Technical Report

ISO/TR 8955

Railway infrastructure — Track quality evaluation — Chord-based method

Applications ferroviaires — Qualité géométrique de la voie — Méthode sur la base du cordeau

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Foreword

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This document was prepared by Technical Committee ISO/TC 269, *Railway applications*, Subcommittee SC 1, *Infrastructure*.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

ISO 23054-1 describes the wavelength range method and the chord-based method in parallel as methods for evaluating track geometry quality. ISO 23054-1 specifies a detailed technique for obtaining the track geometry in a desired wavelength range from the signal measured by an inertial measurement system or the chord measurement system. ISO 23054-1 does not specify a technique for obtaining the signal by a particular chord-based method from the signal measured by an inertial measurement system or a chord measurement system with a different chord base.

The chord-based method is a method of managing the track geometry using an evaluation signal that emphasizes the track geometry of a specific wavelength component, and is a method used in many countries. The chord measurement system and the chord-based method are used to measure and evaluate the track geometry parameters: alignment and longitudinal level.

This document provides information on the chord-based method for track geometry evaluation, looking specifically at the relationship between an inertial measurement system and a chord measurement system applying the chord-based method with different chord length and chord division. This document is intended to be used in conjunction with ISO 23054-1.

Railway infrastructure — Track quality evaluation — Chord-based method

1 Scope

This document describes the relationship between an inertial measurement system and a chord measurement system applying the chord-based method with different chord length and chord division.

This document is applicable to 1 435 mm and wider track gauges. This document does not apply to urban/light rail systems, tramways and any track gauge narrower than 1 435 mm.

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.

ISO 23054-1, *Railway applications — Track geometry quality — Part 1: Characterization of track geometry and track geometry quality*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 23054-1 and the following apply.

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

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

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

3.1
wavelength range method
evaluation method for longitudinal level and alignment using signals not coloured by the transfer function

3.2
chord-based method
evaluation method for longitudinal level and alignment using signals coloured by the transfer function

3.3
coloured signal
signal distorted in magnitude and phase by the transfer function

3.4
colouring
process of generating a chord measurement signal from a non-coloured measurement signal

3.5
decolouring
process of removing the distortion of a chord measurement signal to retrieve a non-coloured measurement signal

3.6
recolouring
process of transforming a coloured signal into another coloured signal

4 Symbols and abbreviated terms

For the purposes of this document, the symbols given in ISO 23054-1 and following apply.

a length of trailing chord section (i.e. $L = a + b$), variations: a_e, a_m

a_k filter coefficient (denominator) of the Z-transform

b length of trailing chord section (i.e. $L = a + b$) , variations: b_e, b_m

b_k filter coefficient (numerator) of the Z-transform

d distance (m)

d_s sampling distance for variable s (m)

C_1 short chord length class based on line speed

C_2 long chord length class based on line speed

F Fourier Transform

F^{-1} inverse of the Fourier Transform

$h(s)$ impulse response

$h_s(q)$ discrete form of h such that $h_s(q) = h(q \cdot d_s)$

H transfer function in Fournier domain, Fournier transform of $h(s)$, variations: H_I, H_R, H_e, H_{em}, H_m, H_m^w

H_e colouring transfer function for chord $[a_e, b_e]$

H_{em} transfer function between the measurement signal and the evaluation signal (i.e. the transfer function for the recolouring process)

H_I imaginary part of the transfer function

H_m colouring transfer function for chord $[a_m, b_m]$

H_R real part of the transfer function

H_m^w decolouring transfer function for chord $[a_m, b_m]$ (i.e. the Wiener inverse of H_m)

$H_L(\mathrm{p})$ transfer function of h in the Laplace domain

H^E estimation of H

$H_z(\mathrm{Z})$ transfer function in the form in the Z-domain

j imaginary unit

l normalized chord length

L chord length

m magnitude of the transfer function

M magnitude of the coefficient of Z-transform (numerator and denominator)

p Laplace variable

q discrete form of the space variable s (i.e. $q = \frac{s}{d_s}$; q is an integer)

r_0 chord division ratio

$R_{n/s}$ Noise over signal ratio

s space variable (m)

S_{XX} power spectral density of the input signal $x(s)$

S_{YX} cross-spectral density of the input signal $x(s)$ and the output signal $y(s)$

V offset from chord to rail at the measurement point

w wavelength (m)

W_x wavelength range (see ISO 23054-1)

$x_s(q)$ discrete form of signal x such that $x_s(q) = x(q \cdot d_s)$

$x(s)$ variable input signal along space, e.g. versine signal

X_r real axis

$X(\omega)$ Fourier Transform of $x(s)$

$y_a(s)$ amplitude of $y(s)$ (m)

$y_e(s)$ amplitude error of an alignment or longitudinal level signal (m)

$y(s)$ variable output signal along space, e.g. alignment signal or longitudinal level signal

Y_i imaginary axis

$y_s(q)$ discrete form of signal y such that $y_s(q) = y(q \cdot d_s)$

$y^D(s)$ space shifted version of $y(s)$ with delay D $y^D(s) = y(s+D)$

$y_s^D(q)$ discrete form of signal $y^D(s)$ such that $y_s^D(q) = y(q \cdot d_s + D)$

$Y(\omega)$ Fourier Transform of $y(s)$

δ Dirac delta function

ω spatial angular frequency

5 Relationship of measuring systems and evaluation methods for longitudinal level and alignment

5.1 Measuring systems

There are two measuring systems used for longitudinal level and alignment:

— inertial measurement system;

— chord measurement system.

5.2 Evaluation methods

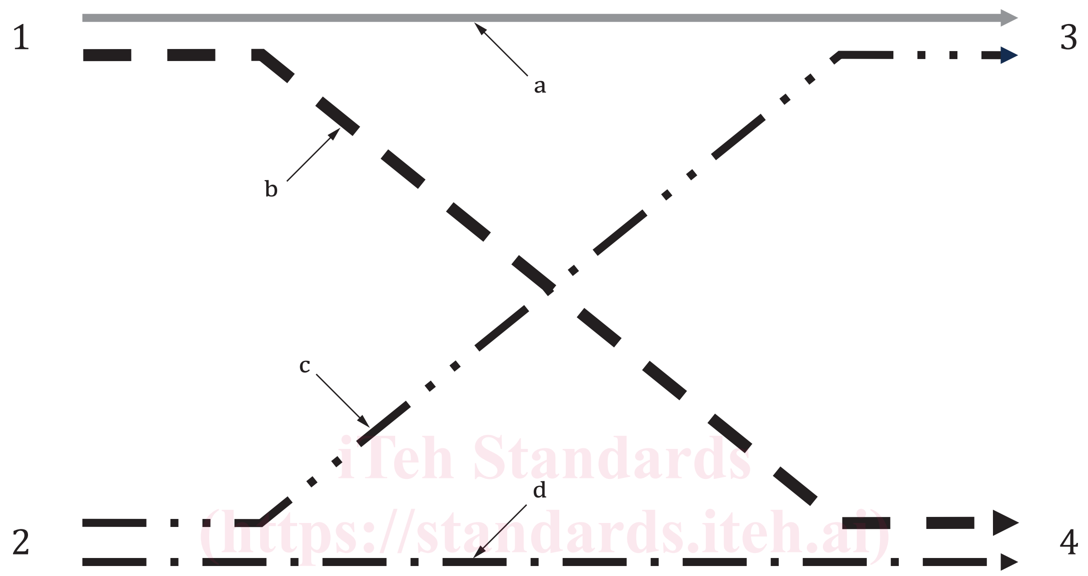
There are two evaluation methods for longitudinal level and alignment:

— wavelength range method;

— chord-based method.

5.3 Relationship of measuring systems and evaluation methods

Measuring systems and evaluation methods of track geometry have a relationship which permits mutual conversion between them (Figure 1).



Key

1 inertial measurement system

2 chord measurement system

3 wavelength range method

4 chord based method

a Filtering process to convert track geometry measured by an inertial measurement system for the evaluation of track irregularity by wavelength range method; see ISO 23054-1:2022, Annex C and D.

b Colouring process to convert track geometry measured by an inertial measurement system for the evaluation of track irregularity by chord-based method, see Clause 7.

c Decolouring process to convert track geometry measured by a chord measurement system for the evaluation of track irregularity by wavelength range method; see ISO 23054-1:2022, Annex E.

d Recolouring process to convert track geometry measured by a specified chord measurement system for the evaluation of track irregularity by another chord-based method; see Clause 8. If the same chord for measurement and assessment is used, the recolouring process is not used.

Figure 1 — Measuring systems and evaluation methods relationship

The railway authority and infrastructure manager can adopt any of the measuring systems and evaluation methods listed in this clause.

6 Chord measurement system and chord-based method of longitudinal level and alignment

6.1 Chord measurement system

6.1.1 General

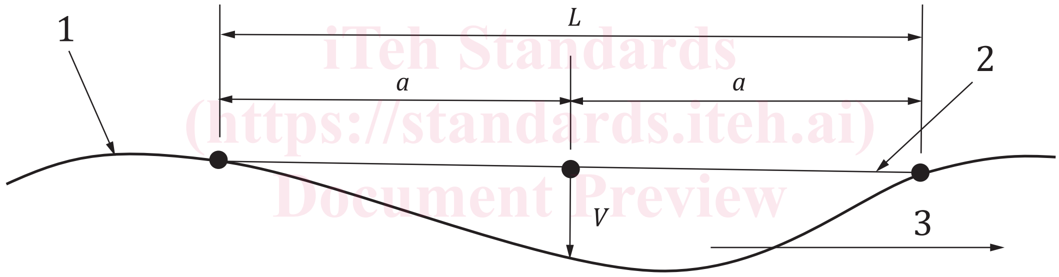
The chord measurement system is a method for measuring the longitudinal level and alignment of the track geometry. The chord measurement system measures the offset from a straight chord to the rail at a defined position between the two end points of the chord.

The straight chord can be either mechanical or optical. In both cases, the interaction between the static and dynamic behaviour of the vehicle (or the carrier of the measurement system) is evaluated with regards to the required accuracy.

NOTE Chord measurement systems have come to be applied to vehicles recording track geometry. The body of the vehicles is used as the reference chord for measurement. As the deformation of the car body cannot always be neglected, a laser beam installed inside the car body of the track geometry recording vehicles can be used as a reference chord.

6.1.2 Symmetrical chord method

In the case of a symmetrical chord, the offset from the rail is measured in the centre of the chord. This means that the lengths of both chord sections are not equal; see Figure 2.



Key

1 rail

2 chord

3 measurement direction

V offset from chord to rail at the measurement point

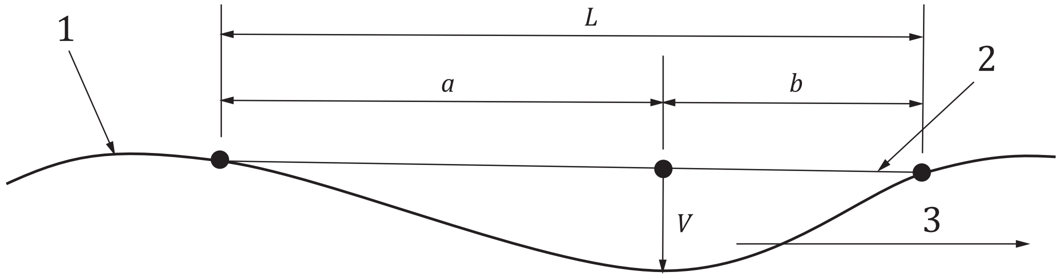
L chord length

a divided chord length, $L = 2a$

Figure 2 — Symmetrical chord method

6.1.3 Asymmetrical chord method

In the case of an asymmetrical chord, the offset from the rail is not measured in the centre of the chord. This means that the lengths of both chord sections are not equal; see Figure 3.



Key

1 rail

2 chord

3 measurement direction

V offset from chord to rail at the measurement point

L chord length

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

Figure 3 — Asymmetrical chord method

6.2 Transfer function

6.2.1 General

The transfer function between the alignment or the longitudinal level and the signal obtained with a chord measurement system ($L = a + b$) is expressed by Formulae (1) and (2). The absolute value of the transfer function $|H(\lambda)|$ indicates the amplitude characteristic, and the argument of the transfer function $\angle H(\lambda)$ indicates the phase characteristic.

As the chord division order, regarding the measurement direction, is substantial for the transfer function expression, in this document "*a*" is defined as the trailing chord division and "*b*" is defined as the leading chord division.

$$|H(w)| = \sqrt{\left[\left(1 - \frac{b}{L}\cos\left(\frac{2\pi a}{w}\right) - \frac{a}{L}\cos\left(\frac{2\pi b}{w}\right)\right)^2 + \left(\frac{b}{L}\sin\left(\frac{2\pi a}{w}\right) - \frac{a}{L}\sin\left(\frac{2\pi b}{w}\right)\right)^2\right]} \quad (1)$$

$$\angle H(w) = \tan^{-1}\frac{H_I(w)}{H_R(w)} \quad (2)$$

where

H is the transfer function;

w is the wavelength;

L is the chord length;

a, b are the divided chord lengths, $L = a + b$;

NOTE 1 In the case of symmetrical chord, $b = a$.

NOTE 2 The order of *a* and *b* is meaningful; see Figure 3.

H_I is the imaginary part of the transfer function;

H_R is the real part of the transfer function.

The complete formulation of the transfer function can be found, for example, in Formulae (3) and (4). A detailed presentation is provided in Reference [1]. The Laplace transform of the filter can be expressed as follows:

$$H_L(p) = \left[\frac{b}{a+b} \exp(-a\, p) + \frac{a}{a+b} \exp(b\, p) - 1 \right] \tag{3}$$

$$p = s + j\omega = s + j\frac{2\pi}{w} \tag{4}$$

where

H_L is the transfer function in the form in the Laplace domain;

p is the Laplace variable;

s is the distance;

j is the imaginary unit;

ω is the spatial angular frequency.

This continuous spectrum is obtained as described in Reference [1] from the impulse function response in s in Formula (5):

$$h(s) = \frac{b}{a+b}\delta(s-a) + \frac{a}{a+b}\delta(s+b) - \delta(s) \tag{5}$$

where

h is the impulse function;

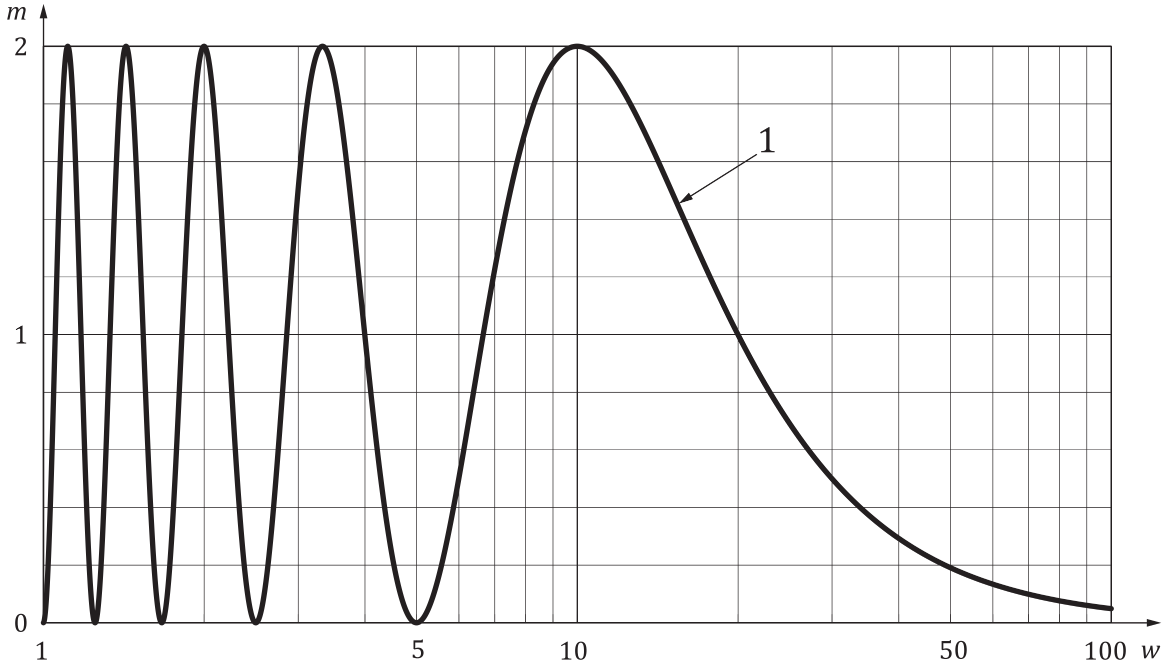
s is the measurement distance;

δ is the Dirac delta function.

6.2.2 Ratio of the chord division

By changing the ratio of the chord division of the chord measurement system, the characteristics of the transfer function between the alignment or the longitudinal level and the signal obtained with a chord measurement system ($L = a + b$) also change.

Figure 4 shows an example transfer function with a chord length, L, of 10 m and a chord division ($a = b$) of 5 m. This method is called the 10 m symmetrical chord method. In the symmetrical chord method, the gain is 2 at wavelength $L/(2n\text{-}1)$ with $n \geq 1$. The gain is zero at wavelength $L/(2n)$ with $n \geq 1$, where n is a positive integer.



Key

m magnitude of the transfer function

w wavelength (m)

1 transfer function — 5 m/5 m

Figure 4 — Example of transfer function of 10 m symmetrical chord method ($a = b = 5$ m)

To avoid these zero gains in the transfer function, it is advisable to set the ratio of chord division to a condition that is not an integral multiple. Figure 5 shows the transfer functions for the case where:

— L = 10 m, a = 2,5 m and b = 7,5 m ($b = 3a$); and

— L = 10 m, a = 4,5 m and b = 5,5 m (b = (5,5/4,5)·a approximately 1,22·a).

These are called 10 m asymmetrical chord methods.

The transfer function has zero gain at each wavelength equal to a common divisor of the chord divisions. For example, for L = 4 m + 6 m, the greatest common divisor (GCD) is 2 m and the zero gains occur at all wavelengths, w = GCD/n = 2/n with $n \geq 1$.