Railway applications — Track — Track geometry quality —

Part 2: Measuring systems — Track recording vehicles

The European Standard EN 13848-2:2006 has the status of a British Standard

ICS 93.100

British Standards

National foreword

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The UK participation in its preparation was entrusted to Technical Committee RAE/2, Railway track components, which has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep UK interests informed;

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Contents

Page

Foreword

This document (EN 13848-2:2006) 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of an identical text or by endorsement, at the latest by November 2006, and conflicting national standards shall be withdrawn at the latest by November 2006.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association.

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

— *Part 1: Characterisation 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 light weight devices*

— *Part 5: Geometric quality assessment*

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

Introduction

This part 2 of the European Standard EN 13848 defines the specification for measurement systems to ensure that all track-recording vehicles produce comparable results when measuring the same track. In order to achieve this, it is essential to ensure that the methods of measurement are equivalent, the transfer functions of the filters are identical and the outputs and data storage formats are comparable. This standard doesn't define the requirements for vehicle acceptance.

1 Scope

This European Standard specifies the minimum requirements for measuring principles and systems in order to produce comparable results. It applies to all measuring equipment fitted on dedicated recording vehicles, or on vehicles specifically modified for the same purpose, after the coming into force of the standard. It also defines the requirements of measurement.

2 Normative references

The following referenced documents are indispensable for the application 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 13848-1, *Railway applications – Track – Track geometry quality – Part 1: Characterisation of track geometry*

Other informative references concerning the environmental conditions (refer to 5.2) are provided in the Bibliography.

3 Terms and definitions

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

3.1
track recording vehicle
self propelled or hauled vehicle with fixed, dedicated, measuring equipment and systems, used for the measurement, assessment and recording of track geometry parameters under loaded conditions, which measures and produces consistent results, to the requirements of EN 13848-1

3.2
sensor
device which detects, measures and translates characteristics of track geometry into quantities that can be used for further data processing

3.3
repeatability
degree of agreement between the values of successive measurements of the same parameter made under the same conditions (speed, direction of measurement), where the individual measurements are carried out on the same section of track subject to the following controls*:*

- same measurement method;
- same vehicle orientation;
- same method of interpretation;
- similar environmental conditions;
- short period of time between successive runs.

3.4
reproducibility
degree of agreement between the values of successive measurements of the same parameter made under varying conditions, where the individual measurements are carried out on the same section of track using the same measurement and interpretation methods, subject to one or more of the following*:*

— variation of speed;

— different directions of measurement;

— different vehicle orientations;

— different environmental conditions;

— short period of time between successive runs.

3.5
comparability
degree of agreement of different track recording vehicles achieved under the same conditions

3.6
validation
set of tests for determining if a track recording vehicle complies with the requirements of this standard

3.7
calibration
set of procedures for adjusting the measuring devices of track recording vehicles in order to meet the requirements of this standard

3.8
event
record of a track or line-side feature that can be either technical, physical or natural

3.9
localisation
information required to locate events and the measured track geometry

3.10
reference track
track with known characteristics necessary to allow adequate testing of the track geometry recording system

4 Symbols and abbreviations

For the purposes of this European Standard, the following symbols and abbreviations apply.

Table 1

No.	Symbol	Designation	Unit
1	*D1*	Wavelength range 3 m < $\lambda \leq$ 25 m	m
2	*D2*	Wavelength range 25 m < $\lambda \leq$ 70 m	m
3	*D3*	Wavelength range 70 m < $\lambda \leq$ 150 m for longitudinal level Wavelength range 70 m < $\lambda \leq$ 200 m for alignment	m
4	*Lo*	Lower limit of wavelength range *D1, D2, D3*	m
5	*Lu*	Upper limit of wavelength range *D1, D2, D3*	m
6	λ	Wavelength	m
7	ℓ	Twist base-length	m

5 Track recording vehicle

5.1 General description

For the purpose of this standard, the track geometry recording system of the vehicle is divided into several units as represented in Figure 1 below:

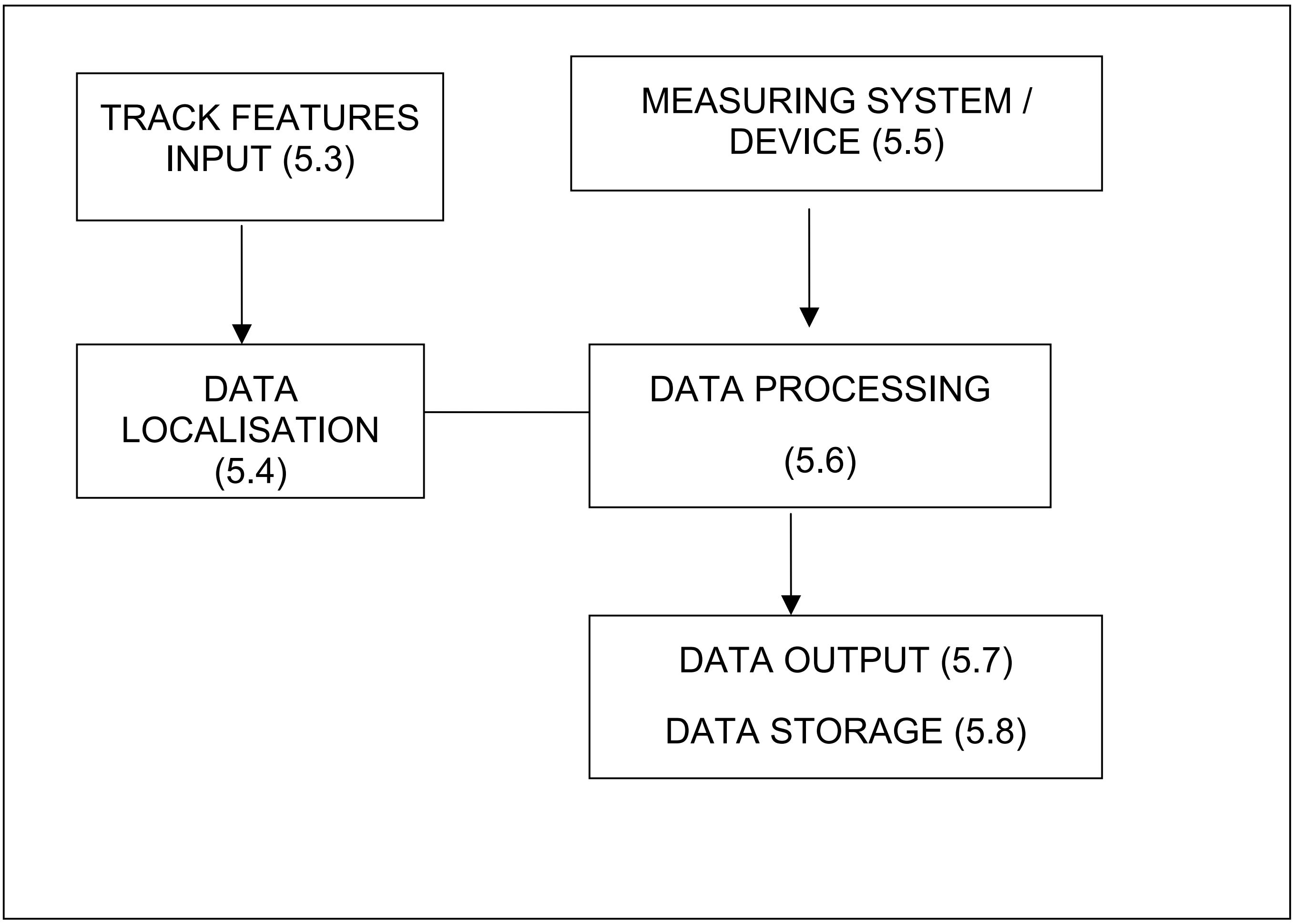

Figure 1 — Track geometry recording system

The track recording vehicle shall produce consistent results, irrespective of the measuring speed and direction of travel. These results can be used for track quality monitoring, maintenance planning and safety assurance as related to track geometry.

The track geometry recording system represents the totality of the equipment permanently installed on a track recording vehicle, intended to:

- measure track geometry parameters;
- measure the distance run by the vehicle during measuring operations;
- associate these two measurements in order to locate precisely on the track the values exceeding a prescribed threshold or other elements characterising the track;
- record these parameters on paper or on computer readable media;
- calculate, based on the direct measured parameters, other parameters of the track geometry (twist, curvature);
- process the measured data, preferably on board, in order to analyse the track geometry parameters;
- store the results analysis, preferably on board, in a form easily transferable to a database.

The output of the track geometry recording system shall meet the individual parameter requirements of EN 13848-1. All the measurements specified in EN 13848-1 shall be taken and stored during the run. They shall be graphically recorded and analysed in strict relation to the corresponding distance location.

The track geometry recording system shall be controlled and shall, either by means of contact-type or non-contact type sensors, allow track geometrical measurements as specified in EN 13848-1 under loaded conditions of the track.

The speed range shall be from standstill to the maximum permissible measuring speed of the vehicle if a chord-type measuring system is used; if an inertial-type measurement is used, a minimum speed may be necessary to measure some parameters (5 km/h is recommended).

The computer system shall be of a kind and type suitable for railway vehicle bound applications and shall represent a widely used and supported technology.

To prevent the interruption of the track geometry measurement and the loss of recorded data in case the measuring hardware power supply fails, it is recommended that an adequate uninterruptible power supply be provided.

5.2 Environmental conditions

5.2.1 Introduction

All the measuring devices fitted on a track-recording vehicle shall comply with the environmental conditions specified below.

5.2.2 Climatic conditions

For outside and inside components the following elements shall be respectively considered:

- **Outside components**
  - ambient temperature;

  - condensation, particularly with sudden variation of temperature at the entrance or at the exit of a tunnel;
  - possibility of snow;
  - ambient relative humidity.
- **Inside components**
  - ambient temperature for operating and storage conditions;
  - ambient relative humidity.

5.2.3 Operating conditions

The following elements shall be considered:

- ballast or iron fragments impacts;
- grease on the rail;
- reflection condition of the rail;
- characteristic light conditions;
- dust, water and snow in connection with aerodynamic conditions;
- safety requirements (laser beam, for example);
- user friendliness;
- vibrations and shocks;
- electromagnetic environment;
- compatibility with signalling and communication systems.

5.3 Track features input

The track features input supports the data localisation (see 5.4) and shall include at least:

- line identification;
- track identification;
- kilometreage;
- increasing/decreasing kilometreage;
- events such as switches, level crossings, bridges, tunnels.

Other inputs may be required as, for example, the altitude for inertial devices.

All these data shall be able to be entered by manual or automatic means.

5.4 Data localisation

The reference point for the data localisation system may be the kilometre post or other fixed points.

The data localisation system gives the track recording vehicle's position along the track and shall fulfil the following functions:

— synchronises the position with the reference point by various methods, using for example the satellite based positioning system, active or passive beacons or other singular points;

— measures the distance covered by the track recording vehicle, compensated for direction "*reverse*", and is generally based on a synchronisation signal, which could be given by a wheel-mounted encoder or any other equivalent method;

— corrects manually or automatically the inaccuracies caused by:

  — wear, sliding, conicity of the track recording vehicle wheels;

  — difference of kilometre's length;

  — uncertainty of the distance run transducer.

5.5 Measuring system/device

5.5.1 General

Track geometry measuring relies on sensors, signal transmission and signal processing following various measuring principles as described in Annex B.

5.5.2 Sensors

The sensors shall measure in real time the track geometry parameters or their components. In order to measure the parameters under track loaded conditions, the sensors placed under the vehicle's frame shall be as close as possible to one of the vehicle's loaded axles to respect measurement conditions indicated in EN 13848-1.

The sensors' mechanical and electrical characteristics (frequency response, signal-to-noise ratio, gain, etc.) shall be adequate to enable the generation of track geometry parameters, independently of the environmental conditions on the railway network.

5.5.3 Signal transmission

Signal transmission shall comply with all elements, which are necessary for data interchange between the sensors and the signal processing unit.

It shall at least comply with the following requirements:

— correction of phase shift;

— no distortion of results data;

— compliance with appropriate industry-accepted data interchange standards.

The transmission characteristics shall be appropriate to the maximum measuring speed of the track recording vehicle and the data volume.

5.5.4 Signal processing

5.5.4.1 Introduction

A track geometry parameter is obtained from a combination of signals coming from several sensors. The signal processing (signal filtering, sampling, amplification and calculation) forms the track geometry parameters from the sensors signals.

Track-recording vehicles shall give comparable results when measuring the same track. To do this, it is necessary to ensure that the measurement results are equivalent and the output formats are compatible. These aspects are considered below.

5.5.4.2 Sampling

The sampling for track geometry signals shall be triggered by a distance-based event so that the measurements are spatially orientated at equal intervals along the length of the track.

All measurements shall be sampled at constant distance based intervals not larger than 0,5 m.

5.5.4.3 Filtering

The filter characteristics shall be made identical. Thus, the transition (cut-off) wavelength, type of filter and the rate of attenuation (number of poles) shall be specified.

To prevent aliasing of the data the analogue signal shall be filtered in accordance with the sampling theorem.

In order to have a true representation of the variation in track geometry and to compare results obtained from different track measuring methods the signals shall be corrected and filtered so that the actual form of a track geometry variation is shown taking into consideration the track wavelengths recorded.

The filters applied to the recorded track data shall have the following characteristics:

- lower cut-off wavelength, defined at –3 dB, *Lo* = lower limit of wavelength range *D1, D2, D3* (for high-pass and band-pass filters);
- upper cut-off wavelength, defined at –3 dB, *Lu* = upper limit of wavelength range *D1, D2, D3* (for low-pass and band-pass filters);
- slope of at least 24 dB/octave in the stop-band.

5.6 Data processing

5.6.1 General requirements

The data processing system hardware shall be suitable for use aboard a track recording vehicle.

The software shall be flexible and modular in order to facilitate comparisons.

An increase in the number of input signals as well as of the number of calculations made shall be foreseen in the system design.

5.6.2 Parameter generation

The signals processed in 5.5.3 shall be calculated in order to obtain parameters complying with requirements of EN 13848-1.

5.6.3 Parameter analysis

Parameter analysis shall include the following methods:

- Calculation of standard deviation and mean value;
- Determination of values that exceed a prescribed threshold (acceptance, alert, intervention and safety levels for example) with the following indications: localisation, involved parameter, level of detection and length of defect.

NOTE Another useful processing method is frequency analysis.

If processing is done on board, it shall be possible to modify the calculation parameters, e.g. section lengths, thresholds, during a measuring run.

5.6.4 Preparation for output interfaces

The data processing system shall condition signals and associated information for different outputs:

- data storage;
- parameters visualisation;
- track geometry chart;
- detection of threshold exceeding values;
- calculation of standard deviation and mean values;
- on-line calibration;
- on-line validation.

5.7 Data output

5.7.1 Visualisation

Two kinds of visualisation shall be presented during the recording run:

a) one for the operator who needs it to monitor the track geometry recording system with graphical and text format information.

The general characteristics for the operator interface shall be:

- graphic window with:
  - selection of sensors and/or measured parameters in order to monitor the track geometry recording system;
  - text format information.
- interface with suitable drop-down menus and icons;
- context sensitive on-line help;
- tree structure menu with hot keys for rapid selection of the most used functions.

b) one for the users of the measured data, e.g. permanent way engineers, who are more particularly interested in the track geometry condition.

The general characteristics for the user interface shall be:

— display of all parameters, either on a chart output, or on one or several monitors. The chart advancing or screen scrolling rate should be proportional to the running distance, irrespective of vehicle speed;

— localisation information given on both chart and monitor outputs;

— possibility to have at any moment, all or part of the display in a graphical form;

— software allowing adjustment of the graphic output.

5.7.2 Output of analysis results

Outputs shall be provided in accordance with requirements stated in EN 13848-1 and 5.6.3 above.

5.7.3 Data transmission

The data shall be transferable using removable storage media, a network or radio link complying with an industry standard.

5.8 Data storage

As a minimum, the following data shall be stored in a prescribed retrievable format:

— measured parameters as described in EN 13848-1;

— results of the parameters analysis described above, including settings, if processing is done on board;

— localisation information linked to measured parameters;

— date and time of the measuring run;

— identification of the measuring vehicle;

— user remarks and actions;

— information of measurement validity.

6 Testing of track geometry recording system

6.1 Introduction

This clause covers actions and procedures, which are necessary to ensure effective operation of both the measuring devices and the processing system.

However, it shall be noted that this paragraph does not deal with static and dynamic vehicle acceptance.

Compliance shall be demonstrated by both calibration and field tests:

a) Calibration

This ensures an accurate setting of the sensors and track geometry recording system.

b) Validation by field tests

This demonstrates that the whole system complies with EN 13848-1 requirements.

In addition, repeatability and reproducibility tests shall be undertaken.

In general calibration and field tests should follow the basic steps outlined in Figure 2.

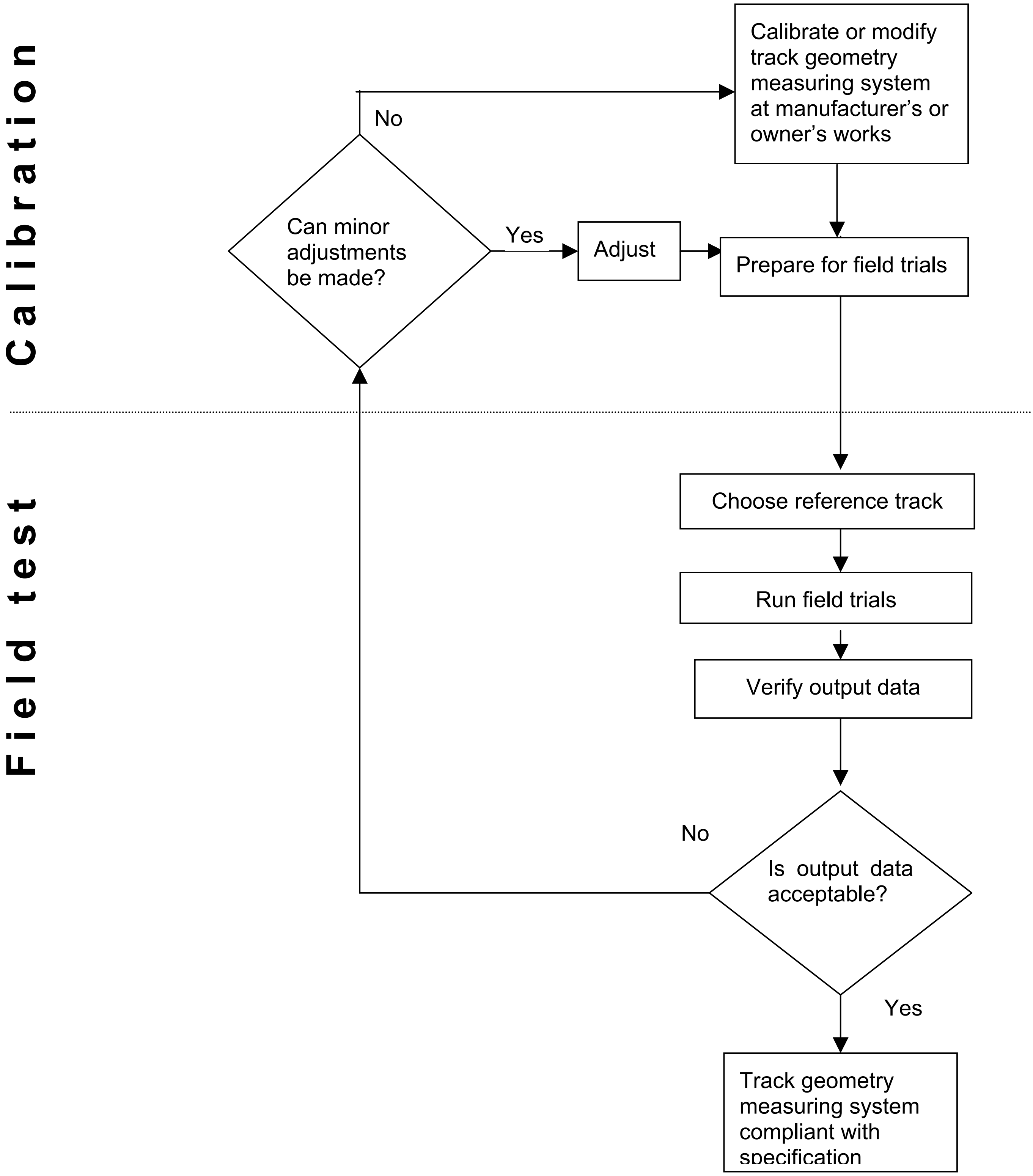

Figure 2 — Testing of track geometry measuring system

6.2 Compliance with EN 13848-1

The track geometry recording systems shall be compliant with the requirements stated in EN 13848-1.

This will ensure the comparability of results.

6.3 Calibration

The measuring device shall be calibrated to ensure the continued accuracy of measurements. A manual describing the calibration requirements for both the measuring device and the processing system shall be prepared by the relevant manufacturer.

The calibration requirements shall cover the method of checking and adjusting the system.

Calibration shall be carried out at specified stages. As a minimum calibration shall take place:

a) after the measuring equipment has been installed in the vehicle;

b) after changes (new or maintained state) to the software or hardware systems or to the measuring equipment or to the vehicle which may affect the track geometry recording system;

c) after periodic maintenance or repair of the vehicle or track geometry recording systems as described in the relevant manual.

6.4 Validation by field tests

6.4.1 Overview

In addition to a static verification of the accuracy of the track geometry recording system, a method based on comparison between different measurements of the same section (repeatability and reproducibility) shall be used to assess a measuring system.

Validation procedures shall be applied to the following:

— initial testing of a new or modified track geometry recording system;

— after a maintenance or repair operation on the track geometry recording system.

NOTE 1 Validation of output data can be achieved by measuring known track geometry characteristics, which occur naturally in a given track. Certain parameters can be validated by simulation on a test bed.

NOTE 2 A method of cross check for linked parameters (for example, alignment of each rail and the gauge or longitudinal level of each rail and the cross level) may additionally be used, in particular during recording runs (see Annex A).

6.4.2 Test conditions

The track geometry recording system shall meet the requirements of EN 13848-1 in all the following test conditions:

— normal vehicle operation;

— various measuring speeds which shall include at least the minimum and maximum possible measuring speeds taking into account the line operating conditions and the recording vehicle speed;

— both measuring directions;

— both measuring orientations of the vehicle.

The track geometry recording system shall be tested over a wide range of:

— track design features: curves of various radii and directions, significant cant, frequent alternation of curves and straight lines etc;

— track geometric quality: good and bad track sections.

NOTE 1 The track geometric quality, minimum curvature and the minimum measuring speed should be defined by those in charge of the infrastructure following their own rules of maintenance.

NOTE 2 A bad track section should be defined as a section having frequent individual defects with values near the maintenance intervention levels respectively to the maximum speed of the considered section.

A reference track should be used and the length of a test run should not be less than 5 km (typical length: 10 km).

Data defining the characteristics, such as curve radii, and geometric quality of the track used for the test runs shall be provided with the test report.

6.4.3 Comparison between different runs

6.4.3.1 Overview

As a minimum, one of the following three methods shall be used to compare recording runs:

— statistical analysis of parameter data;

— statistical analysis of standard deviations;

— frequency analysis of parameter data.

6.4.3.2 Statistical analysis of parameter data

Comparison of parameter data requires precise synchronisation of the two signals before the validation calculations.

The calculation shall be made for each parameter to be validated and for each run used for the comparison. It consists of the following steps:

— calculation of the difference between the values;

— evaluation of the distribution of the differences.

6.4.3.3 Statistical analysis of standard deviations

The standard deviation shall be calculated over a fixed length (typically 200 m).

If this method of comparison is used, this calculation shall be made for each parameter to be validated and for each run used for the comparison.

The comparison consists of the following steps:

— calculation of the difference between the standard deviations;

— evaluation of the distribution of the differences.

6.4.3.4 Frequency analysis of parameter data

Another way to compare two runs is to use frequency analysis such as transfer and coherence functions. A brief description of these functions is given in Annex A.

With this method it is possible to see how much two records of a same zone are similar and in which frequency range they are comparable.

The transfer function indicates the distortions existing in frequency domain, and the coherence function, the degree of reliability for the calculation made on transfer function.

The modulus of the transfer function should be as close as possible to unity and the phase as close as possible to zero for the wavelength ranges specified in EN 13848-1.

The fixed relationship between the frequency resolution and the wavelength range in which the frequency analysis is made shall be taken into account to determine the length of the analysis section (see Annex A).

NOTE 1 This method can also be applied to compare two different track geometry recording systems (see Annex A).

NOTE 2 As the coherence and transfer functions are very sensitive to shift, which could exist between input and output, these signals should be adjusted as close as possible.

6.4.4 Cross check

Some parameters are linked, for example, alignment of each rail and the gauge, or longitudinal level of each rail and the cross level. When two linked parameters are detected by a different set of measuring devices, incorrect operation of a device can be found by a cross check. This method can be effective on a single run (see Annex A).

6.4.5 Field tests

6.4.5.1 New system

Two types of tests shall be carried out:

— Repeatability;

— Reproducibility.

NOTE 1 Additionally, a comparison with a well known system can be made. In this case, the transfer functions of the corresponding track geometry recording systems should be considered (see Annex A).

NOTE 2 A cross check may also be useful.

New system tests shall comply with the requirements of Annex C.

6.4.5.2 During measuring runs (normal use)

Periodic checking shall be carried out by the operators in accordance with the cross check or other procedures.

6.4.5.3 After a maintenance or repair operation

In addition to the calibration detailed in 6.3, repeatability tests shall be carried out.

NOTE A cross check and reproducibility test may also be useful.

The values of Annex C shall be fulfilled.

Annex A
(informative)

Transfer and coherence functions

A.1 General description

A.1.1 Transfer function

A track recording vehicle gives a representation of the track geometry parameters modified by the filters and the filtering effects of the track geometry recording system itself. These modifications are dependent on the wavelength range of the considered parameter.

A transfer function $H(\nu)$ expresses in the frequency domain the distortions existing between an input signal x and an output signal *y* of a system. It is defined by the following formula:

$$Y(\nu) = H(\nu) \times X(\nu)$$

or $H(\nu) = Y(\nu) / X(\nu)$

where

- λ is the wavelength
- ν is the spatial frequency ($\nu = 1/\lambda$)
- X the Fourier transform of the input x
- Y the Fourier transform of the output y

NOTE 1 In the following, lower case letters will represent the signal expressed as a function of distance ℓ, for example: $x(\ell)$, $y(\ell)$, and capital letters will represent the Fourier transform expressed in spatial frequency domain as a function of ν, for example: $X(\nu)$, $Y(\nu)$.

NOTE 2 In order to simplify the formulae, the variables ℓ or ν will be omitted.

The transfer function can also be expressed as follows:

$$H = \frac{X \times \overline{Y}}{X \times \overline{X}} = \frac{S_{xy}}{S_{xx}}$$

where

- $\overline{X}$ is the complex conjugate
- S_{xy} is the cross-spectral density between x and y signals
- S_{xx} is spectral density of x

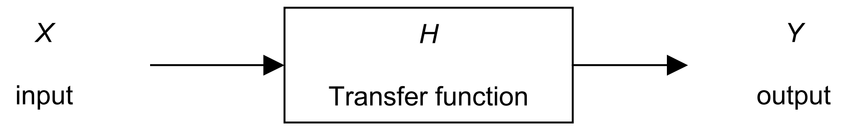

Figure A.1 — Transfer function

The transfer function consists of a real and an imaginary part. In practice, the transfer function is characterised by its module, and its phase.

- The modulus gives the way in which the amplitude of the input is modified by the system, according to frequency.
- The phase represents the delay and hence the way in which the shape of the input is modified, according to frequency.

A.1.2 Coherence function

The coherence function Γ corresponds in the time domain to a correlation function. It represents the degree of linearity between input and output, i.e. the degree of confidence in the result obtained with the transfer function.

It can be represented by the following formula:

$$\Gamma = \frac{\left|S_{xy}\right|^2}{S_{xx} \times S_{yy}}$$

where

— S_{xy} is the cross-spectral density

— S_{xx} and S_{yy} are respectively the spectral densities of x and y

The coherence function is always ≤ 1, and the nearer to unity it is, the more linear is the system.

In practice coherence between 0,85 and 1 could be considered as good. A lower value of coherence can indicate problems:

— Non linearity existence in measuring system;

— Multiple inputs, e.g. noise, present in the signals.

A.2 Practical calculation

Considering two signals x and y, representing respectively the input and output of a system, the practical calculation can be done as follows:

— Averaging of spectral densities calculated over several successive sections.

NOTE In case of track sections, typically for D1 domain 20 sections of 500 m length, for each signal (x and y).

$$S_{xx} = X \times \overline{X} = |X|^2$$

$$S_{yy} = Y \times \overline{Y} = |Y|^2$$

where $\overline{X}$ and $\overline{Y}$ represent the complex conjugates

— Averaging of cross-spectral density between the two parameters. Cross-spectral density has both real and imaginary parts.

$$S_{xy} = X \times \overline{Y}$$

— Calculation of transfer and coherence functions.

$$H = \frac{S_{xy}}{S_{xx}} \quad \text{and} \quad \Gamma = \frac{|S_{xy}|^2}{S_{xx} \times S_{yy}}$$

A.3 Applications within this standard

A.3.1 Comparison between two runs

This comparison can be made for one given parameter in the following cases:

- Repeatability test;
- Reproducibility test;
- Comparison between two track geometry recording systems.

This latter case is more general, because the measuring transfer function can be different for the two systems. It is described below.

When a same track is measured twice by two systems the respective transfer functions H_1 and H_2 of each system can be expressed as follows:

- $H_1 = Y_1 / X$ and $H_2 = Y_2 / X$ Y_1 and Y_2 are respectively the output data coming from the 2 systems

The transfer function H between the data obtained with two successive runs is

- $H = Y_2 / Y_1$

Replacing Y_1 and Y_2 by the expression for H_1 and H_2, H becomes

- $H = H_2 / H_1$

It represents the ratio between the transfer function H_1 and H_2 of each track geometry recording system. So when a measurement is made twice on a same section with two different track geometry recording systems, the transfer function between the outputs of each system (y_1 and y_2) can be compared to the ratio of theoretical transfer function of each system.

This can be summarised as follows:

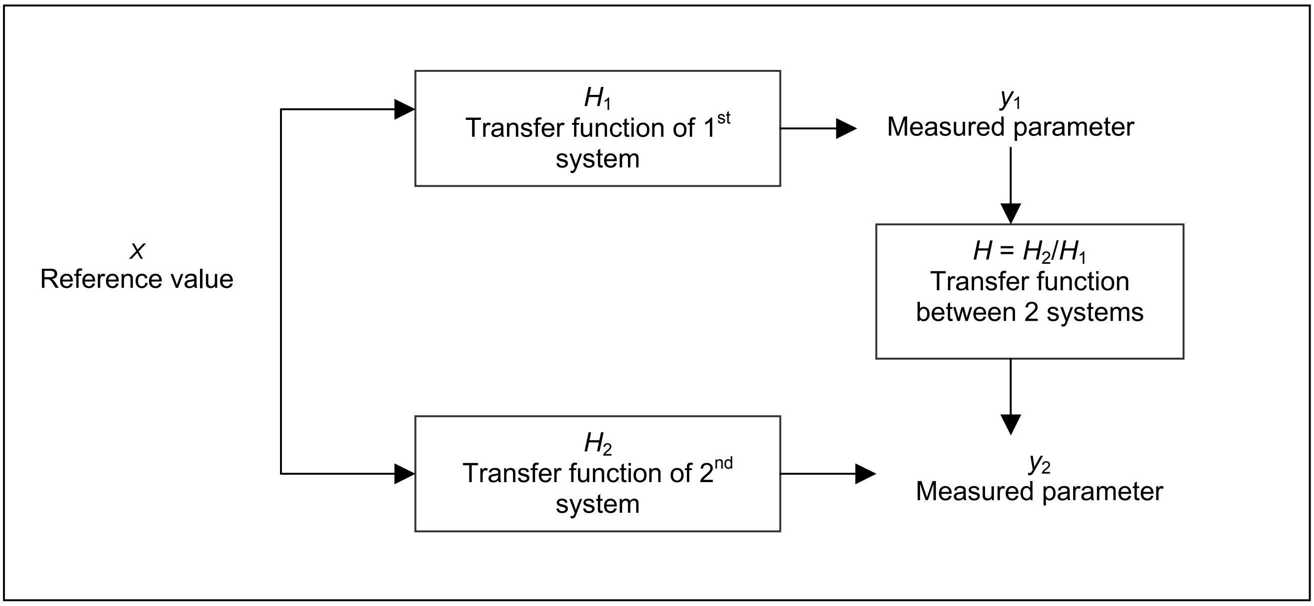

Figure A.2 — Comparison of two track geometry recording systems

For repeatability and reproducibility tests, the same vehicle is used, so $H_2 = H_1$ and the transfer function H between the two runs has to be compared to 1. This allows assessing with the help of coherence the frequency domain in which the repeatability or reproducibility is fulfilled.

A.3.2 Cross check

Gauge and cross level are generally not modified by the track geometry recording system (the transfer function is equal to 1 for all spatial frequencies). On the other hand, alignment and longitudinal level are modified by the transfer function of the measuring systems.

An evaluation of the theoretical transfer function can be made using as input one single signal, for example gauge or cross level, and as output a combination of signals representing the difference of alignment of each rail or the difference of longitudinal level of each rail.

This corresponds, for gauge and alignment, to the following expressions:

— $H_{AL} = (Y_{AL1} - Y_{AL2}) / X_G$ Transfer function of alignment measurement applied to the difference of alignment of each rail

— $X_G = X_{AL1} - X_{AL2}$

— $H_G = Y_G / X_G = 1$ Transfer function of gauge measurement (equal to 1)

where:

— Y_{AL1} , Y_{AL2} : Fourier transform of the output alignment of each rail

— X_{AL1} , X_{AL2} : Fourier transform of the input alignment of each rail

— X_G : Fourier transform of the input gauge

— Y_G : Fourier transform of the output gauge

Combining these expressions leads to $H_{AL} = (Y_{AL1} - Y_{AL2}) / Y_G$

A similar calculation for the cross level leads to: $H_{LL} = (Y_{LL1} - Y_{LL2}) / Y_{CL}$

where:

— Y_{LL1} , Y_{LL2} : Fourier transform of the output longitudinal level of each rail

— Y_{CL} : Fourier transform of the output cross level

The calculated transfer function can be compared to the theoretical one in order to assess, with the help of the coherence function, the spatial frequency domain where the measuring system is reliable.

Annex B
(informative)

Principles of measurement

B.1 General description

The principles of measurement of the parameters, described in EN 13848-1, are discussed below. Up to now, two main principles can be considered:

- chord measuring system;
- inertial measuring system.

This applies to measurement of longitudinal level and alignment, which is described in B.2. Measurement of other parameters is briefly described in B.3 to B.5.

B.2 Longitudinal level and alignment

B.2.1 Chord measuring system

The track geometry is taken from the offset measured at an intermediate point from a straight-line chord.

The offset measurement needs in any case a reference, which can be given by the body of the vehicle, if it is stiff enough, or, if not, by a compensation of its movement. In the latter case, the compensation can be obtained by measuring the body behaviour in bending and twist relatively to an external and absolute reference (e.g. laser beam).

The sensors can be of contact or non-contact type. Normally, contact measurement sensors use the wheels in vertical direction, and specific sensors, like trolleys or rollers for lateral direction.

Considering the measurement itself, one main characteristic of the chord method is its complicated transfer function. This can be readily corrected using analytical methods in order to comply with the requirements of EN 13848-1 in terms of wavelength ranges. However, this requires an asymmetrical base to avoid zeros in particular wavelengths.

A chord measuring system does not require any minimum speed to be operated.

B.2.2 Inertial measuring system

The track geometry is taken from the position of the rail in vertical and lateral direction, relative to an inertial reference, which may be provided by accelerometers or gyroscopes.

Depending on where the inertial system is mounted, e.g. vehicle body or bogie, additional sensors are used to measure the distance between rails and the inertial reference system.

For inertial systems, a minimum speed of measurement is necessary to give reliable results.

B.3 Gauge

Gauge is measured either by use of mechanical sensors (trolleys or rollers) or non-contact sensors (generally optical sensors) which may be fitted to a bogie or the vehicle body.

B.4 Cant

Cant is normally measured using an inertial measuring system. Additional sensors may be necessary in order to compensate for the motion of the inertial system relative to the rails.

B.5 Twist

As explained in EN 13848-1, twist can be either derived from cant measurement or measured directly with contact or non-contact type sensors.

Annex C
(normative)

Description of field tests: values to be respected

C.1 General

In the following tables, values stated for wavelength ranges D2 and D3 may be considered as informative.

C.2 Repeatability

C.2.1 Statistical analysis of parameter data

The distribution of the difference between the parameter data obtained on each run shall be evaluated for each parameter. The 95th percentile of the distribution shall be between the values given in Tables C.1 to C.3.

Table C.1 — Repeatability — Parameter data — Longitudinal level and alignment — 95th percentile

Parameter	Dimensions in millimetres		
	Wavelength range		
	D1	***D2***	***D3***
Longitudinal level	± 0,5	± 1	± 3
Alignment	± 0,7	± 2	± 4

Table C.2 — Repeatability — Parameter data — Gauge and cross level — 95th percentile

Parameter	Dimensions in millimetres
Gauge	± 0,5
Cross level	± 1,5

Table C.3 — Repeatability — Parameter data — Twist — 95th percentile

Parameter	Dimensions in millimetres/metre	
	ℓ ≤ 5,5 m	*5,5 m < ℓ ≤ 20 m*
Twist direct measurement	± 0,7/ℓ	± 0,8/ℓ
Twist computed from cross level	± 1/ℓ	± 2/ℓ
ℓ :Twist base-length		

C.2.2 Statistical analysis of standard deviations

The distribution of the difference between the standard deviations obtained on each run shall be evaluated for each parameter for which the calculation of standard deviation is required in Part 1. The 95th percentile of the distribution shall be below the values given in Tables C.4 and C.5.

Table C.4 — Repeatability — Standard deviation — Longitudinal level and alignment — 95th percentile

Parameter	Dimensions in millimetres		
	Wavelength range		
	D1	***D2***	***D3***
Longitudinal level	0,04	not applicable	not applicable
Alignment	0,06	not applicable	not applicable

Table C.5 — Repeatability — Standard deviation — Twist — 95th percentile

Parameter	Dimensions in millimetres/metre	
	ℓ ≤ 5,5 m	*5,5 m < ℓ ≤ 20 m*
Twist direct measurement	0,04/ℓ	0,04/ℓ
Twist computed from cross level	0,1/ℓ	0,2/ℓ
ℓ :Twist base-length		

C.2.3 Frequency analysis

The transfer and coherence functions obtained on two runs made under the same conditions shall be evaluated for each parameter.

The values given in the following tables (C.6 to C.8) represent the possible range of variation for the modulus of the transfer function and for the coherence function (theoretically equal to one).

Table C.6 — Frequency analysis — Repeatability — Longitudinal level and alignment — Tolerances

Parameter	**Function**	**Wavelength range**		
		D1	***D2***	***D3***
Longitudinal level	**Transfer function**	± 5 %	± 7%	± 10 %
	Coherence function	> 0,97	> 0,95	> 0,90
Alignment	**Transfer function**	± 7 %	± 10 %	± 15 %
	Coherence function	> 0,95	> 0,90	> 0,85

Table C.7 — Frequency analysis — Repeatability — Gauge and cross level — Tolerances

Parameter	Function	Tolerance
Gauge	**Transfer function**	± 5 %
	Coherence function	> 0,95
Cross level	**Transfer function**	± 10 %
	Coherence function	> 0,90

Table C.8 — Frequency analysis — Repeatability — Twist — Tolerances

Parameter	Function	Tolerance	
		$\ell \leq 5{,}5\ m$	$5{,}5\ m < \ell \leq 20\ m$
Twist direct measurement	**Transfer function**	± 5%	± 5%
	Coherence function	> 0,97	> 0,97
Twist computed from cross level	**Transfer function**	± 5%	± 5%
	Coherence function	> 0,97	> 0,97
ℓ :Twist base-length			

C.3 Reproducibility

C.3.1 Statistical analysis of parameter data

The distribution of the difference between parameter data obtained on each run shall be evaluated for each parameter. The 95th percentile of the distribution shall be between the values given in Tables C.9 to C.11.

Table C.9 — Reproducibility — Parameter data — Longitudinal level and alignment — 95th percentile

Parameter	Dimensions in millimetres		
	Wavelength range		
	D1	***D2***	***D3***
Longitudinal level	± 0,8	± 2	± 5
Alignment	± 1,1	± 3	± 7

Table C.10 — Reproducibility — Parameter data — Gauge and cross level — 95th percentile

Parameter	Dimensions in millimetres
Gauge	± 1
Cross level	± 2,5

Table C.11 — Reproducibility — Parameter data — Twist — 95th percentile

Parameter	Dimensions in millimetres/metre	
	$\ell \leq 5{,}5$ m	5,5 m < $\ell \leq 20$ m
Twist direct measurement	± 1/ℓ	± 1/ℓ
Twist computed from cross level	± 1,5/ℓ	± 3/ℓ
ℓ :Twist base-length		

C.3.2 Statistical analysis of standard deviations

The distribution of the difference between the standard deviations obtained on each run shall be evaluated for each parameter. The percentile at 95th of the distribution shall be below the values given in Tables C.12 and C.13.

Table C.12 — Reproducibility — Standard deviation — Longitudinal level and alignment — 95th percentile

Parameter	Dimensions in millimetres		
	Wavelength range		
	D1	***D2***	***D3***
Longitudinal level	0,08	not applicable	not applicable
Alignment	0,1	not applicable	not applicable

Table C.13 — Reproducibility — Standard deviation — Twist — 95th percentile

Parameter	Dimensions in millimetres/metre	
	$\ell \leq 5{,}5$ m	$5{,}5$ m $< \ell \leq 20$ m
Twist direct measurement	$0{,}08/\ell$	$0{,}08/\ell$
Twist computed from cross level	$0{,}2/\ell$	$0{,}3/\ell$
ℓ :Twist base-length		

C.3.3 Frequency analysis

The transfer and coherence functions obtained on two runs made under varying conditions shall be evaluated for each parameter.

The values given in the following tables (C.14 to C.16) represent the possible range of variation for the modulus of the transfer function and for the coherence function (theoretically equal to one).

Table C.14 — Frequency analysis — Reproducibility — Longitudinal level and alignment — Tolerances

Parameter	Function	Wavelength range		
		D1	*D2*	*D3*
Longitudinal level	**Transfer function**	± 7 %	± 10 %	± 15 %
	Coherence function	> 0,95	> 0,90	> 0,85
Alignment	**Transfer function**	± 10 %	± 15 %	± 20 %
	Coherence function	> 0,90	> 0,85	> 0,80

Table C.15 — Frequency analysis — Reproducibility — Gauge and cross level — Tolerances

Parameter	Function	Tolerance
Gauge	**Transfer function**	± 10 %
	Coherence function	> 0,90
Cross level	**Transfer function**	± 15 %
	Coherence function	> 0,85

Table C.16 — Frequency analysis — Reproducibility — Twist — Tolerances

Parameter	Function	Tolerance	
		ℓ ≤ 5,5 m	*5,5 m < ℓ ≤ 20 m*
Twist	**Transfer function**	± 7 %	± 7 %
direct measurement	**Coherence function**	> 0,95	> 0,95
Twist	**Transfer function**	± 7 %	± 7 %
computed from cross level	**Coherence function**	> 0,95	> 0,95
ℓ :Twist base-length			

C.4 Cross check

C.4.1 General

Cross check calculations shall be made at least for the two following groups of parameters:

- difference of alignment and gauge;
- difference of longitudinal level and cross level.

C.4.2 Transfer function

The values given in the following table represent the accepted range of variation (in percentage) in comparison with the modulus of the theoretical transfer function.

Table C.17 — Cross check — Transfer function — Tolerances

Parameter	**Wavelength range**		
	D1	***D2***	***D3***
Gauge and difference of alignment	± 5 %	± 7 %	± 10 %
Cross level and difference of longitudinal level	± 5 %	± 7 %	± 10 %

C.4.3 Coherence function

The values given in the following table represent the accepted minimum values for the coherence function

Table C.18— Cross check — Coherence function — Tolerances

Parameter	**Wavelength range**		
	D1	***D2***	***D3***
Gauge and difference of alignment	> 0,97	> 0,95	> 0,90
Cross level and difference of longitudinal level	> 0,97	> 0,95	> 0,90

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