FINAL DRAFT
International
Standard

ISO/FDIS 13473-4

Characterization of pavement texture by use of surface profiles —

Part 4:
One third octave band spectral analysis of surface profiles

Caractérisation de la texture d'un revêtement de chaussée à partir de relevés de profils de la surface —

Partie 4: Analyse spectrale par bande d'un tiers d'octave des profils de la surface

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Foreword

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This document was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

This second edition cancels and replaces the first edition (ISO/TS 13473-4:2008), which has been technically revised.

The main changes are as follows:

— the pre-processing of the input data to the spectral analysis has been improved and is in line now with the procedure of ISO 13473-1

— an old analogue technique has been removed and there is one normative method of the spectral analysis defined;

— significant improvements have been made to the uncertainty analysis.

A list of all parts in the ISO 13473 series can be found on the ISO website.

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

Pavement texture is a basic road surface characteristic and is related to many important functional characteristics, such as noise emission from tyre-road interaction, friction between tyre and road, rolling resistance, tyre wear and the technical condition of the road surface.

Spectral analysis is commonly used in various fields of signal processing and has been found to be a useful method of pavement characterization for pavement surface profiles including texture measurements.

There are many ways to perform spectral analysis. The current document describes the spectral analysis, in octave and one-third-octave bands.

Characterization of pavement texture by use of surface profiles —

Part 4:
One third octave band spectral analysis of surface profiles

1 Scope

This document describes the methods that are available to perform a spectral analysis of a pavement surface profile. It specifies a method for performing spatial frequency analysis (or texture wavelength analysis) of two-dimensional surface profiles that describe the pavement texture amplitude as a function of the distance along a straight or curved trajectory over the pavement. It also details an alternative (non-preferred) method to obtain these spectra:

a) constant-percentage bandwidth obtained by digital filtering (normative method);

b) constant narrow bandwidth frequency analysis by means of discrete Fourier transform (DFT), followed by a transformation of the narrow-band spectrum to an octave- or one-third-octave-band spectrum (informative).

The result of the frequency analysis will be a spatial frequency (or texture wavelength) spectrum in constant-percentage bandwidth bands of octave or one-third-octave bandwidth.

The objective of this document is to standardize the spectral characterization of pavement surface profiles. This objective is pursued by providing a detailed description of the analysis methods and related requirements for those who are involved in pavement characterization but are not familiar with general principles of frequency analysis of random signals. These methods and requirements are generally applicable to all types of random signals; however, they are elaborated in this document for their use in pavement surface profile analysis.

NOTE The spectral analysis as specified in this document cannot express all characteristics of the surface profile under study. In particular, the effects of asymmetry of the profile, e.g. the difference of certain functional qualities for "positive" and "negative" profiles cannot be expressed by the power spectral density, as it disregards any asymmetry of the signal (see Annex B).

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 13473-2, *Characterization of pavement texture by use of surface profiles — Part 2: Terminology and basic requirements related to pavement texture profile analysis*

ISO 13473-3, *Characterization of pavement texture by use of surface profiles — Part 3: Specification and classification of profilometers*

IEC 61260-1, *Electroacoustics — Octave-band and fractional-octave-band filters — Part 1: Specifications*

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13473-2 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
drop-out
data in the measured profile indicated by the sensor as invalid

3.2
drop-out rate
percentage (%) of measured points within the *evaluation length* (3.3) which are identified as being invalid

3.3
evaluation length
l
length of a portion of a profile which has been or is to be analysed

Note 1 to entry: The evaluation length may or may not be equal to the *profile measurement length* (3.5) (but never greater).

Note 2 to entry: Evaluation length is normally expressed in metres (m) or millimetres (mm).

3.4
measurement speed
v
speed at which the *profilometer* (3.7) sensor traverses the surface to be measured

Note 1 to entry: Measurement speed is normally expressed in kilometres per hour (km/h) or metres per second (m/s).

3.5
profile measurement length
l_p
length of an uninterrupted profile measurement

Note 1 to entry: Profile measurement length is normally expressed in metres (m) or millimetres (mm).

3.7
profilometer
device used for measuring the two-dimensional (2D) profile of a pavement surface

Note 1 to entry: Any design of profilometer could be used if the requirements in ISO 13473-3 is fulfilled for the specific purpose of the analysis.

Note 2 to entry: Profilometers can be divided into stationary, mobile low speed or mobile high speed devices.

3.8
power spectral density
PSD
quantity expressing the power contained in a signal per unit frequency or per unit wavelength as a function of frequency or wavelength

Note 1 to entry: In the case of a discrete Fourier transform of a sampled signal, the PSD may be defined as the squared magnitude of the components of the Fourier series divided by the effective bandwidth of the (narrow) bands of the Fourier spectrum (see C.4).

Note 2 to entry: In the case of spectral analysis of a pavement surface profile, the signal is not a function of time but of evaluation length *l*. The Power Spectral Density may then be given as a function of the spatial frequency or the (texture) wavelength and will be expressed in the unit $m^2/m^{-1} = m^3$ or in the unit m^2/mm, respectively.

Note 3 to entry: The word “Power” in this designation originates from electric and acoustic signal terminology where signals incorporate actual power and where the squared amplitude is a measure of this power.

3.9
sampling interval
ΔX
distance between two adjacent data points of the surface profile, which is equal to the measurement speed divided by the sampling frequency of the sensor

Note 1 to entry: Sampling interval is normally expressed in millimetres (mm).

3.10
spatial frequency
f_{sp}
number of sinusoidal cycles per unit length

Note 1 to entry: Spatial frequency is normally expressed in reciprocal metres (m^{-1}); see also 3.13, Note 3.

Note 2 to entry: The term “frequency” used in the time domain, corresponds to “spatial frequency” in the space domain.

3.11
surface profile
texture profile
$Z(X)$
upper contour of a vertical cross-section through a pavement

Note 1 to entry: Texture profile is similar to surface profile but limited to the texture range.

Note 2 to entry: The profile of the surface is described by two coordinates: one in the surface plane, called distance (the abscissa), and the other in the direction normal to the surface plane, called vertical displacement (the ordinate). The distance may be in the longitudinal or lateral (transverse) directions in relation to the travel direction on a pavement, or in a circle or any other direction between these extremes.

3.12
surface profile spectrum
texture spectrum
spectrum obtained when a profile curve has been analysed by either digital filtering or Digital Fourier Transform (DFT) techniques to determine the magnitude of its spectral components at different *wavelengths* (3.13) or *spatial frequencies* (3.10)

Note 1 to entry: Wavelengths between 0,5 mm and 500 mm belongs to the texture spectrum and 0,5 m to 50 m belongs to the unevenness spectrum[12].

Note 2 to entry: A texture spectrum presents the magnitude of each spectral component as a function of either texture wavelength or spatial frequency.

3.13
texture wavelength
λ
quantity describing the horizontal dimension of the amplitude variations of a *surface profile* (3.11)

Note 1 to entry: (Texture) wavelength is normally expressed in metres (m) or millimetres (mm).

Note 2 to entry: Wavelength is a quantity commonly used and accepted in electrotechnical and signal processing vocabularies. Since many users of this document might not be accustomed to use the term wavelength in pavement applications, and because electrical signals are often used in the analyses of road surface profiles, there is a possibility of confusion. Hence, the expression “texture wavelength” is preferred here to make a clear distinction in relation to other applications.

Note 3 to entry: Texture wavelength in ISO 13473 is the reciprocal of the spatial frequency, the unit of which is reciprocal metre (equivalent to cycles per metre). See also 3.10.

Note 4 to entry: Wavelengths are represented physically as the various lengths of periodically repeated parts of the profile.

3.14
texture profile level
$L_{tx,\lambda}$
logarithmic transformation of an amplitude representation of a surface profile curve $Z(X)$, the latter expressed as a root mean square value

EXAMPLE $L_{tx,80}$ denotes the texture profile level for the one-third-octave band having a centre wavelength of 80 mm, see ISO 13473-2:2002, Table 1

Note 1 to entry: Octave-band and one-third-octave-band filters are specified in ISO 13473-2:2002, 4.4.

Note 2 to entry: Texture amplitudes expressed as root-mean-square values, whether filtered or not, may have a range of several magnitudes, typically 10^{-5} m to 10^{-2} m. Spectral characterization of signals is used frequently in studies of acoustics, vibrations and electrotechnical engineering. In all those fields, it is most common to use logarithmic amplitude scales. The same approach is preferred in this document.

Note 3 to entry: Texture profile levels in practical pavement engineering typically range from 20 dB to 80 dB with these definitions.

4 Symbols and abbreviated terms

A list of symbols and abbreviations used in this document is given in Table 1.

Table 1 — Meaning of symbols and abbreviations

Symbol or term	unit	Explanation
DFT		Discrete (fast) Fourier transform
FFT		Fast Fourier transform
PSD		Power spectral density
l	m	Evaluation length
l_p	m	Profile measurement length
N	-	Number of samples
λ	m, mm	Texture wavelength,
λ_{max}	m, mm	Longest (texture) wavelength
v	m/s	Measurement speed
$Z(X)$	m	Texture profile
Δf	Hz	Bandwidth of the frequency interval
$L_{TX,\lambda}$	dB	Texture profile level, in octave (wavelength) band λ
$L_{tx,\lambda}$	dB	Texture profile level, in one-third-octave (wavelength) band λ
a_λ	m	Root mean square value of the vertical displacement of the surface profile
a_{ref}	m	Reference value of the surface profile amplitude (= 10^{-6} m)
z_i	m	Amplitude of the ith profile-value of a sampled profile
ΔX	m, mm	Step size of a sampled profile
α	-	Constant factor used as a limit for identifying spikes
f_s	m^{-1}	Sample frequency
f_{sp}	m^{-1}	Spatial frequency
$f_{sp,m}$	m^{-1}	Centre frequency of fractional octave band
b_0	M	Offset of the surface profile
b_1	-	Slope of the surface profile
$w_{i,C}$	-	Split Cosine Bell Window

Table 1 *(continued)*

Symbol or term	unit	Explanation
$Z_{i,win}$	m	Windowed surface profile
Z_k	m	Discrete Fourier Transformation of the windowed profile
$Z_{PSD,k}$	m	Power Spectral Density of narrow band *m*
$Z_{p,m}$	m	Power within fractional-octave band *m*
j	-	Imaginary unit ($j^2 = -1$)
m	-	Index for the fractional-octave band
n	-	Bandwidth designator

5 Basic outline of methodologies of spatial frequency analysis

Principally, there are two alternative methods to obtain a spatial frequency spectrum in constant-percentage bandwidth bands of octave- or one-third-octave width. These two methods are:

a) Method 1 – digital constant-percentage bandwidth filtering.

b) Method 2 – constant narrow bandwidth frequency analysis by means of Discrete Fourier Transform, followed by a transformation of the narrow band spectrum to an octave - or one-third-octave band spectrum.

Method 1 is the main normative method. Both methods yield similar results (within the confidence intervals arising from measurement and analysis uncertainty), on condition that the signal quality is high and that in each of the methods, all signal processing components fulfil the requirements specified in this document. In addition, the narrow bands (method 2) should be appropriately combined into the wider bands, which may be a problem at lower spatial frequencies. Method 2 also includes more steps than Method 1.

The signal processing steps are shown in the scheme of Figure 1. The calculation steps are described in more detail in Clause 6, Clause 7 and Annex C.

NOTE Method 1 and Method 2 yield very similar results for all texture wavelengths[11].

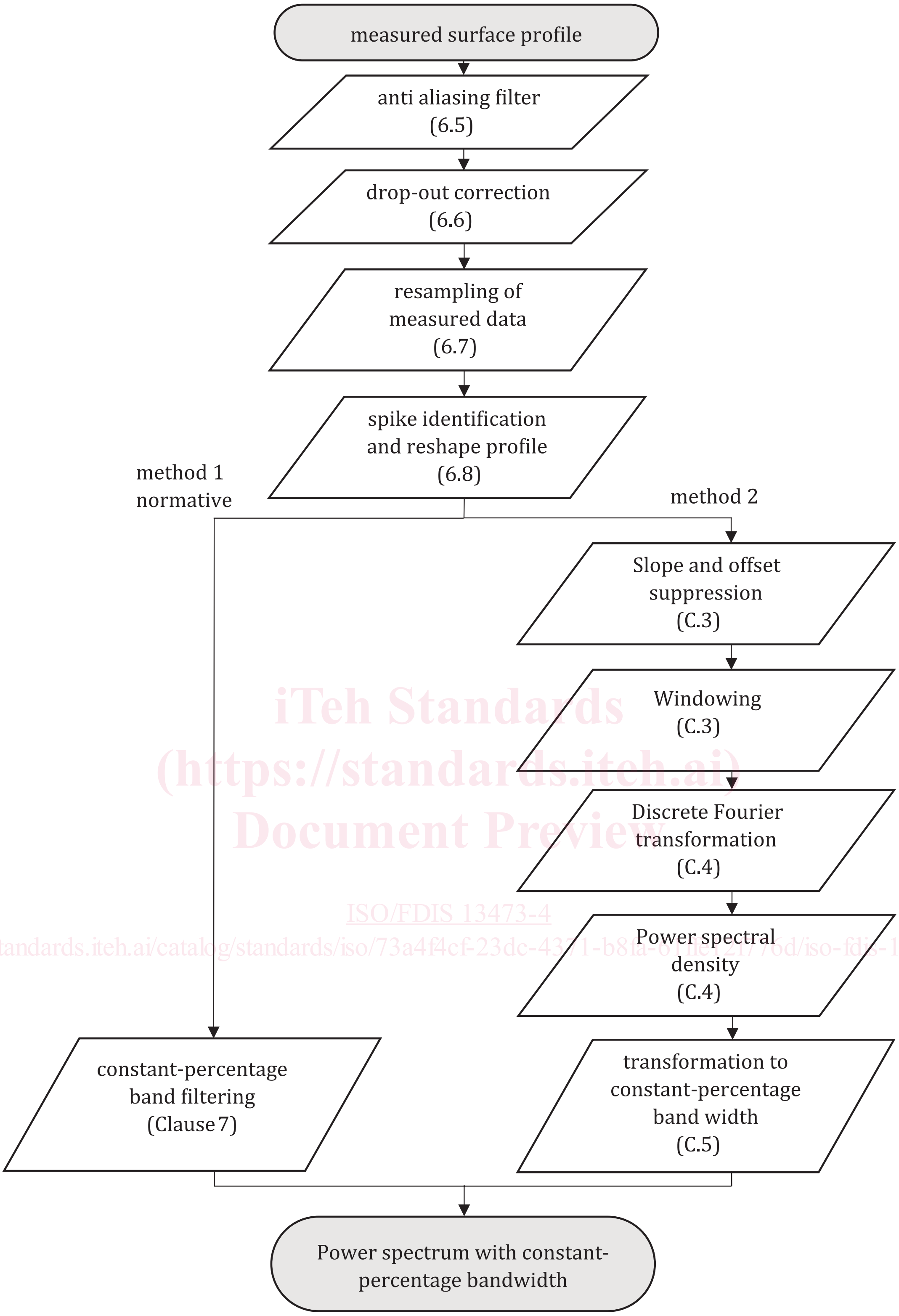

Figure 1 — Scheme for spectral analysis with reference to clauses and subclauses where the subject is described