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Mechanical vibration and shock — Signal processing

Part 1:
General introduction

Vibrations et chocs mécaniques — Traitement du signal

Partie 1: Introduction générale

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Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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Foreword

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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.

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 18431-1 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration and shock*.

ISO 18431 consists of the following parts, under the general title *Mechanical vibration and shock — Signal processing*:

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- *Part 1: General introduction*
- *Part 2: Time domain windows for Fourier Transform analysis*
- *Part 4: Shock response spectrum analysis*

The following parts are under preparation:

- *Part 3: Bilinear methods for joint time-frequency analysis*
- *Part 5: Methods for time-scale analysis*

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Introduction

In the recent past, nearly all data analysis has been accomplished through mathematical operations on digitized data. This state of affairs has been accomplished through the widespread use of digital signal acquisition systems and computerized data-processing equipment. The analysis of data is therefore primarily a digital signal-processing task.

The analysis of experimental vibration and shock data should be thought of as a part of the process of experimental mechanics that includes all steps from experimental design through data evaluation and understanding.

This part of ISO 18431 assumes that the data have been sufficiently reduced so that the effects of instrument sensitivity have been included. The data considered in this part of ISO 18431 are considered to be a sequence of time samples of a physical quantity, such as a component of velocity, acceleration, displacement or force. Experimental methods for obtaining these data are outside the scope of this part of ISO 18431.

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Mechanical vibration and shock — Signal processing

Part 1:
General introduction

1 Scope

This part of ISO 18431 defines the mathematical transformations, including the physical units, that convert each category of vibration and shock data into a form that is suitable for quantitative comparison between experiments and for quantitative specifications. It is applicable to the analysis of vibration that is deterministic or random, and transient or continuous signals. The categories of signals are defined in Clause 6.

Extreme care is to be exercised to identify correctly the type of signal being analysed in order to use the correct transformation and units, especially with the frequency domain analysis.

The data may be obtained experimentally from measurements of a mechanical structure or obtained from numerical simulation of a mechanical structure. This category of data is very broad because there is a wide variety of mechanical structures, for example, microscopic instruments, musical instruments, automobiles, manufacturing machines, buildings and civil structures. The data can determine the response of machines or of humans to mechanical vibration and shock.

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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 2041:1990, *Vibration and shock — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 2041 and the following apply.

3.1
aliasing
false representation of spectral energy caused by mixing of spectral components above the Nyquist frequency with those spectral components below the Nyquist frequency

3.2
confidence interval
range within which the true value of a statistical quantity will lie, given a value of the probability

3.3
data
sampled measurements of a physical quantity

3.4
statistical degrees of freedom

number of independent variables in a statistical estimate of a probability

3.5
frequency resolution

difference between two adjacent spectral lines

3.6
number of lines

number of spectral lines that are displayed

3.7
Nyquist frequency

maximum usable frequency available in data taken at a given sampling rate

$$f_{\mathrm{N}} = f_{\mathrm{s}}/2$$

where

f_{N} is the Nyquist frequency;

f_{s} is the sampling frequency

3.8
record length

number of data points comprising a contiguous set of sampled data points

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3.9
sampling

measurement of a varying physical quantity at a sequence of values of time, angle, revolutions or other mechanical, independent variable

3.10
sampling frequency

number of samples per unit of time for uniformly sampled data

3.11
sampling interval

number of units (e.g. time, angle, revolutions) between two successive samples

3.12
sampling period

duration of time between two successive samples

3.13
sampling rate

number of samples per unit of time, angle, revolutions or other mechanical, independent variable for uniformly sampled data

3.14
side-lobes

sequence of peaks in the frequency domain caused by the use of a finite time window with the Fourier Transform

3.15
signal bandwidth

interval over frequency between the upper and lower frequencies of interest

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3.16
spectral leakage
width of the peak in the power spectrum due to a single spectral component caused by using a finite window with the Fourier Transform

4 Symbols and abbreviated terms

ADC	analog-to-digital converter
B	signal bandwidth
B_{e}	equivalent noise bandwidth
C_{a}	amplitude scaling factor
DFT	Discrete Fourier Transform
$E\{\,\}$	expectation operator that computes the statistical mean value or average value
$F(n)$	time-dependent force
$H_1(m)$	frequency response function of the first type
$H_2(m)$	frequency response function of the second type
K	summation limit of time delay k or length of window $w(k)$
I	number of data blocks
L	record length
L_i	level in units U_x for amplitude histogram of signal $x(n)$
N	data block length: the number of sampled points that are transformed
$O_x(k,m)$	wavelet transform of $x(n)$
$P_{xx}(m)$	power spectral density of signal $x(n)$
$P_{xx,\mathrm{low}}(m)$	low frequency part of the power spectral density of signal $x(n)$
$P_{x2,\mathrm{low}}(m)$	low frequency part of the power spectral density of signal $x^2(n)$
$P_{xy}(m)$	cross power spectral density of signal $x(n)$ with $y(n)$
Q	quality factor of a single degree-of-freedom system
$R_{xx}(m)$	r.m.s. spectrum of signal $x(n)$
$S_x(m,n)$	short-time Fourier Transform of $x(n)$
T	total time of a block of digital data = $N\Delta t$
$V(k,m)$	Cohen class filter for smoothing the Wigner distribution
$X(m)$	Discrete Fourier transform of $x(n)$
$Y(m)$	Discrete Fourier transform of $y(n)$
b	number of increments, also known as bits, in an ADC
$c_{xx}(k,n)$	auto-covariance of $x(n)$
$c_{xy}(k,n)$	cross-covariance of $x(n)$ with $y(n)$
$e_{xx}(m)$	energy spectral density of signal $x(n)$
$e_{xy}(m)$	cross energy spectral density of signals $x(n)$ and $y(n)$
f	frequency = $m\Delta f$
f_{N}	Nyquist frequency, the highest frequency present in a sampled signal
f_{n}	natural frequency of a single degree-of-freedom system
f_{s}	sampling frequency = $1/\Delta t$
i	index of data block
k	index of time shift
l	index of summation
m	index of frequency or scale
$\overline{x(n)}$	mean of non-stationary signal $x(n)$

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$\bar{x}$	mean of stationary signal $x(n)$
n	index of time
p	lower limit of summation
q	upper limit of summation
r	upper limit of summation
$r_{xx}(k,n)$	auto-correlation of non-stationary data $x(n)$
$r_{xx}(k)$	auto-correlation of stationary data $x(n)$
$r_{xy}(k,n)$	cross-correlation of non-stationary data $x(n)$ with $y(n)$
$r_{xy}(k)$	cross-correlation of stationary data $x(n)$ with $y(n)$
t	time = $n\Delta t$
$v_x(n)$	variance of the non-stationary data $x(n)$
v_x	variance of the data $x(n)$
$w(n)$	window function
$x(n)$	physical data in the time domain
$y(n)$	physical data in the time domain
Δt	sample period
Δf	frequency resolution
ε_{r}	relative random error
$\gamma_{xy}{}^2(m)$	coherence function
$\nu(n)$	noise component of measured signal
$\psi(n)$	mother wavelet
$\sigma_x{}^2$	statistical variance of x
$\Xi_x(m,n)$	Cohen class Wigner distribution using Cohen class filter $V(n,m)$
$\Omega_x(m,n)$	Wigner distribution of signal $x(n)$

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5 Signal conditioning

5.1 Cautionary overview

The electrical signal from a transducer shall be properly conditioned for digitization by an analog-to-digital converter (ADC). This signal conditioning requires the determination of several parameters associated with amplification, filtering and digitization. The selection of these parameters is very important for the acquisition of data that is appropriate for signal processing.

5.2 Filtering

Before the signal can be successfully digitized by the ADC, the signal shall be low-pass filtered to prevent aliasing. Aliasing occurs when there are components of the signal at a frequency that is too high. The highest frequency in the signal is limited by the sampling frequency, f_{s}, of the ADC. The range of settings of f_{s} are found in the specifications of the ADC. The highest frequency component of the signal may be no greater than $f_{\mathrm{N}} = f_{\mathrm{s}}/2$, which is known as the Nyquist frequency. The upper frequency of the low-pass filter depends on the roll-off characteristics of the filter and the spectral properties of the signal. If the phase of the data is important, attention shall also be paid to the phase characteristics of the filter.

The following test should be performed to check the adequacy of the low-pass filter. A signal should be digitized and recorded. Then a Fourier transform should be performed on the data. The amplitude of the Fourier-transformed signal at the Nyquist frequency should be less than or equal to the expected noise level of the Fourier-transformed signal at the frequency of interest. If this is not the case, then the sampling rate should be increased or the upper frequency of the low-pass filter should be lowered.

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In addition to the low-pass filter, a high-pass filter may also be required because a non-negligible d.c. component of the signal may reduce the useful range of the ADC. Reducing or eliminating this offset prior to digitizing is preferable unless the d.c. component or low-frequency components are important.

The external analog anti-aliasing filtering considerations for a sigma delta ADC are different. The analog signal shall meet the Nyquist criterion for the high frequency 1-bit digitizer, not the frequency for the end result. With sigma delta digitizers, the manufacturer usually includes the low-pass filter needed for the analog input and an internal digital low-pass filter to match the output sample rate.

5.3 Sampling

The ADC converts an analog signal into a sequence of integers. The output integers are proportional to the input over a range of voltage. This range of voltage is given in the specifications of the ADC and determines the proper gain setting discussed in 5.1.

NOTE The number of increments b in the largest output number determines the dynamic range of the ADC, which is specified in terms of decibels, $6b$ + 1,8 dB.

The sequence of numbers is sampled at a rate called the sampling frequency, f_s, discussed in 5.1. A signal may be resampled to order track the signal into samples that are equal increments of units other than time, for example angular displacement or degrees.

Another parameter to be selected is the number of samples, the record length. The record length shall be large enough to capture the whole signal if the signal is transient or limited in time.

The sampling frequency, f_s, fixes the following parameters:

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— the maximum (Nyquist) frequency $f_N = f_s/2$

— the sampling interval $\Delta t = 1/f_s$

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6 Determination of signal type

6.1 Signal taxonomy

The signals that make up the data are considered to be approximate members of idealized categories. In this part of ISO 18431, the signals are categorized by the taxonomy shown in Table 1.The category of signal often determines the methods of analysis. If an inappropriate analysis is used, then the results may be misleading or inconclusive. Usually data contain a mixture of two types of signals. For example, a signal may be the sum of a deterministic, non-periodic transient signal and a random, stationary, continuous signal. The triggering, filtering and processing to determine the characteristics of the two signals are very different. The type of signal to be described determines the signal conditioning digitization and data analysis. For example, specifying a mechanical environment for equipment requires random, non-stationary transients to be sufficiently described so that the mechanical conditions can be experimentally modelled with deterministic, non-periodic transients.

The signal taxonomy shown in Table 1 implies the decision tree required to determine the nature of the signal of interest and also the subsequent data analysis.