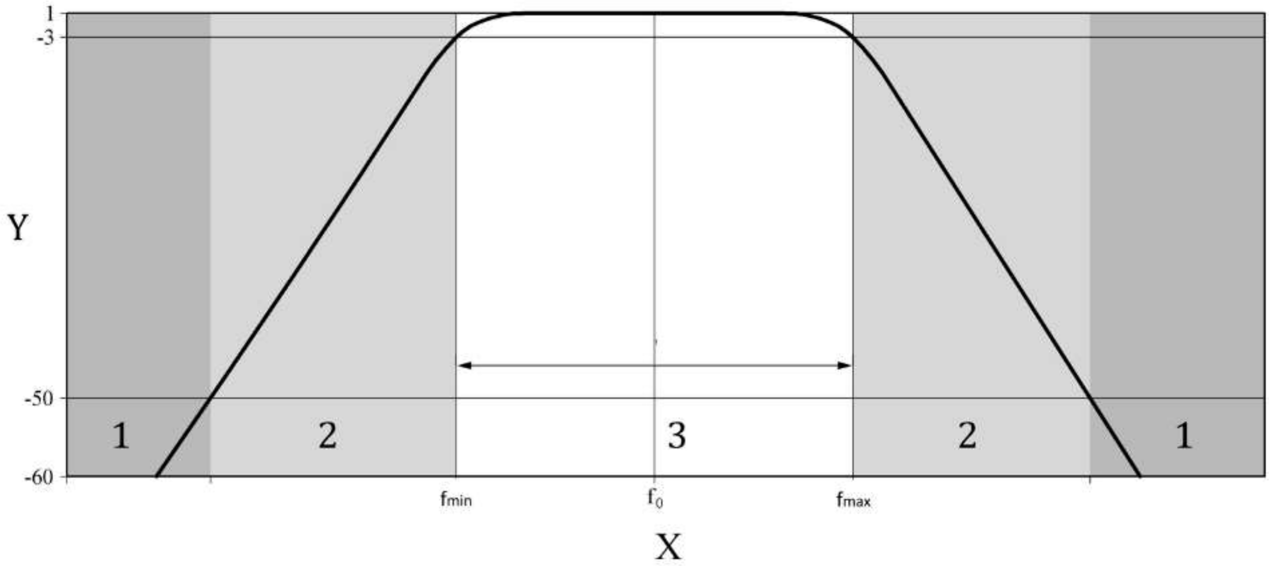
— transition band is the wavelength range between passband and stopband.

The following indexes are also defined:

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

— bandwidth BW is the difference between f_{high} and f_{low};

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



Key

1 stopband

2 transition band

3 passband

X frequency [1/m]

Y amplitude [dB]

Figure D.1 — Bandpass filter

Given the centre frequency and Q factor of a filter, the cut-off frequencies are obtained with the following formulae:

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

$$f_{high}\left(Q\right) = f_0\left(\sqrt{1+\frac{1}{4Q^2}} + \frac{1}{2Q}\right) \tag{D.2}$$

The frequencies have been chosen by multiplying Q with multiplicands as given in the table below.

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

Table D.1 — Tolerance band

f **[1/m]**	**Lower limit [dB]**	**Upper limit [dB]**	**Tolerance [dB] (upper-lower)**	**Remark**
$f \leq f_{low}(Q/5,4)$	- Inf	−50	Inf	stopband
$f = f_{low}(Q/5)$	−57,0	−47,0	10	transition band
$f = f_{low}(Q/4,5)$	−53,4	−43,4	10	transition band
$f = f_{low}(Q/4)$	−49,3	−39,3	10	transition band

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

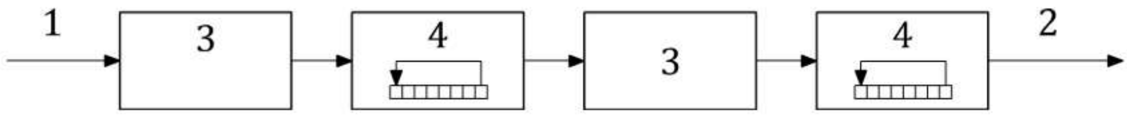
f [1/m]	Lower limit [dB]	Upper limit [dB]	Tolerance [dB] (upper-lower)	Remark
$f = f_{high}(Q/1,1)$	−7,8	−2,8	5	transition band
$f = f_{high}(Q/1,2)$	−10,3	−3,3	7	transition band
$f = f_{high}(Q/1,3)$	−12,7	−4,7	8	transition band
$f = f_{high}(Q/1,4)$	−14,5	−5,5	9	transition band
$f = f_{high}(Q/1,5)$	−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

D.3 Implementation of filters

D.3.1 Off-line implementation

An off-line implementation of the filter is possible using Infinite Impulse Response (IIR) filters in cascade with signal reversal (refer to Figure D.2).

The cascade of two 2nd order Butterworth with signal reversal, as shown in the following figure, fulfils the requirements about the slope as well as the linear phase (in this case zero-phase).



Key

1 input signal

2 filtered signal

3 2nd orders Butterworth −1,5 dB cut-off frequency

4 signal reversal

Figure D.2 — Cascade of two 2nd order Butterworth with signal reversal

This can be considered as target for the online implementation.

D.3.2 Online implementation

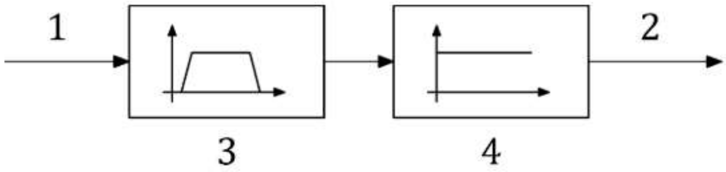
For the online implementation, two different design approaches are possible:

— Finite Impulse Response (FIR) filter;

— Infinite impulse response (IIR) filter with phase equalization.

Using an FIR filter is the best way for fulfilling the requirement about linear phase (to accomplish the linear phase only a symmetric kernel is required).

IIR filters require phase equalization in order to have a linear phase in pass band. The phase correction can be obtained with another IIR all-pass filter. The schemes illustrated in Figures D.3 and D.4 are both possible:



Key

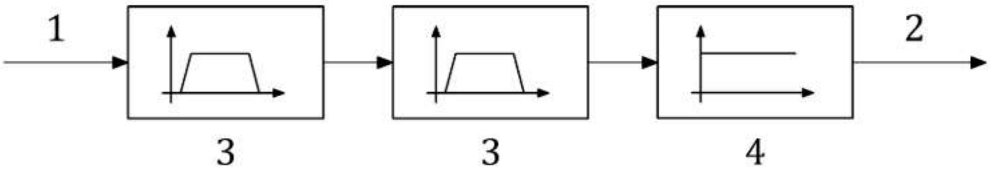
1 input signal

2 filtered signal

3 Butterworth 4th order −3,0 dB cut-off frequency

4 all-pass filter nonlinear phase

Figure D.3 — IIR filters with phase equalization



Key

1 input signal

2 filtered signal

3 Butterworth 2nd order −1,5 dB cut-off frequency

4 all-pass filter nonlinear phase

Figure D.4 — Two cascaded IIR filters with phase equalization

D.4 Reference filter

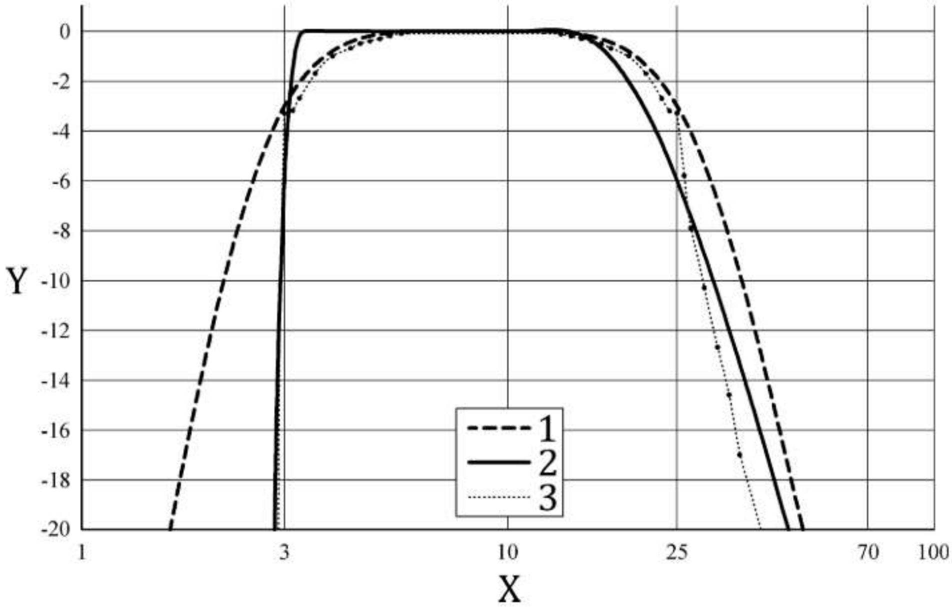
While the tolerance bands of Annex C define a valid range for filter characteristics, it is often necessary to refer to a single reference filter. It may be used e.g. for specifying a target filter for measurement systems, for the comparison of different filters against a reference, or for research purposes. Since the cascaded 2nd order Butterworth with zero-phase as described in D.3 is widely used for (offline) filtering, it is defined as the reference filter.

D.5 Conversion of results of deviating filters

As stated in C.1, filters with transfer functions partly below the tolerance bands might be used, in which case the limit values of EN 13848-5:2017 shall be adapted accordingly. A method to determine the conversion factor is described in the following, including an example for a simple FIR filter.

The conversion factor for the limit values is computed by means of a statistical analysis, where the results of the filter with the deviating transfer function and the results of the reference filter (D.4) are being compared. Both filters are applied to track data which has to cover at least the wavelength range where the filter responses are greater than −50 dB. It is further required to use track data with large amplitudes close to the immediate action limits (IAL) of EN 13848-5:2017. The track data are split into sections of e.g. 200 m for *D1* and 400 m for *D2*. At least 500 sections are required in order to obtain representative results. In each section, the maximum amplitudes are computed for both filters to be compared. The maximum amplitudes of the investigated filter are then plotted over the maximum amplitudes of the reference filter. This is the basis for adapting the limit values.

In the following example, an FIR filter of order 200 with −6 dB instead of −3 dB at the cut-off wavelengths is used. Such a filter can be readily generated with typical signal processing software. The transfer function of this filter is displayed in Figure D.5, together with the transfer function of the reference filter (Butterworth, zero-phase) and of the lower limit of the tolerance band. The main difference is found between 15 m and 30 m wavelength, where the transfer function of the FIR filter clearly lies below the lower tolerance limit.



Key

1 reference filter (Butterworth, zero-phase)

2 FIR, order 200, −6 dB

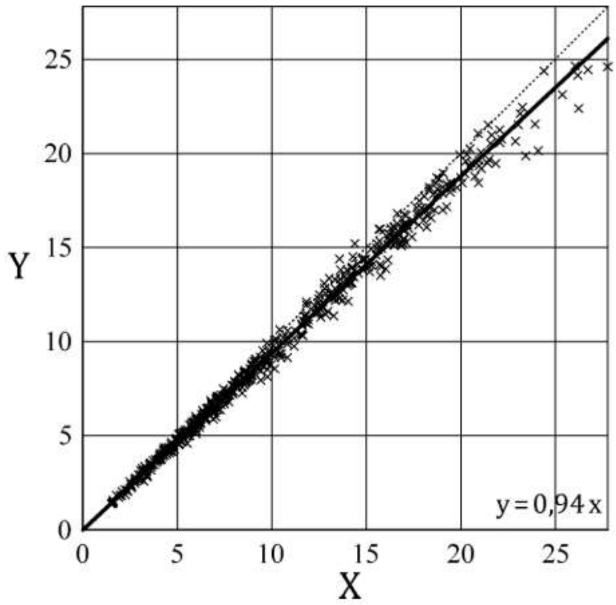
3 lower tolerance

X length [m]

Y magnitude [dB]

Figure D.5 — Transfer functions of filter example

The scatter plot with the peak values for this example is depicted in Figure D.6. Of each point, the x value represents the peak value obtained by the reference filter, and the y value represents the peak value obtained by the FIR filter. The linear regression line is also shown and has a slope of 0,94, which means that the application of the FIR filter leads to peak values which are in average 6 % lower than the reference values.



Key

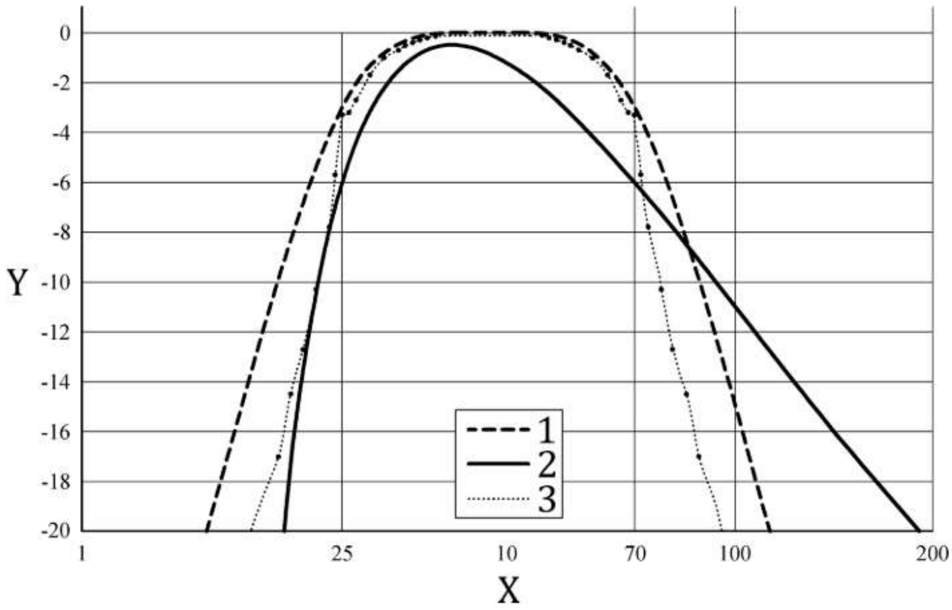
X reference filter (Butterworth, zero-phase)

Y FIR, order 200, −6 dB

Figure D.6 — Scatter plot of peak values in sections

The same kind of analysis with various realistic filters inside the tolerance band has shown very small differences with average errors not more than 1 %.

In a second example, for the wavelength range *D2*, an FIR filter of order 400 with −6 dB instead of −3 dB at the cut-off wavelengths is demonstrated. The transfer function of this filter is displayed in Figure D.7, together with the transfer function of the reference filter (Butterworth, zero-phase) and of the lower limit of the tolerance band. This FIR filter is clearly below the tolerance limit in the whole *D2* wavelength range. Accordingly, the scatter plot in Figure D.8 shows maximum amplitudes significantly lower than with the reference filter. The average error is 14 %.



Key

1 reference filter (Butterworth, zero-phase)

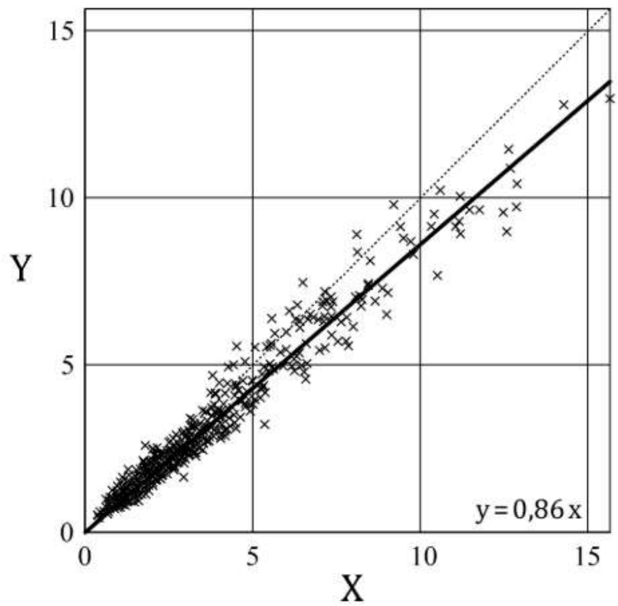
2 FIR, order 400, −6 dB

3 lower tolerance

X length [m]

Y magnitude [dB]

Figure D.7 — Transfer functions of *D2* filter example



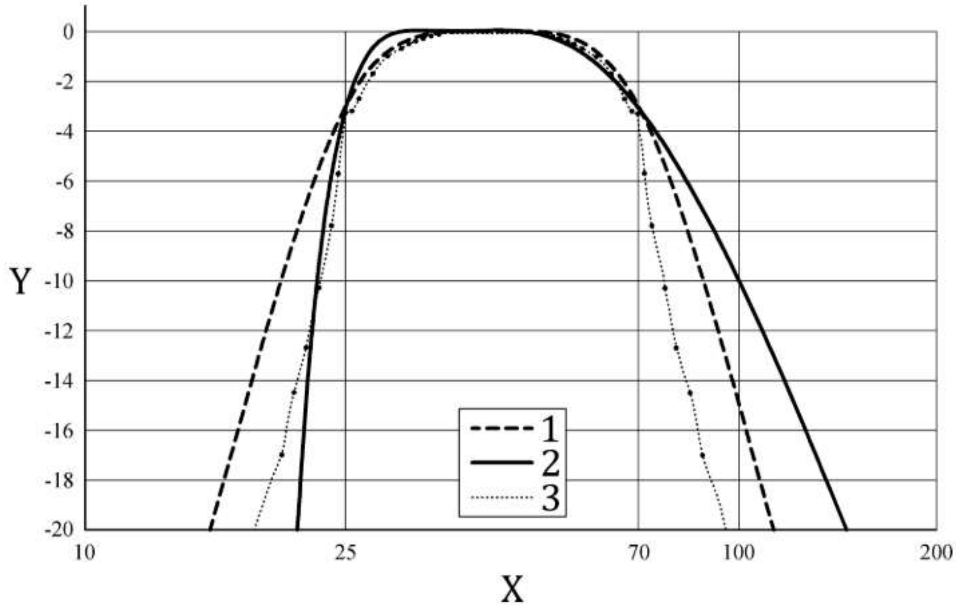
Key

X reference filter (Butterworth, zero-phase)

Y FIR, order 400, −6 dB

Figure D.8 — Scatter plot of peak values in sections, *D2* filter example

Another example for wavelength range *D2* demonstrates an FIR filter of order 700 using Hamming windowing (as in the previous example). The cut-off wavelengths are modified to 23,75 m and 83 m in order to meet −3 dB at 25 m and 70 m, respectively. As shown in Figure D.9, the transfer function is partly below the lower tolerance limit, in particular between 50 m and 65 m. On the other hand, it is clearly above the reference filter at wavelengths above 70 m. Figure D.10 shows that the resulting maximum amplitudes are in average 4 % larger than with the reference filter.



Key

1 reference filter (Butterworth, zero-phase)

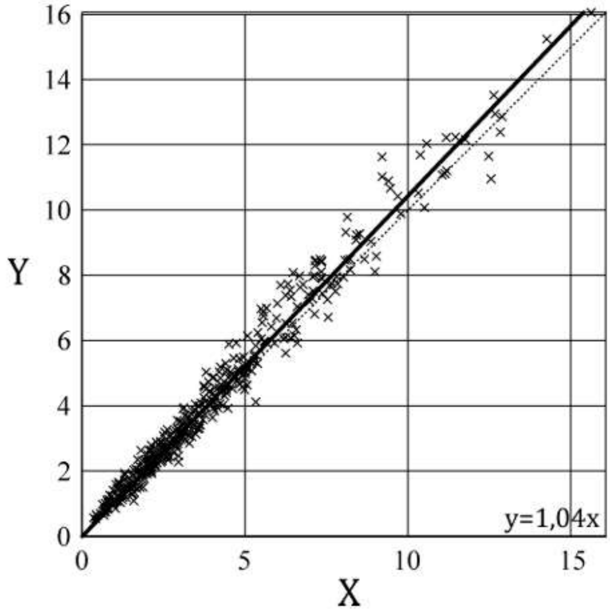
2 FIR, order 700, −3 dB (adapted cut-off wavelength)

3 lower tolerance

X length [m]

Y magnitude [dB]

Figure D.9 — Transfer functions of *D2* filter example 2



Key

X reference filter (Butterworth, zero-phase)

Y FIR, order 700, −3 dB

Figure D.10 — Scatter plot of peak values in sections, *D2* filter example 2

D.6 Comparison of different measurement systems

If results of different measurement systems are compared, it is recommended to use identical filters in order to exclude differences due to the filtering. If it is not possible to use identical filters, the difference due to the filtering shall be considered in the comparison.

Annex E
(informative)

Measurement of acceleration

E.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 should 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.

E.2 Measurement method

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

— C1 – vertical axle box acceleration – for the detection of rail surface defects (e.g. corrugation) and isolated geometrical defects.

— C2 – transverse bogie acceleration for the detection of short wavelength track geometry defects (alignment or cross level).

— C3 – transverse and vertical car body acceleration for the detection of defects that have an influence on comfort.

E.3 Frequency range

— C1 – vertical axle box acceleration 0 to 500 Hz

— C2 – bogie acceleration 0 to 100 Hz

— C3 – car body acceleration 0 to 50 Hz

E.4 Range of measurement

— C1 – vertical axle box acceleration ±1 000 m/s^2

— C2 – bogie acceleration ±50 m/s^2

— C3 – car body acceleration ±20 m/s^2

E.5 Sampling frequency

The sampling frequency should be at least 5 times the cut-off frequency applied to the signal e.g. ≥ 2 500 Hz for axle box acceleration (i.e. 5 × 500 Hz).

E.6 Measurement conditions

— C1 – (vertical axle box acceleration) the measuring speed should be adapted to the used sensors and the analysis method.

— C2 and C3 – (bogie and car body acceleration) measurement should be made at the operating speed for the line within a tolerance of ± 10 %.

E.7 Analysis method

— C1 – (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.

— C2 and C3 – (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.

E.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.

E.9 Output presentation

— C1 – (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.

— C2 and C3 – (bogie and car body acceleration) presented as isolated defects that exceed a prescribed threshold.

Annex F
(informative)

Track geometry data for simulation purposes

F.1 Introduction

The dynamic behaviour of a railway vehicle and its interaction with track can be simulated with a computer software system including models for vehicle, track and wheel-rail contact. The use of measured track geometry data allows simulating the vehicle dynamics under real conditions. Important applications for the vehicles are the virtual homologation, investigation of possible designs or parameter changes. Additionally, simulations can be used for the assessment of track geometry based on vehicle responses.

This annex gives information about which data are required in order to successfully perform simulations. The required data are similar to the data used for track geometry assessment and hence can be provided by most track measurement systems. The main difference is the extended wavelength range of longitudinal level and alignment. Moreover, track layout data like curvature can be included.

F.2 Contents of track geometry data for simulation purposes

Measured track geometry data typically includes track irregularity data as well as track layout data. Both are needed in order to perform realistic simulations.

Track irregularity data of longitudinal level and alignment are used as excitation signals for the dynamic analysis of a vehicle-track system. This requires undistorted track geometry and therefore decolouring in case of chord measurement data. The required wavelength content depends on the purpose of the simulation and on the considered speed (see F.3 for details). It differs from the *D1* and *D2* domains.

Track gauge and cross level shall be provided in addition to longitudinal level and alignment. It is not sufficient to compute track gauge as the difference of alignment and cross level as the difference of longitudinal level, since these have a limited wavelength range and therefore do not contain information about e.g. track gauge widening in curves.

Measured track layout data can include (horizontal) curvature, cant and vertical curvature. It can deviate from the nominal track layout, which is typically given in tabular form as a sequence of track layout elements like straight lines, transition curves, etc. In contrast, measured track layout data are sampled at the same interval as the track irregularity data, e.g. at 25 cm. For simulations, measured track layout data are preferred over nominal layout data, because it reflects the real situation on the track, and because a potential shift along the track between two different data sources is avoided. Measured (horizontal) curvature is provided by most recording systems.

All data should be synchronized along the track.

In summary, the following signals are required for simulations:

— longitudinal level of left and right rail (extended wavelength range);

— alignment of left and right rail (extended wavelength range);

— track gauge;

— cross level;

— (horizontal) curvature.

In addition, information about the line speed and the signal of vertical curvature can be required.

The used sign convention shall be stated for all signals.

F.3 Extended wavelength range

For homologation purposes, vehicle dynamics is assessed for frequencies from 0,4 Hz to 20 Hz. The excitation due to track irregularities shall cover this frequency range, because otherwise the simulation results will be incomplete. Depending on the vehicle speed, this frequency range corresponds to various wavelength ranges, see Table F.1. If it is not possible to provide the full wavelength range, Table F.2 can be used to identify the corresponding frequency range for a particular wavelength range. It then has to be discussed individually about how a limited frequency range will affect the validity of simulation results.

Table F.1 — Conversions from frequencies f [Hz] to wavelengths λ [m]

	Wavelength [m]	
Speed	$F = 20$ Hz	$F = 0,4$ Hz
V = 80 km/h	1,1	56
V = 120 km/h	1,7	83
V = 160 km/h	2,2	111
V = 230 km/h	3,2	160
V = 300 km/h	4,2	208
V = 360 km/h	5	250

Table F.2 — Conversions from wavelengths λ [m] to frequencies [Hz]

	Frequency [Hz]					
Speed	λ = 1 m	λ = 3 m	λ = 25 m	λ = 70 m	λ = 150 m	λ = 200 m
V = 80 km/h	22,2	7,4	0,9	0,3	0,1	0,1
V = 120 km/h	33,3	11,1	1,3	0,5	0,2	0,2
V = 160 km/h	44,4	14,8	1,8	0,6	0,3	0,2
V = 230 km/h	63,9	21,3	2,6	0,9	0,4	0,3
V = 300 km/h	83,3	27,8	3,3	1,2	0,6	0,4
V = 360 km/h	100	33,3	4	1,4	0,7	0,5

In general, a wavelength range from 1 m to 200 m is provided by modern track recording systems. This covers the required frequency range for most speed categories.

F.4 Numerical resolution

If track data are given with low numerical resolution, the signals can become step-like, with repeated samples of identical amplitude and jumps which are much larger than in reality. This will lead to unrealistic simulation results. It is therefore recommended to provide track data in a high numerical resolution, e.g. with 10^{-3} mm. This is clearly beyond the precision of the measurement system, but prevents problems in the simulation.

F.5 Pre-processing for simulation

After the track geometry data has been provided, some pre-processing is necessary in order to make the measurement data suited for simulations.

Track measurement data typically contains both irregularity and layout data. It shall be ensured that there is no overlap and no gap of the wavelength content between the respective signals, in particular between alignment and curvature. Filtering may be used, where the cut-off wavelength depends on the line characteristics like curve radii and transition lengths.

For simulation, depending on the software, it can be necessary or may be preferred to convert the track irregularities of the individual rails (as given by most measurement systems) to irregularities at the track centre. Figure F.1 depicts both representations. The nominal track centre C_0 and the nominal tangent t_0 to the top of both rails define the nominal position of the track and its rails. The actual track centre C lies on the actual tangent t to the top of both rails in the middle between the track gauge points Pl and Pr. With respect to C_0, the position of C is defined by the lateral displacement y and the vertical displacement z, and t is rotated by α with respect to t_0. Together with the actual track gauge *g*, the actual position of both rails is defined. If the irregularities are referring to the individual rails, the left and right vertical deviations zl and zr are the vertical distances from the top of rail points Tl and Tr to t_0. The left and right lateral deviations yl and yr plus half of the nominal track gauge g_0 give the lateral distances from Pl and Pr to C_0. The arrows in the figure indicate positive signs of the displacements and rotation.

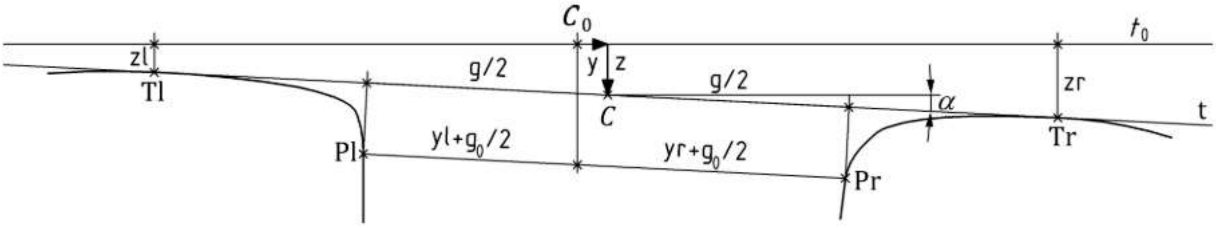


Figure F.1 — Track centre related and rail related irregularities

A conversion from rail related signals to track centre related signals (and vice versa) can be accomplished by the following formulas. The lateral base b is the distance between Tl and Tr, where typically only the nominal value is used. The angle α is assumed to be small. Differences in the wavelength ranges of the signals are not considered in the formulas.

y = (yl+yr)/2	yl = y - (g-g0)/2
z = (zl+zr)/2	yr = y + (g-g0)/2
α = (zr-zl)/b	zl = z - α*b/2
g = yr-yl+g0	zr = z + α*b/2

Annex ZA
(informative)

Relationship between this European Standard and the Essential Requirements of EU Directive 2008/57/EC aimed to be covered

This European Standard has been prepared under a Commission's standardization request M/483 to provide one voluntary means of conforming to the essential requirements of the Directive 2008/57/EC on the interoperability of the rail system (recast) and with the associated TSIs.

Once this standard is cited in the Official Journal of the European Union under that Directive 2008/57/EC, compliance with the normative clauses of this standard given in Table ZA.1 confers, within the limits of the scope of this standard, a presumption of conformity with the corresponding Essential Requirements of that Directive and associated EFTA regulations and with the TSI requirements.

Table ZA.1 — Correspondence between this European Standard, Commission Regulation (EU) No 1299/2014 of 18 November 2014 on the technical specifications for interoperability relating to the 'infrastructure' subsystem of the rail system in the European Union, and Directive 2008/57/EC

Corresponding text, articles/§/annexes of the Directive 2008/57/EC	Chapter/§/annexes of the TSI	Clauses/subclauses of this European Standard	Comments
Annex III, Essential requirements 1 General requirements 1.1 Safety Clauses 1.1.1, 1.1.2 (first sentence), 1.2.Reliability and Availability	4. Description of the Infrastructure subsystem 4.2. Functional and technical specifications of subsystem 4.2.8. Immediate action limits on track geometry defects 4.2.8.1. The immediate action limit for alignment 4.2.8.2. The immediate action limit for longitudinal level 4.2.8.3. The immediate action limit for track twist 4.2.8.4. The immediate action limit of track gauge as an isolated defect 4.2.8.5. The immediate action limit for cant.	Clause 6 Principal track geometric parameters 6.1 Track gauge 6.2 Longitudinal level 6.3 Cross level 6.4 Alignment 6.5 Twist Clause 7 Measurement conditions Annex C (normative) - Filter requirements	Clause 4.2.8.3 of the merged TSI INF mandates EN 13848-1:2003+A1:2008 Clause 4. for the definition of track twist. According to subclause 6.3.1 of the standard, cross level is also called cant or superelevation.

WARNING 1 — Presumption of conformity stays valid only as long as a reference to this European Standard is maintained in the list published in the Official Journal of the European Union. Users of this standard should consult frequently the latest list published in the Official Journal of the European Union.

WARNING 2 — Other Union legislation may be applicable to the products falling within the scope of this standard.

Bibliography

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[2] EN 14363, *Railway applications — Testing and Simulation for the acceptance of running characteristics of railway vehicles — Running Behaviour and stationary tests*

[3] EN 13803, *Railway applications — Track — Track alignment design parameters — Track gauges 1 435 mm and wider*

[4] EN 13848-6, *Railway applications — Track — Track geometry quality — Part 6: Characterisation of track geometry quality*

[5] ISO 21748, *Guidance for the use of repeatability, reproducibility and trueness estimates in measurement uncertainty evaluation*

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- Norsk Standard fastsettes av Standard Norge og er varemerkebeskyttet.
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