TECHNICAL SPECIFICATION

ISO/TS 13473-4

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Characterization of pavement texture by use of surface profiles —

Part 4: 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 des profils de la surface

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In other circumstances, particularly when there is an urgent market requirement for such documents, a technical committee may decide to publish other types of document:

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An ISO/PAS or ISO/TS is reviewed after three years in order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn. If the ISO/PAS or ISO/TS is confirmed, it is reviewed again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.

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

ISO/TS 13473-4 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

ISO 13473 consists of the following parts, under the general title *Characterization of pavement texture by use of surface profiles*:

— *Part 1: Determination of Mean Profile Depth*

— *Part 2: Terminology and basic requirements related to pavement texture profile analysis*

— *Part 3: Specification and classification of profilometers*

— *Part 4: Spectral analysis of surface profiles* [Technical Specification]

— *Part 5: Determination of megatexture*

Introduction

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

Spectral analysis of measured surface profiles is frequently used as a method of pavement characterization. However, recent practice has shown that the methodology of spectral analysis is not sufficiently well known in the field of pavement measurements to assure reproducible results. Improvement of the reproducibility by offering guidance in the form of a standardization document seems therefore advisable.

Although the principles of frequency analysis are used in various fields of signal processing, it seems that a tailored elaboration of these principles for the application in the field of pavement texture measurements is appropriate and will enhance the use of these methods and the quality of the results achieved.

This elaboration, in the form of an ISO Technical Specification, is intended to stimulate the international exchange of knowledge and data concerning pavement characteristics.

Characterization of pavement texture by use of surface profiles —

Part 4: Spectral analysis of surface profiles

1 Scope

This Technical Specification describes the methods that are available to perform a spectral analysis of pavement surface profile signals. It specifies three possible methods for spatial frequency analysis (or texture wavelength analysis) of two-dimensional surface profiles that describe the pavement roughness amplitude as a function of the distance along a straight or curved trajectory over the pavement.

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.

This Technical Specification offers three alternative methods to obtain these spectra:

1) analogue constant-percentage bandwidth filtering;

2) digital constant-percentage bandwidth filtering;

3) 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.

The objective of this Technical Specification 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, but are elaborated in this Technical Specification in a specific description aimed at their use for pavement surface profile signals.

NOTE The user of this Technical Specification should be aware that 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 F.)

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.

ISO 13473-2:2002, *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, *Electroacoustics — Octave-band and fractional-octave-band filters*

3 Terms and definitions

For the purpose of this document, the terms and definitions given in ISO 13473-2:2002 and the following apply. To assist the users, the most relevant terms and definitions from ISO 13473-2:2002 have been copied into this Technical Specification.

3.1
(texture) wavelength
λ
quantity describing the horizontal dimension of the amplitude variations of a surface profile

NOTE 1 (Texture) wavelength is normally expressed in metres (m) or millimetres (mm).

NOTE 2 Wavelength is a quantity commonly used and accepted in electrotechnical and signal processing vocabularies. Since many users of this Technical Specification may not be accustomed to using 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 The profile may be considered as a stationary, random function of the distance along the surface. By means of a Fourier analysis, such a function may be mathematically represented as an infinite series of sinusoidal components of various frequencies (and wavelengths), each having a given amplitude and initial phase. For typical and continuous surface profiles, a profile analysed by its Fourier components contains a continuous distribution of wavelengths. The 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 3.14.

NOTE 4 The wavelengths may be represented physically as the various lengths of periodically repeated parts of the profile.

3.2
profile sampling
selection of representative parts of a road surface of which the profile will be measured

3.3
profilometer
device used for measuring the profile of a pavement surface

NOTE Current designs of profilometers used in pavement engineering include, but are not limited to, sensors based on laser, light sectioning, needle tracer and ultrasonic technologies.

3.4
measurement speed
v
speed at which the profilometer sensor traverses the surface to be measured

NOTE Measurement speed is normally expressed in kilometres per hour (km/h) or metres per second (m/s).

3.5
digital signal sampling
determination of discrete measurement values of a signal at regularly spaced data points (and the subsequent conversion of these values into digital code)

NOTE In this generic definition of digital signal sampling, the regular spacing of the data points may be applied either in the time or in the spatial domain, depending on the domain (time or space) in which the signal is captured.

3.6
sampling interval
distance between two adjacent data points on the surface, which is equal to the measurement speed divided by the sampling frequency of the sensor

NOTE Sampling interval is normally expressed in millimetres (mm).

3.7
profile measurement length
l_p
length of an uninterrupted profile measurement

NOTE Profile measurement length is normally expressed in metres (m) or millimetres (mm).

3.8
repetition interval
r
distance between the beginning of two consecutive profile measurement lengths, the latter as defined in 3.7

NOTE Repetition interval is normally expressed in metres (m).

3.9
evaluation length
l
length of a sample from a profile which has been or is to be analysed

NOTE 1 The evaluation length may or may not be equal to the profile measurement length (but never greater).

NOTE 2 Evaluation length is normally expressed in metres (m) or millimetres (mm).

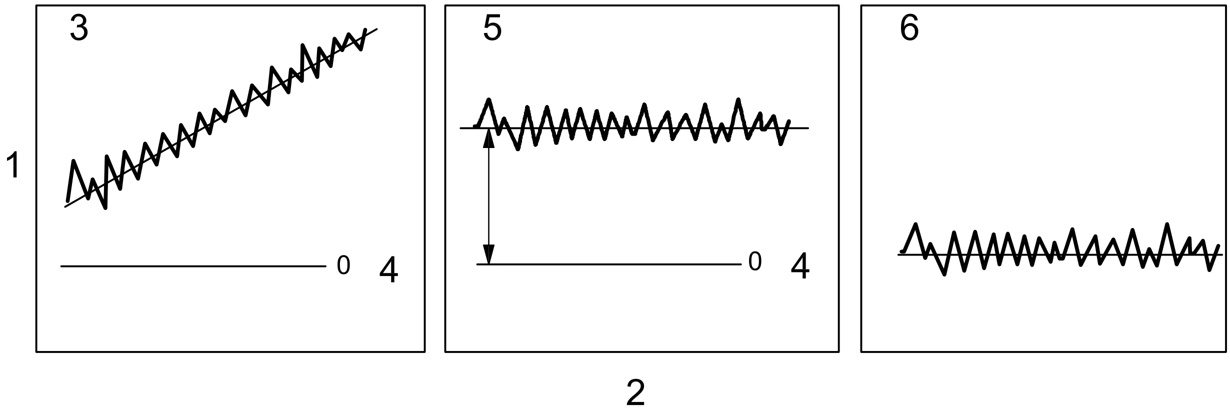
3.10
drop-out
measured point (sample) on the profile which is recognized as invalid, and which is usually discarded in the subsequent data processing

3.11
drop-out rate
percentage (%) of measured points within the evaluation length which are recognized as being invalid

3.12
zero-mean, slope-suppressed profile curve
$Z(x)$
profile curve, $Z(x)$, for which the mean level of the profile over the evaluation length has been brought to zero and for which long-wavelength trends have been removed

NOTE 1 To obtain a profile curve useful for mathematical calculations, it is necessary to remove any slope or long-wavelength component (slope suppression), as well as to bring the mean level of the profile over the evaluation length to zero (offset suppression). This can be accomplished by subtracting a least-squares fit from the profile, see 9.2. The resulting mean line of the profile is then at zero level. See illustration in Figure 1.

NOTE 2 The features in Figure 1 are exaggerated in order to make the illustration clearer. If subtracting a least-squares fit from the profile, the two steps from left to right in the figure are performed in one operation (which can be performed also by high-pass filtering).



Key

1 vertical distance
2 horizontal distance
3 original profile
4 0 level
5 slope suppression applied
6 offset suppression applied

Figure 1 — Illustration of slope and offset suppressions

3.13
surface profile spectrum
texture spectrum
unevenness spectrum
spectrum obtained when a profile curve has been analysed by either digital or analogue filtering techniques in order to determine the magnitude of its spectral components at different wavelengths (3.1) or spatial frequencies (3.14)

NOTE A texture spectrum presents the magnitude of each spectral component as a function of either texture wavelength or spatial frequency.

3.14
spatial frequency
inverse of (texture) wavelength

NOTE 1 Spatial frequency is normally expressed in reciprocal metres (m^{-1}); see also 3.1, Note 3.

NOTE 2 The term “frequency” used in the time domain, more precisely “temporal frequency”, corresponds to “spatial frequency” in the space domain.

3.15
surface (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 Table 1 in ISO 13473-2:2002.

NOTE 1 The texture profile level can be expressed by the following equation:

$$L_{TX,\lambda} \text{ or } L_{tx,\lambda} = 10 \lg \frac{a_\lambda^2}{a_{ref}^2} = 20 \lg \frac{a_\lambda}{a_{ref}} \text{ dB} \quad (1)$$

where

$L_{tx,\lambda}$ is the texture profile level in one-third-octave bands (ref. 10^{-6} m), in decibels;

$L_{TX,\lambda}$ is the texture profile level in octave bands (ref. 10^{-6} m), in decibels;

a_{λ} is the root mean square value of the vertical displacement of the surface profile, in metres;

a_{ref} is the reference value (= 10^{-6} m);

λ is the subscript indicating a value obtained with a one-third-octave-band or octave-band filter having centre wavelength λ.

NOTE 2 Octave-band and one-third-octave-band filters are specified in 4.4 of ISO 13473-2:2002.

NOTE 3 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 part of ISO 13473.

NOTE 4 Texture profile levels in practical pavement engineering typically range from 20 dB to 80 dB with these definitions.

3.16
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 In the case of a bandwidth filtered signal in the time domain, the PSD may be defined as the limit value of the time averaged squared signal within a certain frequency interval divided by the bandwidth of this frequency interval when the bandwidth approaches zero and the averaging time goes to infinity, resulting in the spectrum being presented in terms of squared amplitude per unit frequency, as expressed by Equation (2).

$$X_{PSD} = \lim_{\Delta f \to 0,\, T \to \infty} \frac{1}{(\Delta f)T} \int_0^T x^2(f_0, \Delta f, t)\,\mathrm{d}t \tag{2}$$

where

X_{PSD} is the power spectral density of a time signal x;

Δf is the bandwidth of the frequency interval in hertz, Hz;

T is the averaging time in seconds, s.

NOTE 2 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 9.4)

NOTE 3 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 4 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.

4 Basic outline of methodologies of spatial frequency analysis

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

Method 1 – analogue constant-percentage bandwidth filtering;

Method 2 – digital constant-percentage bandwidth filtering;

Method 3 – 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.

All three methods may be expected to give equivalent results (within the confidence intervals arising from measurement and analysis uncertainty), on condition that the signal quality is high (among other things: free of drop-outs), and that in each of the methods, all signal processing components fulfil the requirements specified in this Technical Specification. If, however, the signal is not free from drop-outs, Method 1 is not recommended because it does not include the possibility for treatment of drop-outs, which may lead to erroneous results.

Method 2 and 3 will produce fully equivalent results. Method 3 includes more steps than Method 2, but may offer greater flexibility in the choice of analysis parameters.

The three alternative methods are shown in the scheme of Figure 2. The left path shows the steps for analogue constant-percentage bandwidth filtering, the middle path shows the steps for digital constant-percentage bandwidth filtering and the right path shows the steps for analysis using the Discrete Fourier Transform.

NOTE 1 In the stepwise approach of Method 2, the steps of "digital sampling" and "digital filtering" may be integrated.

NOTE 2 The different steps of Methods 2 and 3 may be implemented in hardware as well as in software.

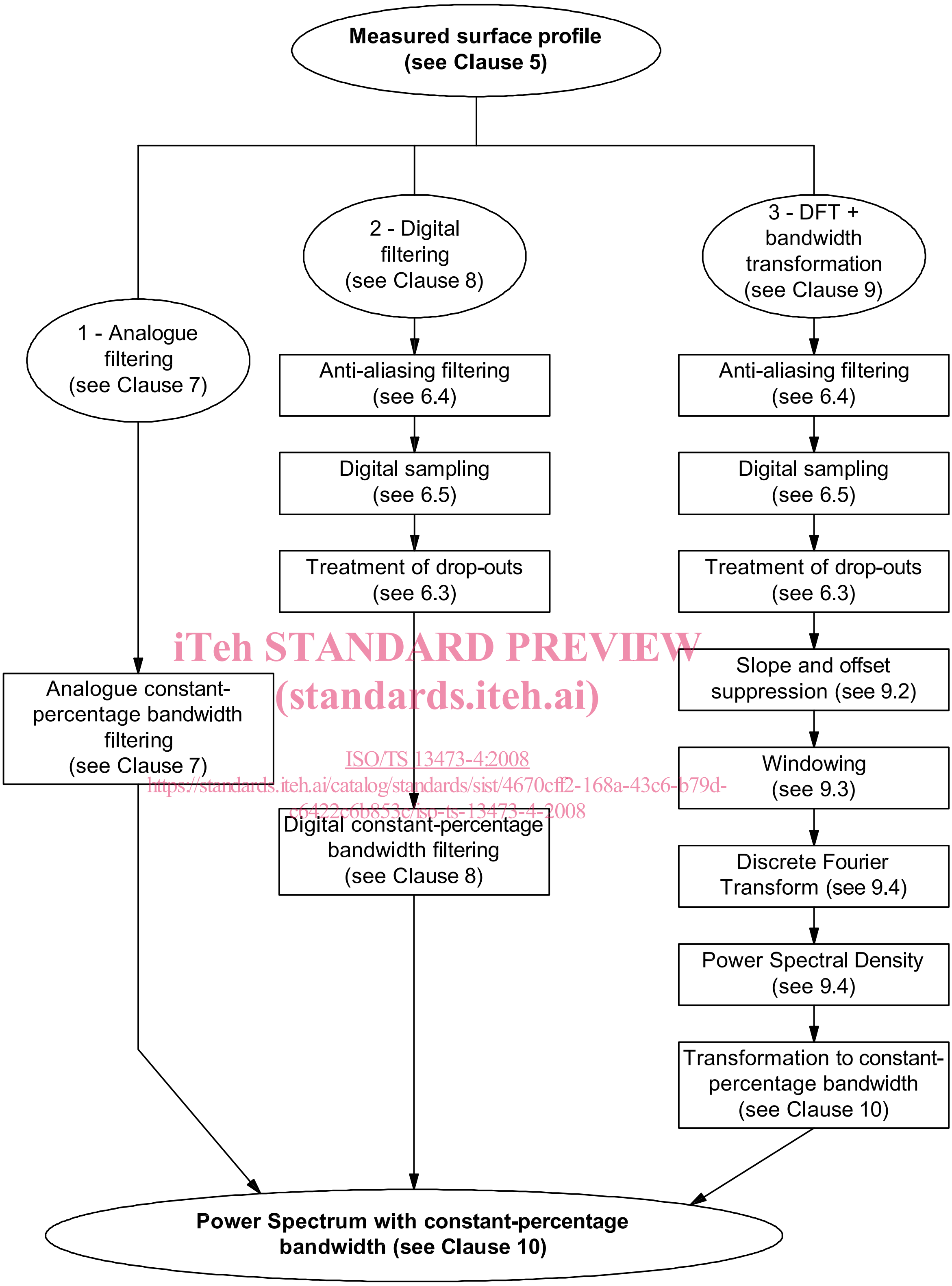


Figure 2 — Scheme for spectral analysis with reference to clauses and subclauses where the subject is discussed