SLOVENSKI STANDARD

SIST-TP CEN/TR 16891:2016

01-september-2016

Železniške naprave - Akustika - Metode merjenja kombinirane hrapavosti, stopnje upadanja tirnice in prenosnih funkcij

Railway applications - Acoustics - Measurement method for combined roughness, track decay rates and transfer functions

Bahnanwendung - Geräuschemission - Messmethode für kombinierte Rauheit, Schienenabklingraten und Übertragungsfunktions

Ta slovenski standard je istoveten z: CEN/TR 16891:2016

ICS:

17.140.30	Emisija hrupa transportnih sredstev	Noise emitted by means of transport
93.100	Gradnja železnic	Construction of railways

SIST-TP CEN/TR 16891:2016 **en,fr,de**

TECHNICAL REPORT

RAPPORT TECHNIQUE

TECHNISCHER BERICHT

CEN/TR 16891

May 2016

ICS 17.140.30; 93.100

English Version

Railway applications - Acoustics - Measurement method for combined roughness, track decay rates and transfer functions

Bahnanwendungen - Akustik - Messmethode für kombinierte Rauheit, Gleisabklingraten und Übertragungsfunktionen

This Technical Report was approved by CEN on 13 May 2016. It has been drawn up by the Technical Committee CEN/TC 256.

CEN members are the national standards bodies of 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, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

Ref. No. CEN/TR 16891:2016 E

Contents

Page

European foreword

This document (CEN/TR 16891:2016) has been prepared by Technical Committee CEN/TC 256 “Railway applications”, the secretariat of which is held by DIN.

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.

Introduction

This Technical Report provides a basis for a standard on measurement of combined wheel-rail roughness, track decay rates and transfer functions from train pass-bys.

The main items required for a standard are covered but also additional background information and benchmark results are included.

1 Scope

This method is used to determine combined wheel-rail roughness and track decay rates from rail vibration during the pass-by of a train. By combining sound pressure measurement from the same pass-by, a vibro-acoustic transfer function for rolling noise is determined.

The track decay rate is a vibration quantity that characterizes the attenuation of rail vibration along the track for a given wheel/rail contact excitation, and thereby affects the amount of sound radiation from the track.

Combined roughness is a quantity that determines the level of excitation of wheel-rail rolling noise. It can be determined from vertical rail vibration during a train pass-by and the vertical track decay rate. The transfer function can be used to characterize the vibro-acoustic behaviour of the vehicle-track system for a given roughness excitation and in relation to rolling noise. Combined roughness, track decay rates and transfer functions are determined as one-third octave spectra.

The method can be used for the following purposes:

- to measure track decay rates under operational conditions;
- to characterize the effectiveness of noise control measures in terms of combined roughness, transfer function and track decay rate;
- to compare the combined roughness before and after noise control measures are implemented (thereby quantifying the effect of any change in wheel or rail roughness);
- to monitor wheel roughness during a pass-by, either of whole trains or parts of trains;
- to separate rolling noise from other sources;
- to assess a threshold for the rail roughness by measuring multiple pass-bys.

The method is not for approval of sections of reference track in terms of acoustic rail roughness and track decay rates, which are covered by EN 15610 and EN 15461, respectively.

The method is applicable to trains on conventional tracks, i.e. normal ballasted tracks with wooden or concrete sleepers and on ballastless track systems.

The method has not yet been validated for:

- non-standard wheel types such as small wheels up to 600 mm diameter, resilient tram wheels;
- non-standard track types such as embedded rail or grooved rail;

The method is not applicable to track with rail joints.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 15461, *Railway applications — Noise emission — Characterisation of the dynamic properties of track sections for pass by noise measurements*

EN 15610, *Railway applications — Noise emission — Rail roughness measurement related to rolling noise generation*

EN ISO 266, *Acoustics — Preferred frequencies (ISO 266)*

3 Terms and definitions

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

3.1
pass-by time
t_p [s]
duration of vehicle pass-by from buffer to buffer

3.2
number of axles
N_{ax} [-]
number of axles in the selected train or part of train

3.3
one-third octave band frequency
f_c [Hz]
centre frequency of a one-third octave frequency band

3.4
one-third octave wavelength
λ [m]
centre wavelength of a one-third octave wavelength band

3.5
sound pressure signal
$p(t)$ [Pa]
time signal of the sound pressure measured at a fixed point

3.6
equivalent sound pressure level spectrum
$L_{p\text{eq},\text{Tp}}(f_c)$ dB re 2.10^{-5} [Pa]
one-third octave spectrum of the sound pressure energy averaged over pass-by time t_p

3.7
acceleration signal
$a(t)$ [m/s^2]
time signal of the rail acceleration

3.8
equivalent vertical rail vibration level spectrum
$L_{a\text{eq},\text{Tp}}(f_c,V)$ dB re 10^{-6} [m/s^2]
one-third octave spectrum of the sound pressure energy averaged over pass-by time t_p at running speed *v*

3.9
decay exponent
β [m^{-1}]
decay exponent characteristic for the vibration decay in the rail

3.10

vertical track decay rate

$D_Z(f_C)$ [dB/m]

decay rate of vertical rail vibrations along the rail head

3.11

lateral track decay rate

$D_y(f_C)$ [dB/m]

decay rate of lateral rail vibrations along the rail head

3.12

combined effective roughness wavelength spectrum

L_{Rtot} (λ), dB re 10^{-6} [m]

wavelength spectrum in one-third octaves of the combined effective wheel-rail roughness including the contact filter

3.13

combined effective roughness frequency spectrum at speed *v*

L_{Rtot} (f_C,v) dB re 10^{-6} [m]

frequency spectrum in one-third octaves of the combined effective wheel-rail roughness including the contact filter

3.14

rolling noise transfer function

$L_{HpR,tot,nl}$ (f_C) [dB re 20 Pa/$\sqrt{}$m]

transfer function in one-third octave bands between the sound pressure at a fixed point, 7,5 m, and the combined effective roughness frequency spectrum, normalized to the axle density N_{ax}/l

4 Symbols and abbreviations

Symbol	Definition	Unit
ℓ	length of train, vehicle or train part	[m]
v	train speed	[m/s]

5 Instrumentation

Instrumentation for sound pressure measurement should comply with requirements in EN ISO 3095.

The whole measurement chain shall be capable of measuring in the frequency range 25 Hz to 10 kHz. The signal sample rate for acceleration and sound pressure signals should be sufficient for the frequency range required. A sample frequency of 25 kHz or 32 kHz is sufficient for a measurement range up to 10 kHz.

The accelerometer type should be consistent with the expected vibration range and frequency range. The accelerometer and its measurement chain shall be selected and adjusted to cover the typical vibration range without signal clipping or overloading. Vertical railhead vibration can reach up to 5 000 m/s^2 or more. The dynamic range shall be at least 70 dB.

The accelerometer and its connector shall be water tight especially if moisture can collect during the measurement.

Optionally a thermometer should be available for measuring the rail temperature.

6 Installation aspects

The accelerometer should be fixed to the rail by means of a glue

NOTE Magnetic fixing is also possible but may reduce the usable frequency range at higher frequencies.

General guidelines on mechanical mounting of accelerometers should be taken into account as set out in ISO 5348.

Attention should be given to firm mounting as the resonance frequency of the accelerometer on its mounting can drop below 10 kHz if not sufficiently stiff.

Overloading and potential loosening or detachment should be avoided and therefore continually monitored during measurement.

Further information on installation aspects can be found in [10].

7 Measurement positions

For vertical track decay rate and combined roughness measurement a single accelerometer is mounted under the longitudinal axis of the rail foot or under the side of the rail head (with angle plate, see Figure 1), next to a sleeper. For lateral decay rate measurement an accelerometer is mounted on the outer side of the rail head. If the transfer function is measured then a microphone is positioned at 7,5 m from the track centreline and at 1,2 m above the rail surface directly opposite the accelerometer. The number of accelerometers may be increased if required, for example to measure the combined roughness on the other rail or along the track to take potential track variations into account.

a) Cross section of the rail, wheel flange on the left side

b) Example of position a

Figure 1 — Suitable positions for measuring vertical railhead vibration a and b

Mounting underneath the side of the railhead (b) should include an angle stud to ensure vertical positioning of the accelerometer. Position c indicates the position for lateral railhead vibration measurement, if required.

The measurement cross-section shall not be close to unusual rail support conditions, in particular:

1) there shall be no pumping sleeper within a distance smaller than 3 m to the accelerometer;

2) there shall be no missing or damaged rail clip (or fastener of any other type, if necessary) on the supports directly adjacent to the accelerometer location;

3) the accelerometer shall not be located within 5 m of a weld;

4) the accelerometer shall not be located within 40 m of an expansion joint.

8 Measured quantities

- Pass-by time t_p of train or train part;
- train speed v;
- vertical railhead acceleration signal $a(t)$;
- sound pressure signal at 7,5 m $p(t)$;
- optionally axle trigger signal $z(t)$ should be recorded during the measurements;
- optionally the rail temperature should be recorded during the measurements.

9 Test procedure

During a whole pass-by of a train the following is recorded:

- vertical railhead vibration (acceleration signal) including the approach and departure of the train;
- sound pressure time signal, if a transfer function is required;
- train speed v;
- train length ℓ, usually determined from known vehicle lengths;
- number of axles N_{ax}, counted or estimated from the vibration or trigger signal;
- optionally the axle trigger signal $z(t)$.

If the lateral decay rate is to be determined, then also lateral railhead vibration shall be registered.

The vertical track decay rate and, if required, the lateral track decay rate shall be averaged over several pass-bys of one or more trains, rejecting outlier curves, see Clause 11.

An indicative result (which shall not be considered as a valid result) of the combined roughness and transfer function can be obtained from a single pass-by.

The measurement uncertainty can be reduced by:

- averaging results over three or more pass-bys of the same train;
- averaging results over two or more train speeds of the same train at least 10 % apart.

Combined roughness can be measured either on a single rail or on both rails depending on the purpose of the measurement.

10 Data processing

The vertical (and if required lateral) rail acceleration time signal is processed by the method described in Clause 11 to determine the track decay rate.

The combined roughness is derived from the vertical decay rate and the equivalent rail vibration level $\mathrm{L}_{\mathrm{aeq,tp}}$ over pass-by time t_p according to the method set out below. The transfer function is derived according to Clause 14 from the equivalent sound pressure level $L_{p\mathrm{eq}}(f_\mathrm{c})$, the combined roughness $\mathrm{L}_{\mathrm{Rtot}}(f_\mathrm{c},v)$ and the number of axles per unit length $\mathrm{N}_{\mathrm{ax}}/\ell$.

11 Method to determine the track decay rate from rail vibration

11.1 General

The track decay rate (both vertical and lateral) shall be determined by the energy iteration method described in 11.2. Alternative methods analysing the slope of the time signal are described in Annex C.

The slope methods described in Annex C generally do not eliminate the contributions from other wheels and can therefore give an underestimation of the decay rate. In addition, where manual interaction is required during processing, more errors can occur in selecting the location of the defining points. The energy method takes the contributions of other wheels into account and is less sensitive to manual inputs as long as the wheel positions are correctly specified. Examples of results from the slope methods compared to the energy method are given in B.3.

Results shall be averaged over at least 3 pass-bys. The average shall be the arithmetic mean of track decay rate levels in each one-third octave frequency band. Results differing by more than 5 dB in any one-third octave frequency band should be rejected, at least in the frequency range concerned.

11.2 Energy iteration method

The energy iteration method to derive the decay rate from the vibration time signal is analogous to the hammer impact method described in EN 15461, with the difference that the moving wheel provides the excitation instead of a hammer, and the track has a real load. Also the signal energy is higher than when using a hammer.

The rail vibration amplitude due to a single wheel is assumed to be described by an exponential function:

$$A(x) \approx A(0)e^{-\beta x} \tag{1}$$

Where

x is the position away from the contact point along the rail;

$A(x)$ is the vibration amplitude along the rail;

$A(0)$ is the instantaneous amplitude at the position of the wheel contact point;

β is a decay exponent.

The decay rate D_z in dB/m can be given as:

$$D_z = 20\log_{10}\left(e^{\beta}\right) \approx 8{,}686\beta\left[\mathrm{db/m}\right] \tag{2}$$

This decay rate is derived from the evaluation of the ratio of the integrated vibration energy over a length L_2, potentially including the whole train pass-by versus the integrated vibration energy over a short length L_1 directly around the wheels. L_1 is taken as the shortest axle distance in the train (or part of the train). A common minimum wheel distance is 1,8 m, in which case the analysis length L_1 extends from – 0,9 m to + 0,9 m around each wheel position. The wheel position is determined by a wheel trigger signal or manually from the acceleration signal. In the latter case, a sufficiently high signal sampling rate is required to accurately locate the axle positions, see Clause 8.

The integrated squared vibration over a length L_1 around all N wheels is, using Formula (1):

$$A^2_{\sum L_1} = \sum_{n=1}^{N} A^2_{n,L_1} = \sum_{n=1}^{N} \int_{-L_1/2}^{L_1/2} \left(A_n(0) e^{-\beta|x|} \right)^2 \mathrm{d}x = \frac{1-e^{\beta L_1}}{\beta} \sum_{n=1}^{N} A_n^2(0) \qquad (3)$$

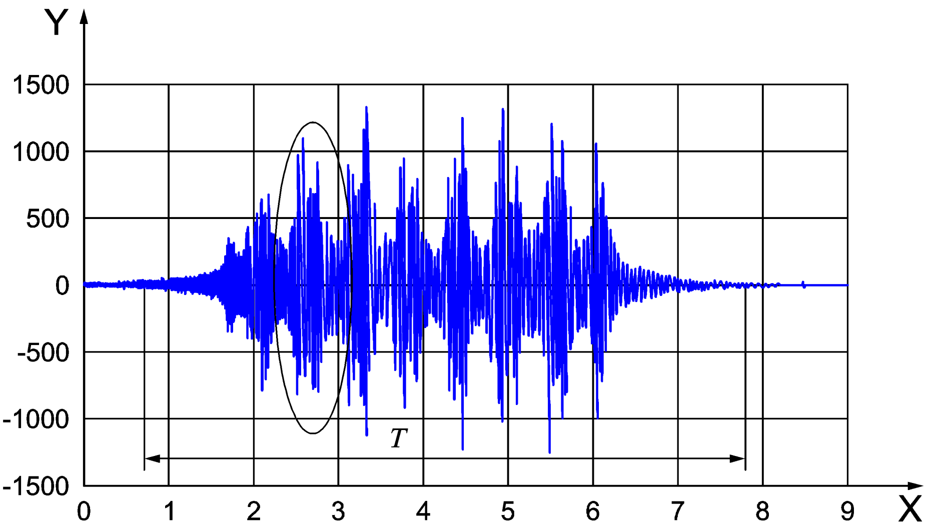
Similarly, the integrated squared vibration over a long length L_2 incorporating all N wheels is:

$$\sum_{n=1}^{N} \int_{L_2} \left(A_n(0) e^{-\beta|x|} \right)^2 \mathrm{d}x = \frac{1-e^{-\beta L_2}}{\beta} \sum_{n=1}^{N} A_n^2(0) \approx \frac{1}{\beta} \sum_{n=1}^{N} A_n^2(0) \qquad (4)$$

The approximation at the right hand side in the above formula is valid for sufficiently large L_2, e.g. a train length or the length of a (group of) vehicle(s).

The quantities $A^2_{\Sigma L1}$ and $A^2_{\Sigma L2}$ can be determined straightforwardly from measured acceleration signals. The transducer time signal is passed through one-third octave band pass filters resulting in a filtered time signal. Then, for each frequency band, the integrated squared vibration is determined over every wheel over length L_1 (time T_x), see Figure 2a and for the whole pass-by (whole train) for L_2 (time T). Using Formulae (3) and (4) the vibration energy ratio R of $A^2_{\Sigma L1}$ and $A^2_{\Sigma L2}$ for each one-third octave band frequency f_c is given as:

$$R(f_c) = \frac{A^2_{\sum L_1}(f_c)}{A^2_{\sum L_2}(f_c)} \approx 1 - e^{-\beta L_1} \qquad (5)$$

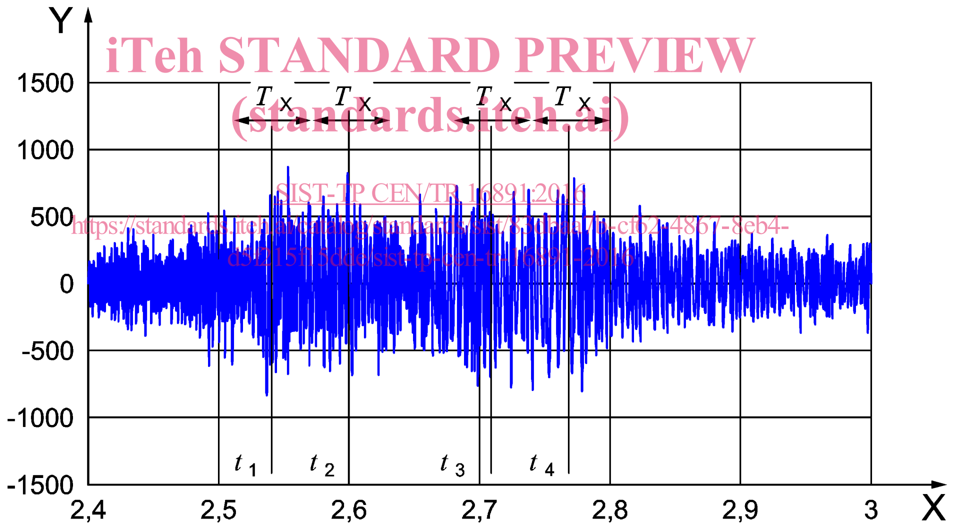


Key

Y acceleration in m/s^2

X time in s

a) **Unfiltered time signal of whole pass-by with total integration time *T* indicated**



Key

Y acceleration in m/s^2

X time in s

NOTE The integration is applied to the bandpass-filtered time signal for each one-third octave band.

b) **Selected part of time signal indicated showing integration time T_X around each wheel**

Figure 2 — Time signal of vertical rail vibration

The T_X interval contains mainly energy from the single wheel, but also contributions from other wheels, particularly the nearby ones. T_X should be chosen to be slightly shorter than the shortest distance between wheels over the whole train to avoid overlap in energy summation.

From Formula (5) and Formula (2) the vibration decay rate D_Z (TDR) is determined from: