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Mechanical vibration, shock and condition monitoring — Vocabulary

Vibrations et chocs mécaniques, et leur surveillance — Vocabulaire

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Foreword

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This document was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*.

This fourth edition cancels and replaces the third edition (ISO 2041:2009), which has been technically revised.

The main changes compared to the previous edition are as follows:

— changes in format to conform to the ISO/IEC Directives, Part 2: 2018;

— correction of the formula in 3.1.58 (2.1.58 in the previous edition);

— addition of Figure 4 and Figure 5.

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.

Mechanical vibration, shock and condition monitoring — Vocabulary

1 Scope

This document defines terms and expressions unique to the areas of mechanical vibration, shock and condition monitoring.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

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

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

3.1 General terms

3.1.1
displacement
relative displacement
⟨vibration and shock⟩ time varying quantity that specifies the change in position of a point on a body with respect to a reference frame

Note 1 to entry: The reference frame is usually a set of axes within which a set of coordinates defines the change in position of a point on a body. In general, a rotation displacement vector, a translation displacement vector, or both can represent the displacement.

Note 2 to entry: A displacement is designated as a relative displacement if it is measured with respect to a reference frame other than the primary reference frame designated in a given case.

Note 3 to entry: Displacement can be:

— oscillatory, in which case simple harmonic components can be defined by the displacement amplitude (and frequency), or

— random, in which case the root-mean-square (rms) displacement (and band-width and probability density distribution) can be used to define the probability that the displacement will have values within any given range.

Note 4 to entry: Displacements of short time are defined as transient displacements. Non-oscillatory displacements are defined as sustained displacements, if of long duration, or as displacement pulses, if of short duration.

3.1.2
velocity
relative velocity
⟨vibration and shock⟩ rate of change of displacement

Note 1 to entry: In general, velocity is time-dependent.

Note 2 to entry: The reference frame is usually a set of axes within which a set of coordinates defines the rate of change of displacement of a point on a body. In general, a rotation velocity vector, a translation velocity vector, or both can represent the velocity.

Note 3 to entry: A velocity is designated as a relative velocity if it is measured with respect to a reference frame other than the primary reference frame designated in a given case. The relative velocity between two points is the vector difference between the velocities of the two points.

Note 4 to entry: Velocity can be:

— oscillatory, in which case simple harmonic components can be defined by the velocity amplitude (and frequency), or

— random, in which case the root-mean-square (rms) velocity (and band-width and probability density distribution) can be used to define the probability that the velocity will have values within any given range.

Note 5 to entry: Velocities of short time duration are defined as transient velocities. Non-oscillatory velocities are defined as sustained velocities, if of long duration.

3.1.3
acceleration
relative acceleration
⟨vibration and shock⟩ rate of change of velocity

Note 1 to entry: In general, acceleration is time-dependent.

Note 2 to entry: The reference frame is usually a set of axes within which a set of coordinates defines the rate of change of velocity of a point on a body. In general, a rotation acceleration vector, a translation acceleration vector, or both and the Coriolis acceleration can represent the acceleration.

Note 3 to entry: An acceleration is designated as a relative acceleration if it is measured with respect to a reference frame other than the inertial reference frame designated in a given case. The relative acceleration between two points is the vector difference between the accelerations of the two points.

Note 4 to entry: In the case of time-dependent accelerations, various self-explanatory modifiers, such as peak, average and rms (root-mean-square), are often used. The time intervals over which the average or root-mean-square values are taken should be indicated or implied.

Note 5 to entry: Acceleration can be:

— oscillatory, in which case simple harmonic components can be defined by the acceleration amplitude (and frequency), or

— random, in which case the rms acceleration (and band-width and probability density distribution) can be used to define the probability that the acceleration will have values within any given range.

Note 6 to entry: Accelerations of short time duration are defined as transient accelerations. Non-oscillatory accelerations are defined as sustained accelerations, if of long duration, or as acceleration pulses, if of short duration.

3.1.4
standard acceleration due to gravity
g_n
standard acceleration of free fall
unit, 9,806 65 metres per second-squared (9,806 65 m/s^2)

Note 1 to entry: The value was adopted in the International Service of Weights and Measures in 1901 (Resolution of the 3rd CGPM) as the standard for acceleration due to gravity.

Note 2 to entry: This "standard value" (g_n = 9,806 65 m/s^2 = 980,665 cm/s^2 approximately 386,089 in/s^2 approximately 32,174 0 ft/s^2) should be used for reduction to standard gravity of measurements made in any location on Earth.

Note 3 to entry: Frequently, the magnitude of acceleration is expressed in units of g_n.

Note 4 to entry: The actual acceleration produced by the force of gravity at or below the surface of the Earth varies with the latitude and elevation of the point of observation. This variable is often expressed using the symbol g. Caution should be exercised if this is done so as not to create an ambiguity with this use and the standard symbol for the unit of the gram.

Note 5 to entry: Historically, this value of g_n was the conventional reference for calculating the now obsolete unit kilogram force.

3.1.5
force
dynamic influence that changes a body from a state of rest to one of motion or changes its velocity

Note 1 to entry: A force could also change a body's size or shape if the body resists motion.

Note 2 to entry: Force is expressed in newtons. One newton is the force required to give a mass of one kilogram an acceleration of one metre per second squared.

3.1.6
restoring force
reactive force caused by the elastic property of a structure when it is being deformed

3.1.7
jerk
rate of change of acceleration

3.1.8
inertial reference system
inertial reference frame
coordinate system or frame which is fixed in space or moves at a constant velocity without rotational motion and thus, not accelerating

3.1.9
inertial force
reactive force exerted by a mass when it is being accelerated

3.1.10
oscillation
variation, usually with time, of the magnitude of a quantity with respect to a specified reference when the magnitude is alternately greater and smaller than the specified reference

Note 1 to entry: See *vibration* (3.2.1).

Note 2 to entry: Variations with time such as shock processes or creeping motions are also considered to be oscillations in a more general sense of the word.

3.1.11
environment
all external conditions influencing a system at any given moment

Note 1 to entry: See *induced environment* (3.1.12) and *natural environment* (3.1.13).

3.1.12
induced environment
conditions external to a system generated as a result of the operation of the system

3.1.13
natural environment
conditions generated by the forces of nature and the effects of which are experienced by a system when it is at rest as well as when it is in operation

3.1.14
preconditioning
climatic and/or mechanical and/or electrical treatment procedure which may be specified for a particular system so that it attains a defined state

3.1.15
conditioning
climatic and/or mechanical and/or electrical conditions to which a system is subjected in order to determine the effect of such conditions upon it

3.1.16
excitation
stimulus
external force (or other input) applied to a system that causes the system to respond in some way

3.1.17
response
<system> output quantity of a system

3.1.18
transmissibility
tranmissibility function
dimensionless complex ratio of the response of a system in forced vibration to the excitation

Note 1 to entry: The ratio may be one of forces, displacements, velocities or accelerations.

3.1.19
overshoot
maximum transient response that exceeds the desired response

Note 1 to entry: If the output of a system is changed from a steady value A to a steady value B by varying the input, such that B is greater than A, the response is said to overshoot when the maximum transient response exceeds the value B.

Note 2 to entry: The difference between the maximum transient response and the value B is the value of the overshoot. This is usually expressed as a percentage.

3.1.20
undershoot
minimum transient response that falls below the desired response

Note 1 to entry: If the output of a system is changed from a steady value A to a steady value B by varying the input, such that B is less than A, the response is said to undershoot when the minimum transient response is less than the value B.

Note 2 to entry: The difference between the minimum transient response and the value B is the value of the undershoot. This is usually expressed as a percentage.

3.1.21
system
set of interrelated elements considered in a defined context as a whole and separated from their environment

3.1.22
linear system
system in which the magnitude of the response is proportional to the magnitude of the excitation

Note 1 to entry: This definition implies that the principle of superposition can be applied to the relationship between the output response and the input excitation.

3.1.23
mechanical system
system comprising elements of mass, stiffness and damping

3.1.24
foundation
structure that supports a mechanical system

Note 1 to entry: It can be fixed in a specified reference frame or it can undergo a motion.

3.1.25
seismic system
system consisting of a mechanical system attached to a reference base by one or more flexible elements, with damping normally included

Note 1 to entry: Seismic systems are usually idealized as single-degree-of-freedom systems with linear (viscous) damping.

Note 2 to entry: The natural frequencies of the mass as supported by the flexible elements are relatively low for seismic systems associated with displacement or velocity transducers, and are relatively high for acceleration transducers, as compared with the range of frequencies to be measured.

Note 3 to entry: When the natural frequency of the seismic system is low relative to the frequency range of interest, the mass of the seismic system may be considered to be at rest over this range of frequencies.

3.1.26
equivalent system
system that can be substituted for another system for the purpose of analysis

Note 1 to entry: Many types of equivalence are common in vibration and shock technology:

a) a torsional system equivalent to a translational system;

b) an electrical or acoustical system equivalent to a mechanical system, etc.;

c) equivalent stiffness;

d) equivalent damping.

3.1.27
degrees of freedom
DOF
minimum number of generalized coordinates required to define completely the configuration of a mechanical system

Note 1 to entry: This applies to mechanical systems, not to be confused with statistical degrees of freedom.

3.1.28
discrete system
lumped parameter system
mechanical system in which the mass, stiffness and/or damping elements are discretely located

3.1.29
single-degree-of-freedom system
SDOF
system requiring only one coordinate to define completely its configuration at any instant

3.1.30
multi-degree-of-freedom system
system for which two or more coordinates are required to define completely the configuration of the system at any instant

3.1.31
continuous system
mechanical system in which the mass, stiffness and/or damping properties are spatially distributed rather than discretely located

Note 1 to entry: The configuration of a continuous system is specified by a function of a continuous spatial variable, or variables, in contrast to a discrete or lumped parameter system that requires only a finite number of coordinates to specify its configuration.

3.1.32
centre of gravity
point through which the resultant of the weights of the component particles of a body passes without resulting in a moment given any orientation of that body with respect to a gravitational field

Note 1 to entry: If the field is uniform, the centre of gravity coincides with the *centre of mass* (3.1.33).

3.1.33
centre of mass
point of a body with reference to a Cartesian coordinate system where the first moment of the overall mass is equal to the first moments of mass of all points of that body

Note 1 to entry: This is the point at which an object is in balance in a uniform gravitational field.

3.1.34
principal axes of inertia
three mutually perpendicular axes intersecting each other at a given point about which the products of inertia of a solid body are zero

Note 1 to entry: If the point is the centre of mass of the body, the axes and moments are called central principal axes and central principal moments of inertia.

Note 2 to entry: In balancing, the term "principal inertia axis" is used to designate the one central principal axis (of the three such axes) most nearly coincident with the shaft axis of the rotor and is sometimes referred to as the balance axis or the mass axis.

3.1.35
moment of inertia
sum (integral) of the product of the masses of the individual particles (elements of mass) of a body and the square of their perpendicular distances from the axis of rotation

3.1.36
product of inertia
sum (integral) of the product of the masses of the individual particles (elements of mass) of a body and their distances from two mutually perpendicular planes

3.1.37
stiffness
ratio of change of force (or torque) to the corresponding change in translational (or rotational) deformation of an elastic element

Note 1 to entry: See also *dynamic stiffness* (3.1.58).

3.1.38
compliance
reciprocal of stiffness

Note 1 to entry: See also *dynamic compliance* (3.1.57).

3.1.39
neutral surface
neutral surface of a beam in simple flexure
surface in which there is no strain

Note 1 to entry: It should be stated whether or not the neutral surface is a result of the flexure alone, or whether it is a result of the flexure and other superimposed loads.

3.1.40
neutral axis
neutral axis of a beam in simple flexure
line or plane in a beam where the longitudinal stress, tensile or compressive is zero

3.1.41
transfer function
mathematical representation of the relationship between the input and output of a linear time-invariant system

Note 1 to entry: A transfer function is usually a complex function defined as the ratio of the Laplace transforms of the output to the input of a linear time-invariant system.

Note 2 to entry: It is usually given as a function of frequency, and is usually a complex function. See *response* (3.1.17), *transmissibility* (3.1.18) and *transfer impedance* (3.1.50).

3.1.42
complex excitation
excitation expressed as a complex quantity with amplitude and phase angle

Note 1 to entry: The concepts of complex excitations and responses were evolved historically in order to simplify calculations. The actual excitation and response are the real parts of the complex excitation and response. If the system is linear, the concept is valid because superposition holds in such a situation.

Note 2 to entry: This term should not be confused with excitation by a complex vibration, or vibration of complex waveform. The use of the term “complex vibration” in this sense is deprecated.

3.1.43
complex response
response of a system expressed as a complex quantity with amplitude and phase angle from a specified excitation

Note 1 to entry: See the notes under *complex excitation* (3.1.42).

3.1.44
modal analysis
vibration analysis method that characterizes a complicated, linear system by its modes of vibration, i.e. natural frequencies, modal damping and mode shapes

3.1.45
modal matrix
linear transformation matrix which consists of the eigen vectors or modal vectors of a system

Note 1 to entry: It renders the system both inertially and elastically uncoupled, i.e. the modal mass and modal stiffness matrices are transformed into diagonal matrices.

3.1.46
modal stiffness
stiffness element associated with a specified mode of vibration

3.1.47
modal density
number of modes with respect to a given bandwidth

Note 1 to entry: Modal density is a measure widely used in structural dynamics as a diagnostic tool in assessing vibration power flow in complex, structural systems. It can play a crucial role in determining changes in vibration power flow that may be a precursor to fatigue failure in some part of the structure, or a metric used in structural condition monitoring evaluations. In addition to these applications, it is a parameter required by the Statistical Energy Analysis method for evaluating the high-frequency response of complex structures and in selecting appropriate vibration-control methods and devices.

3.1.48
mechanical impedance
complex ratio of force to velocity at a specified point and degree-of-freedom in a mechanical system

Note 1 to entry: The force and velocity may be taken at the same or different points and degrees-of-freedom in the system undergoing simple harmonic motion.

Note 2 to entry: In the case of torsional mechanical impedance, the terms “force” and “velocity” should be replaced by “torque” and “angular velocity”, respectively.

Note 3 to entry: In general, the term “impedance” applies to linear systems only.

Note 4 to entry: The concept is extended to nonlinear systems where the term “incremental impedance” is used to describe a similar quantity.

3.1.49
direct mechanical impedance
driving point mechanical impedance
complex ratio of the force to velocity taken at the same point or degree-of-freedom in a mechanical system during simple harmonic motion

Note 1 to entry: See the notes under *mechanical impedance* (3.1.48).

3.1.50
transfer impedance
transfer mechanical impedance
complex ratio of the force applied at point *i*, in a specified degree-of-freedom in a mechanical system, to the velocity at another point *j* in a specified direction or degree-of-freedom in the same system, during simple harmonic motion

Note 1 to entry: See the notes under *mechanical impedance* (3.1.48).

3.1.51
free impedance
ratio of the applied excitation complex force to the resulting complex velocity with all other connection points of the system free, i.e. having zero restraining forces

Note 1 to entry: Historically, often no distinction has been made between blocked impedance and free impedance. Caution should, therefore, be exercised in interpreting published data.

Note 2 to entry: Free impedance is the arithmetic reciprocal of a single element of the mobility matrix. While experimentally determined free impedances could be assembled into a matrix, this matrix would be quite different from the blocked impedance matrix resulting from mathematical modelling of the structure and, therefore, would not conform to the requirements for using mechanical impedance in an overall theoretical analysis of the system.

3.1.52
blocked impedance
impedance at the input when all output degrees of freedom are connected to a load of infinite mechanical impedance

Note 1 to entry: Blocked impedance is the frequency-response function formed by the ratio of the phasor of the blocking or driving-point force response at point *i*, to the phasor of the applied excitation velocity at point *j*, with all other measurement points on the structure “blocked”, i.e. constrained to have zero velocity. All forces and moments required to fully constrain all points of interest on the structure need to be measured in order to obtain a valid blocked impedance matrix.

Note 2 to entry: Any changes in the number of measurement points or their location will change the blocked impedances at all measurement points.

Note 3 to entry: The primary usefulness of blocked impedance is in the mathematical modelling of a structure using lumped mass, stiffness and damping elements or finite element techniques. When combining or comparing such mathematical models with experimental mobility data, it is necessary to convert the analytical blocked impedance matrix into a mobility matrix or vice versa.

3.1.53
frequency-response function
FRF
frequency-dependent ratio of the motion-response Fourier transform to the Fourier transform of the excitation force of a linear system

Note 1 to entry: Excitation can be harmonic, random or transient functions of time. The test results obtained with one type of excitation can thus be used for predicting the response of the system to any other type of excitation.

Note 2 to entry: Motion may be expressed in terms of velocity, acceleration or displacement; the corresponding frequency-response function designations are mobility, accelerance and dynamic compliance or impedance, effective (i.e. apparent) mass and dynamic stiffness, respectively (see Table 1).

3.1.54
mobility
mechanical mobility
complex ratio of the velocity, taken at a point in a mechanical system, to the force, taken at the same or another point in the system

Note 1 to entry: Mobility is the ratio of the complex velocity-response at point *i* to the complex excitation force at point *j* with all other measurement points on the structure allowed to respond freely without any constraints other than those constraints which represent the normal support of the structure in its intended application.

Note 2 to entry: The term “point” designates both a location and a direction.

Note 3 to entry: The velocity response can be either translational or rotational, and the excitation force can be either a rectilinear force or a moment.

Note 4 to entry: If the velocity response measured is a translational one and if the excitation force applied is a rectilinear one, the units of the mobility term will be m/(N·s).

Note 5 to entry: Mechanical mobility is the matrix inverse of mechanical impedance.

3.1.55
direct mobility
direct mechanical mobility
driving point mobility
driving point mechanical mobility
complex ratio of velocity and force taken at the same point in a mechanical system

Note 1 to entry: Driving-point mobility is the frequency-response function formed by the ratio, in metres per newton second, of the velocity-response complex amplitude at point *j* to the excitation force complex amplitude applied at the same point with all other measurement points on the structure allowed to respond freely without any constraints other than those constraints which represent the normal support of the structure in its intended application.

3.1.56
transfer mobility
transfer mechanical mobility
mechanical mobility where the velocity and the force are considered at different points of the system

3.1.57
dynamic compliance
frequency-dependent ratio of the spectrum, or spectral density, of the displacement to the spectrum, or spectral density, of the force

3.1.58
dynamic stiffness
dynamic elastic constant
dynamic spring constant
complex ratio of the force, taken at a point in a mechanical system, to the displacement, taken at the same or another point in the system

Note 1 to entry: The dynamic stiffness may be dependent upon the strain (amplitude and frequency), strain-rate, temperature or other conditions.

Note 2 to entry: The complex dynamic stiffness, k^*, of a linear translational single-degree-of-freedom system characterized by the equation

$$m\frac{\mathrm{d}^2x}{\mathrm{d}t^2}+c\frac{\mathrm{d}x}{\mathrm{d}t}+kx=F$$

where $F = F_0\, \mathrm{e}^{\mathrm{i}\omega t}$ and $x = x_0\mathrm{e}^{\mathrm{i}\omega t}$

is equal to

$$k* = \frac{F_0}{x_0} = k - m\omega^2 + \mathrm{i}\omega c = k\left\{1-\left(\frac{\omega}{\omega_0}\right)^2 + 2\mathrm{i}\varsigma\left(\frac{\omega}{\omega_0}\right)\right\}$$

where

c	is the linear (viscous) damping coefficient;
e	is the base of natural logarithms;
F_0	is the force amplitude;
i	$=\sqrt{-1}$;
k	is the elastic (spring) constant;
m	is the mass;

t is the time;

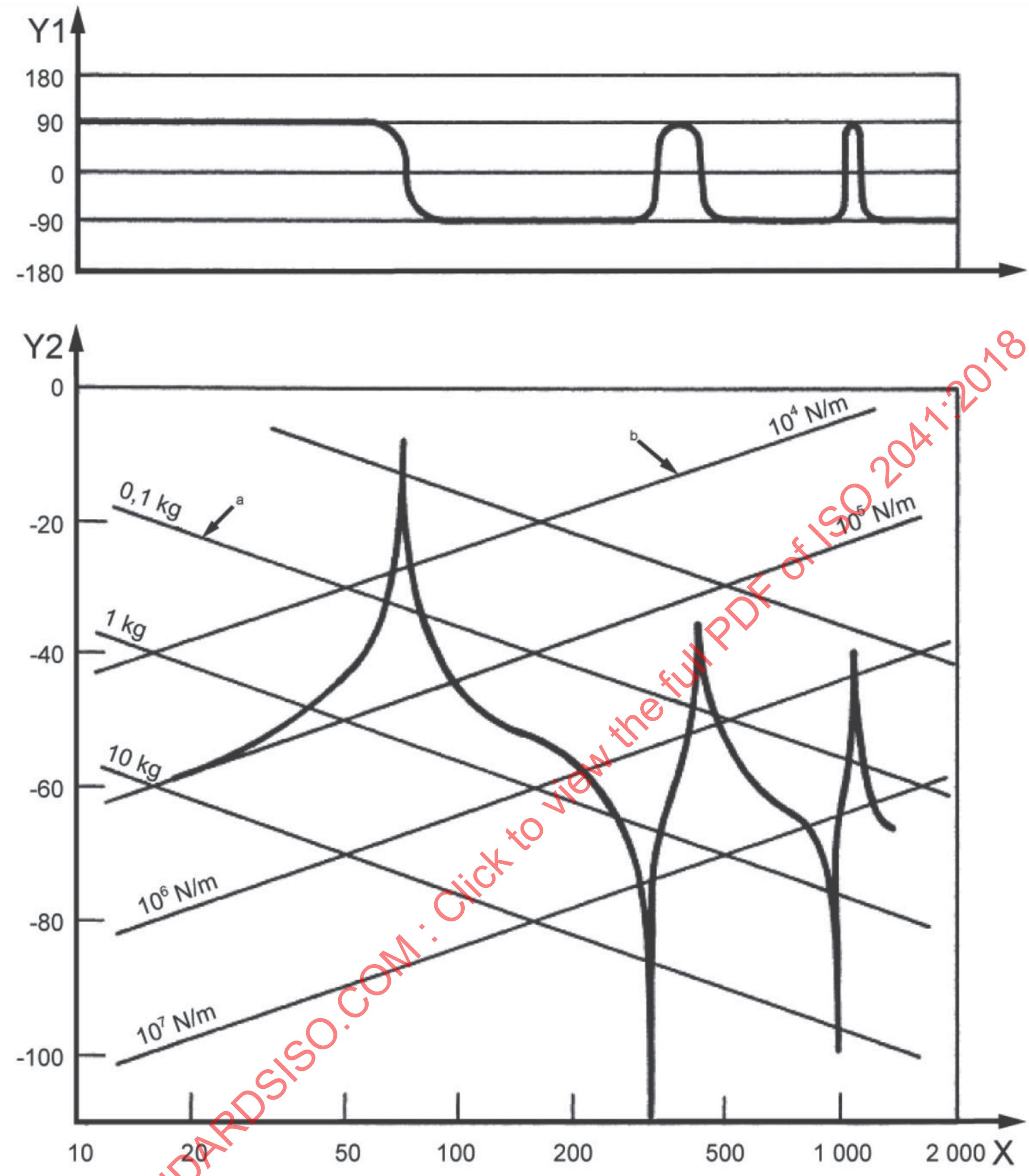
x is the displacement;

x_0 is the displacement amplitude;

$\zeta \left(= \frac{c}{2\sqrt{mk}} \right)$ is the damping ratio;

ω is the angular frequency;

$\omega_0 \left(= \sqrt{k / m} \right)$ is the natural angular frequency.



Key

X frequency, in hertz (Hz)

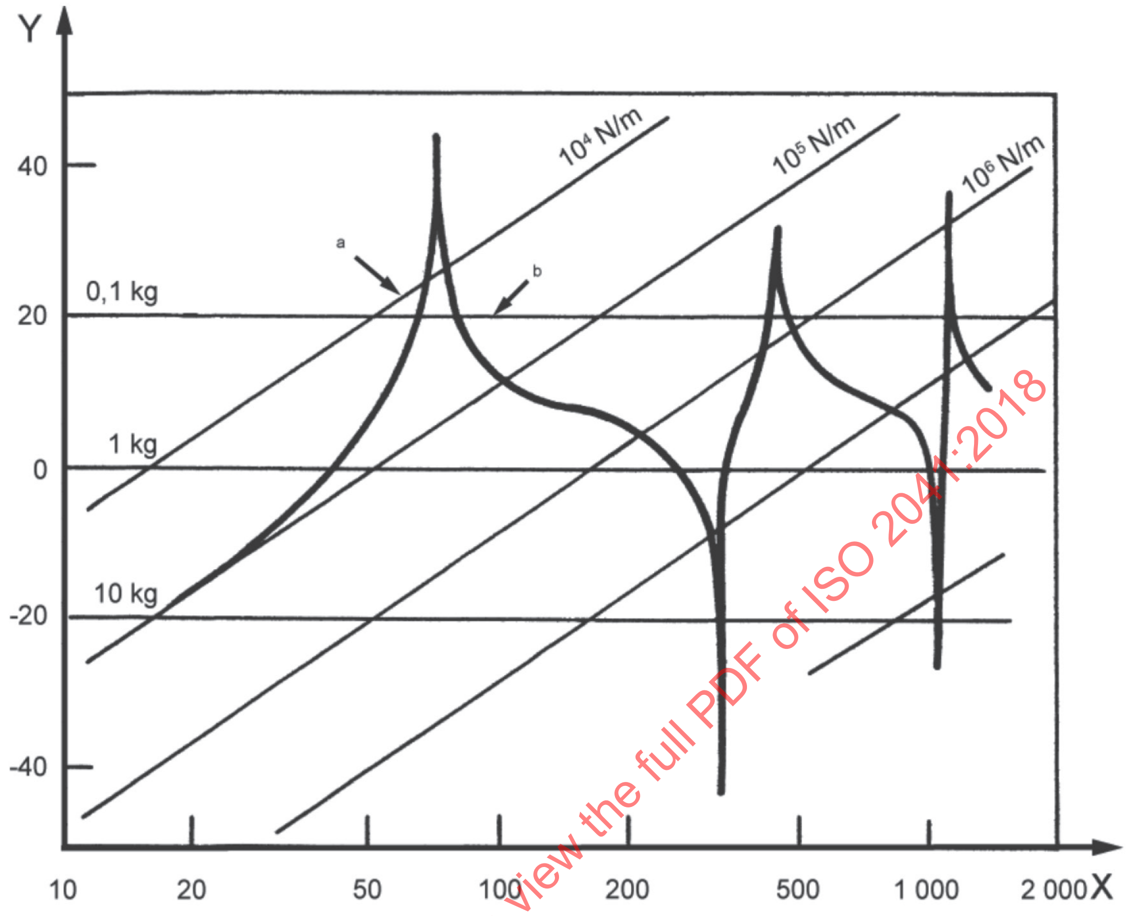
Y1 phase angle, in degrees

Y2 mobility magnitude, in decibels (dB), [ref. 1 m/(N·s)]

a Downwards sloping lines are used for mass.

b Upwards sloping lines are used for stiffness.

Figure 1 — Mobility plot



Key

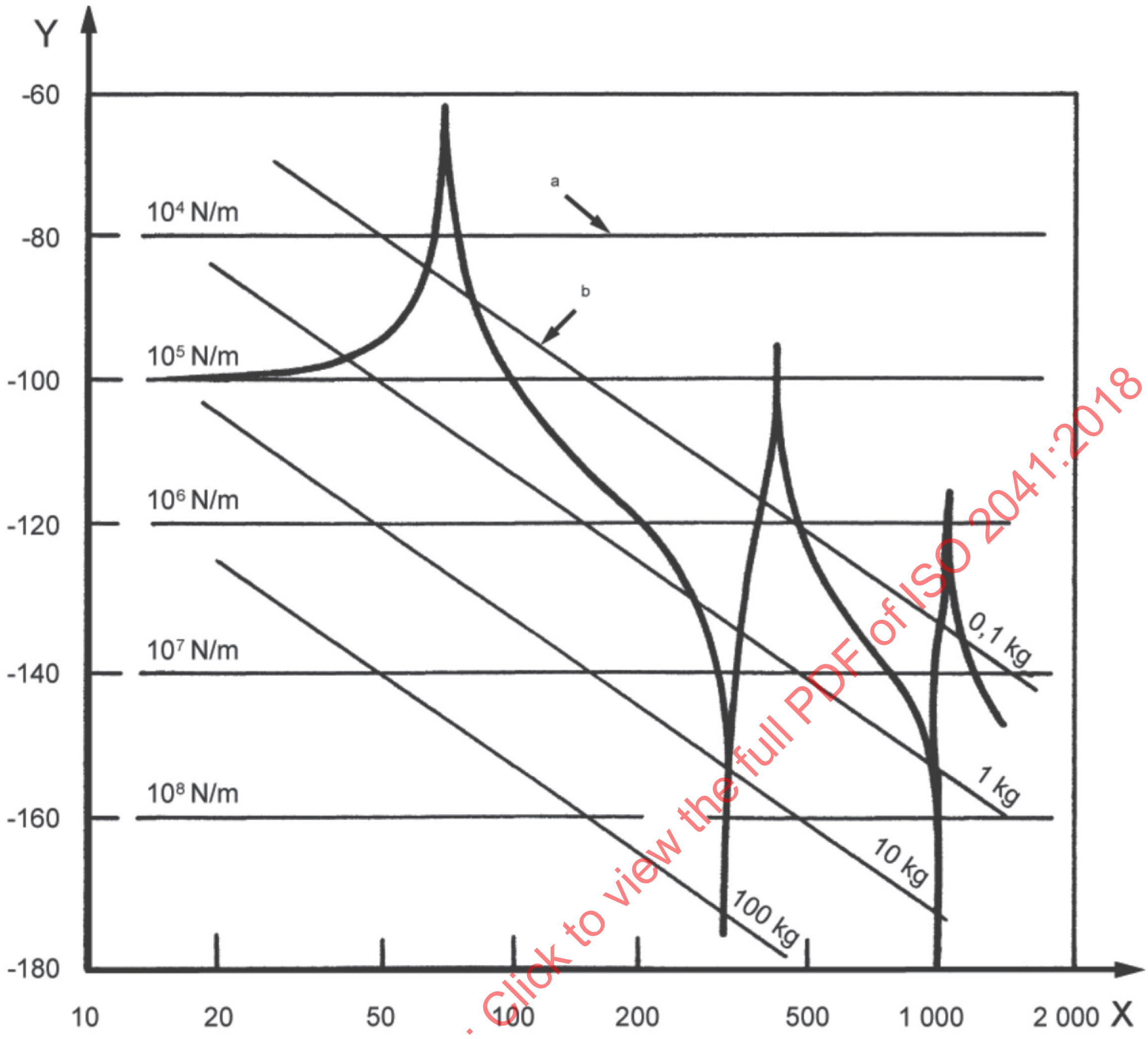
X frequency, in hertz (Hz)

Y accelerance, in decibels (dB), [ref. 1 m/(N·s²)]

a Upwards sloping lines represent stiffness.

b Horizontal lines represent mass.

Figure 2 — Accelerance magnitude plot corresponding to the mobility graph plotted in Figure 1



Key

X frequency, in hertz (Hz)

Y dynamic compliance, in decibels (dB), [ref. 1 m/N]

a Horizontal lines represent stiffness.

b Downwards sloping lines represent mass.

Figure 3 — Dynamic compliance magnitude plot corresponding to the mobility graph plotted in Figure 1

3.1.59
dynamic mass
complex ratio of force to acceleration

3.1.60
accelerance
frequency-dependent ratio of the spectrum, or spectral density, of the acceleration to the spectrum, or spectral density, of the force

3.1.61
spectrum
description of a quantity as a function of frequency or wavelength

3.1.62
level
<quantity> logarithm of the ratio of a quantity to a reference of the same kind

Note 1 to entry: The levels are normally defined in terms of base 10 logarithm. Otherwise, the base of the logarithm is specified.

Note 2 to entry: Examples of kinds of levels in common use are electric-power level, sound-pressure level, and voltage level.

Note 3 to entry: The level of sound-pressure, voltage or other field quantity, *F*, is normally:

$$F = 20 \lg (F/F_0)$$

The level of electric-power or another power quantity, *P*, is normally:

$$P = 10 \lg (P/P_0)$$

Note 4 to entry: A difference in the levels of two like quantities q_1 and q_2 is described by the same formula because, by the rules of logarithms, the reference quantity is automatically divided out as follows:

$$\log_r \frac{q_1}{q_0} - \log_r \frac{q_2}{q_0} = \log_r \frac{q_1}{q_2}$$

Note 5 to entry: In vibration terminology, the term “level” is sometimes used to denote amplitude, average value, root-mean-square value or ratios of these values. These uses are deprecated.

3.1.63
bel
unit of level when the base of the logarithm is 10

Note 1 to entry: Use of the bel is restricted to levels of quantities proportional to power. See also the notes under *level* (3.1.62) and *decibel* (3.1.64).

3.1.64
decibel
dB
one tenth of a bel

Note 1 to entry: The magnitude of a level in decibels is 10 times the logarithm to the base 10 of the ratio of power quantities, i.e., sound energy density

$$L = 10 \lg \frac{X^2}{X_0^2}$$

or the ratio of field quantities, i.e., displacement

$$L = 20 \lg \frac{X}{X_0}$$

Note 2 to entry: Examples of quantities that qualify as power quantities are sound-pressure squared, particle-velocity squared, sound intensity, sound-energy density and voltage squared. However, it is common practice to shorten this to sound-pressure level because ordinarily no ambiguity results from so doing.

3.2 Terms for vibration

3.2.1
vibration
mechanical oscillations about an equilibrium point

Note 1 to entry: The oscillations may be periodic or random.

Note 2 to entry: See *oscillation* (3.1.10).

3.2.2
periodic vibration
vibration where the values of the vibration parameter recur within certain time intervals of equal duration of the independent variable time

Note 1 to entry: A periodic quantity, y, which is a function of time, t, can be expressed as:

$$y = f(t) = f(t \pm nT)$$

where

n is an integer;

t is the independent variable time;

T is the period.

Note 2 to entry: A quasi-periodic vibration is a vibration which deviates only slightly from a periodic vibration.

3.2.3
simple harmonic vibration
sinusoidal vibration
periodic vibration where the values of the vibration parameters can be described as sinusoidal functions of the independent time variable

Note 1 to entry: Simple harmonic motion can be described as:

$$y = y_0 \sin(\omega t + \varphi_0)$$

where

y is the simple harmonic vibration;

y_0 is the amplitude;

ω is the angular frequency;

t is the independent variable time;

φ_0 is the initial phase angle of the vibration.

Note 2 to entry: A periodic vibration consisting of the sum of more than one sinusoid, each having a frequency which is a multiple of the fundamental frequency, is often referred to as a multi-sinusoidal vibration. The use of the term "complex vibration" in this context is deprecated.

Note 3 to entry: A quasi-sinusoidal vibration has the appearance of a sinusoid, but varies relatively slowly in frequency and/or in amplitude.

3.2.4
random vibration
stochastic vibration
vibration where the instantaneous value cannot be predicted

Note 1 to entry: The probability that the magnitude of a random vibration is within a given range can be described by a probability distribution function.

3.2.5
angular vibration
vibration associated with the three rotational degrees of freedom of a point on a body

3.2.6
torsional vibration
periodic vibration caused by an object twisting about its own axis

Note 1 to entry: See *angular vibration* (3.2.5).

Note 2 to entry: This term is commonly used when referring to the rotation of shafts in the plane of the shaft cross-section.

3.2.7
angular displacement
displacement of a body, characterized by one of its rotational degrees of freedom

3.2.8
angular velocity
velocity of a body, characterized by one of its rotational degrees of freedom

3.2.9
angular acceleration
acceleration of a body, characterized by one of its rotational degrees of freedom

3.2.10
non-stationary vibration
vibration with time-dependent statistical properties

3.2.11
stationary vibration
vibration that has statistical characteristics that do not change with time

Note 1 to entry: The amplitude does not increase or decrease with time.

Note 2 to entry: The vibration can be deterministic or random.

3.2.12
noise
undesired signal, generally of a random nature, the spectrum of which does not exhibit clearly defined frequency components

Note 1 to entry: Noise can arise from many sources, including loose electrical connections, ground loops, poorly mounted sensors and triboelectric effects.

Note 2 to entry: If ambiguity exists as to the nature of the noise, a term such as "acoustic noise" or "electrical noise" should be used.

3.2.13
random noise
stochastic noise
noise for which the instantaneous value cannot be predicted

Note 1 to entry: See *random vibration* (3.2.4) and the accompanying note.

3.2.14
Gaussian random vibration
Gaussian stochastic vibration
random vibration whose instantaneous magnitudes have a Gaussian distribution

3.2.15
white random vibration
white stochastic vibration
vibration that has equal energy for any frequency band of constant width over the spectrum of interest

3.2.16
pink random vibration
pink stochastic vibration
vibration that has a constant energy within a bandwidth proportional to the centre frequency of the band

Note 1 to entry: The energy spectrum of pink vibration as determined by an octave bandwidth (or any fractional part of an octave bandwidth) filter has a constant value.

3.2.17
narrow-band random vibration
narrow-band stochastic vibration
random vibration having its frequency components within a narrow band only

Note 1 to entry: The definition of what is meant by "narrow" is a relative matter depending upon the problem involved. It is usually equal to or less than one-third octave.

Note 2 to entry: The waveform of a narrow-band random vibration has the appearance of a sine wave, the amplitude and phase of which vary in an unpredictable manner.

Note 3 to entry: See *random vibration* (3.2.4).

3.2.18
broad-band random vibration
broad-band stochastic vibration
random vibration having its frequency components distributed over a broad frequency band

Note 1 to entry: The definition of what is meant by "broad" is a relative matter depending upon the problem involved. It is usually one octave or greater.

Note 2 to entry: See *random vibration* (3.2.4).

3.2.19
dominant frequency
frequency at which a maximum value occurs in an amplitude spectrum

3.2.20
steady-state vibration
continuous vibration that has on average reached equilibrium

3.2.21
transient vibration
vibration, typically of short duration, that decays with time

Note 1 to entry: This term is basically associated with mechanical *shock* (3.3.1).

3.2.22
forced vibration
vibration of a system due to an external time-dependent force

Note 1 to entry: The vibration (for linear systems) has the same frequencies as the excitation.

3.2.23
free vibration
vibration of a system that occurs after the removal of excitation or restraint

Note 1 to entry: A linear system vibrates as a linear combination of natural modes.

3.2.24
non-linear vibration
vibration of a system which has a non-linear response and can only be described by non-linear differential equations

Note 1 to entry: In a nonlinear system, the relationship between cause and effect is no longer proportional and the principle of superposition does not hold for their solution.

3.2.25
longitudinal vibration
vibration along the longitudinal axis in an elastic body

3.2.26
self-induced vibration
self-excited vibration
vibration of a mechanical system resulting from conversion, within the system, of energy to oscillatory excitation

3.2.27
ambient vibration
all-encompassing vibration associated with a given environment usually a composite vibration from many surrounding sources

3.2.28
extraneous vibration
total vibration other than the vibration of principal interest

Note 1 to entry: Ambient vibration contributes to the magnitude of extraneous vibration.

3.2.29
aperiodic vibration
vibration that is not periodic

3.2.30
jump
phenomenon where the vibration response changes suddenly due to a small change in frequency of an excitation force

3.2.31
cycle, noun
complete range of states or values through which a periodic phenomenon or function passes before repeating itself identically

Note 1 to entry: See *cycle*, verb (3.2.111).

3.2.32
fundamental period
period
smallest interval of time for which a periodic function repeats itself

Note 1 to entry: If no ambiguity is likely, the fundamental period is called the period.

Note 2 to entry: See *periodic vibration* (3.2.2).

3.2.33
frequency
reciprocal of the period

Note 1 to entry: The unit of frequency is the hertz (Hz), which corresponds to one cycle per second.

3.2.34
fundamental frequency
frequency which may be equal to the lowest natural frequency of an undamped linear vibration system or identified as the base frequency of which there exists harmonic or sub harmonic components

Note 1 to entry: The normal mode of vibration associated with the lowest natural frequency is known as the fundamental mode.

Note 2 to entry: See *natural frequency* (3.2.88).

3.2.35
harmonic
DEPRECATED: overtone
harmonic vibration, the frequency of which is an integral multiple of the fundamental frequency

Note 1 to entry: The term "overtone" has frequently been used in place of harmonic, the nth harmonic being called the $(n - 1)$th overtone.

3.2.36
sub harmonic
harmonic vibration, the frequency of which is an integral sub-multiple of the fundamental frequency of the quantity to which it is related

3.2.37
harmonic excitation
sinusoidal excitation

3.2.38
beats
periodic variation in the magnitude of an oscillation resulting from the combination of two oscillations of slightly different frequencies

Note 1 to entry: The beat occurs at the different frequency.

3.2.39
beat frequency
absolute value of the difference in frequency of two oscillations of slightly different frequencies

3.2.40
angular frequency
pulsatance
product of the frequency of a sinusoidal quantity and the factor 2π

Note 1 to entry: The unit of angular frequency is the radian (rad) with respect to time.

3.2.41
phase angle
angle of a complex response which characterizes a shift in time at a given frequency

3.2.42
phase difference
phase angle difference
difference between the respective phases of two harmonic vibrations of the same frequency or, in the case of sinusoidal vibrations, between their phase angles measured from the same origin

3.2.43
amplitude
magnitude, size or value of a quantity

3.2.44
peak value
peak magnitude
positive peak value
negative peak value
maximum value of a vibration during a specified time interval

Note 1 to entry: A peak value vibration is usually taken as the maximum deviation of that vibration from the mean value. A positive peak value is the maximum positive deviation and a negative peak value is the maximum negative deviation.

3.2.45
peak-to-peak value
<vibration> difference between the maximum positive and maximum negative values of a vibration during a specified interval

Note 1 to entry: The magnitude is dependent upon the measurement system response or *rise time* (3.3.18).

3.2.46
excursion
total excursion
<vibration> peak-to-peak displacement

3.2.47
crest factor
<vibration> ratio of the peak value to the rms value

Note 1 to entry: The value of the crest factor of a sine wave is $\sqrt{2}$.

3.2.48
form factor
<vibration> ratio of the rms value to the mean value for one-half cycle between two successive zero crossings

Note 1 to entry: The form factor for a sinusoid is $\pi/\left(2\sqrt{2}\right)=1{,}111$.

3.2.49
instantaneous value
value of a variable quantity at a given instant

3.2.50
maximax
maximum value that is of greatest magnitude when a function contains more than one maximum value within a series of given intervals of the independent variable

3.2.51
vibration severity
value, or set of values, such as a maximum value, average or rms value, or other parameters that are descriptive of the vibration, referring to instantaneous values or to average values

Note 1 to entry: Vibration severity is a generic term, which in the past has been used in relation to vibration velocity. However, it is now more generally used as descriptive of other measurement units such as displacement acceleration, etc.

Note 2 to entry: Vibration severity of a machine is defined as the maximum value of the vibration measured at a number of different points on that machine, such as shafts, bearings or other parts of a machine structure.

Note 3 to entry: The duration of a vibration is sometimes included as a parameter descriptive of vibration severity. This usage is deprecated.

3.2.52
elliptical vibration
vibration in which the locus of a vibrating point is elliptical in form

3.2.53
rectilinear vibration
linear vibration
vibration in which the locus of a vibration point is a straight line

3.2.54
circular vibration
vibration in which the locus of a vibrating point is circular in form

Note 1 to entry: This is a special case of elliptical vibration.

3.2.55
translational motion
motion of a point on a body that represents a linear change in its spatial coordinates, usually characterized by a local set of coordinates in the x-y-z directions

Note 1 to entry: For the case of translational vibration, changes in its spatial coordinates are monitored as a function of time.

3.2.56
rotational motion
motion of a body that represents a change in its three local rotational or angular coordinates, i.e. pure rotation about the x-axis, y-axis and z-axis

Note 1 to entry: For the case of rotational vibration, changes in its angular coordinates are monitored as a function of time.

3.2.57
node
point, line or surface in a mechanical system where some characteristic of the wave field has zero amplitude

3.2.58
antinode
point, line or surface in a mechanical system where the magnitude of some characteristic of the wave field has a peak value

3.2.59
mode of vibration
<system undergoing vibration under harmonic excitation> characteristic, simple harmonic vibration pattern of a system undergoing harmonic excitation

Note 1 to entry: Two or more modes may exist concurrently in a multi-degree-of-freedom system.

3.2.60
natural mode of vibration
mode of vibration assumed by a system when vibrating freely at a natural frequency

Note 1 to entry: If the system has zero damping, the natural modes are the same as the normal modes. See *undamped natural mode* (3.2.66).

Note 2 to entry: This is also called the eigenmode or eigen mode.

Note 3 to entry: Natural mode of vibration is a product of mode of vibration and harmonic function having a natural frequency, damping, mode shape and modal mass.

Note 4 to entry: The number of natural modes of vibration of a system is the same as the number of degrees of freedom.

3.2.61
fundamental natural mode of vibration
mode of vibration of a system having the lowest natural frequency

Note 1 to entry: See *fundamental frequency* (3.2.34).

3.2.62
mode shape
shape of a natural mode of vibration of a mechanical system, given by the maximum change in position, usually normalized to a specified deflection magnitude at a specified point, of its neutral surface (or neutral axis) from its mean value

Note 1 to entry: The mean value is the mean for the given mode of vibration only.

3.2.63
modal number
integer characterizing modes in a multi-degree-of-freedom system

3.2.64
coupled modes
modes of vibration that influence one another because of energy transfer from one mode to another through damping

Note 1 to entry: An energy transfer results from the neighbouring natural frequencies.

3.2.65
uncoupled modes
modes of vibration that are independent from one another because there is no energy transfer from one mode to another

Note 1 to entry: No energy transfer between the modes is observed.

3.2.66
undamped natural mode
natural mode of an undamped mechanical system

Note 1 to entry: The motion of a system consists of the summation of the contribution of each of the participating normal modes.

Note 2 to entry: The terms "natural mode", "characteristic mode" and "eigen mode" (or "eigenmode") are synonymous with "normal" mode for undamped systems.

3.2.67
damped natural mode
natural mode of a damped mechanical system

3.2.68
wave train
succession of a limited number of waves, usually nearly periodic, travelling at the same (or nearly the same) velocity

3.2.69
wavelength
<periodic wave> distance in the direction of propagation of a sinusoidal wave between two successive points where at a given instant in time the phase differs by 2π

[SOURCE: ISO 80000-3:2006, 3-17]

3.2.70
compressional wave
wave of compressive or tensile stresses propagated in an elastic medium

Note 1 to entry: A compressional wave is normally a *longitudinal wave* (3.2.71).

3.2.71
longitudinal wave
wave in which the particle displacement is in the direction of propagation

3.2.72
shear wave
wave of shear stresses propagated in an elastic medium

Note 1 to entry: A shear wave is normally a *transverse wave* (3.2.73).

Note 2 to entry: A shear wave causes no changes in volume.

3.2.73
transverse wave
wave in which the particle displacement is perpendicular to the direction of wave propagation

3.2.74
surface wave
Rayleigh wave
wave associated with the free boundary (or interface between two media) of a solid such that a surface or interface particle describes an ellipse whose major axis is normal to the surface and whose centre is at the undisturbed surface

Note 1 to entry: At maximum particle displacement away from the solid surface, the motion of the particle is opposite to that of the wave.

3.2.75
wave front
locus of points of a progressive wave having the same phase at a given instant

Note 1 to entry: A wave front for a surface wave is a continuous line.

3.2.76
plane wave
wave in which the wave fronts are parallel planes

3.2.77
spherical wave
wave in which the wave fronts are concentric spheres

3.2.78
standing wave
wave having a fixed amplitude distribution in space

Note 1 to entry: A standing wave can be considered to be the result of superposition of opposing progressive waves of the same frequency and kind.

Note 2 to entry: Standing waves are characterized by nodes and antinodes that are fixed in position.

Note 3 to entry: A partial standing wave can be considered to be the result of superposition of opposing progressive waves of the same frequency.

3.2.79
audio frequency
any frequency contained in a normally audible sound

Note 1 to entry: Audio frequencies generally lie between 20 Hz and 20 000 Hz.

3.2.80
resonance
state of a system in forced oscillation when any change, however small, in the frequency of excitation causes a decrease in a response of the system

Note 1 to entry: If the phase angle between the excitation force and output vibration displacement can be measured, the resonance occurs at the frequency when the phase angle between the excitation force and vibration velocity is zero degree.

3.2.81
resonance frequency
frequency at which resonance exists

Note 1 to entry: Resonance frequencies may depend upon the measured variables, for example velocity resonance may occur at a different frequency from that of displacement resonance (see Table 2).

Note 2 to entry: To avoid confusion, the type of resonance needs to be indicated, for example velocity resonance frequency (see Table 2).

3.2.82
antiresonance
state of a system in forced oscillation at a point when any change, however small, in the frequency of excitation causes an increase in a response at this point

3.2.83
antiresonance frequency
frequency at which antiresonance occurs

Note 1 to entry: Antiresonance frequencies may depend upon the measured variable, for example velocity antiresonance may occur at a different frequency from that of displacement antiresonance.

Note 2 to entry: To avoid confusion, the type of antiresonance needs to be indicated, for example velocity antiresonance frequency.

3.2.84
fixed-base natural frequency
natural frequency that a system would have if the foundation to which the equipment is attached is rigid and of infinite mass

Note 1 to entry: The equation given in Table 2 and the natural frequencies shown are for fixed-base conditions.

3.2.85
resonance speed
critical speed
characteristic speed at which resonances of a system are excited

Note 1 to entry: Resonance speed of a rotating system is a speed of the rotating system that corresponds to a resonance frequency (it may also include multiples and submultiples of the resonance frequency) of the system, for example speed in revolutions with respect to time equals the resonance frequency in cycles with respect to time.

Note 2 to entry: Where there are several rotating systems, there are several corresponding sets of resonance speeds, one for each mode of the overall system.

3.2.86
subharmonic response
subharmonic resonance response
response of a mechanical system exhibiting some of the characteristics of resonance with a period that is an integer multiple of the period of excitation

3.2.87
damping
dissipation of energy with time or distance

Note 1 to entry: In the context of vibration and shock, damping is the progressive reduction of the amplitude with time.

3.2.88
natural frequency
<mechanical system> frequency of free vibration of an undamped linear vibration system

Note 1 to entry: For the equation of motion given in Table 2, the natural frequency is $\frac{1}{2\pi}\sqrt{\frac{k}{m}}$.

3.2.89
damped natural frequency
frequency of free vibration of a damped linear system

Note 1 to entry: See Table 2.

3.2.90
linear damping
viscous damping
damping which occurs due to a force which is proportional to and in the opposite direction to the velocity

Note 1 to entry: An element that generates linear (viscous) damping is often referred to as a *dashpot* (3.2.94).

3.2.91
equivalent linear damping
equivalent viscous damping
value of linear (viscous) damping, assumed for the purpose of analysis of a vibratory motion, such that the dissipation of energy per cycle at resonance is the same for the assumed as well as for the actual damping force

3.2.92
linear damping coefficient
viscous damping coefficient
ratio of damping force to velocity

Note 1 to entry: See *linear (viscous) damping* (3.2.90).

3.2.93
hysteresis damping
structural damping
energy losses within a structure that are caused by internal friction within the structure

Note 1 to entry: Dynamic hysteresis damping is essentially linear and includes viscoelastic, rheological damping and internal friction.

Note 2 to entry: Represented by a damping force 90 degrees out of phase with the restoring force. Static hysteresis is nonlinear with stress-strain laws that are insensitive to time, stress rate and strain rate, and includes plastic and plastic flow.

Note 3 to entry: These losses are independent of the frequency of oscillation but are proportional to the vibration amplitude squared.

3.2.94
dashpot
resistance element in a mechanical system associated with linear (viscous) damping in linear systems

Note 1 to entry: This resistance force is proportional to the velocity but more correctly contains a dynamic force term proportional to the square of velocity.

3.2.95
critical damping
critical linear damping
critical viscous damping
<single-degree-of-freedom system> amount of damping which corresponds to the limiting condition between an oscillatory and a non-oscillatory transient state of free vibration

Note 1 to entry: The critical damping coefficient, c_c, is equal to $c_c = 2\sqrt{mk} = 2m\omega_0$ for the single-degree-of-freedom system represented by the equation given in Table 2, where ω_0 is the natural frequency (angular). See *natural frequency* (3.2.88).

3.2.96
damping ratio
ratio of the actual damping coefficient to the critical damping coefficient

Note 1 to entry: The fraction of critical damping may also be expressed in terms of percentage of the critical damping.

Note 2 to entry: See *linear (viscous) damping coefficient* (3.2.92) and *critical damping* (3.2.95).

3.2.97
logarithmic decrement
natural logarithm of the ratio of any two successive maximum values of a vibration in a single-degree-of-freedom system at a damped natural frequency

3.2.98
non-linear damping
damping due to a force or moment which is not proportional to and is in the opposite direction to the velocity

3.2.99
***Q* factor**
quantity characterizing the amplification of a vibration at resonance

Note 1 to entry: The quantity Q is equal to one-half of the reciprocal of the damping ratio, $Q = c_c/2c$.

3.2.100
vibration generator
vibration machine
vibration exciter
machine that is specifically designed for, and is capable of, generating vibrations and of imparting these vibrations to other structures or devices

Note 1 to entry: Equipment to be tested may be attached to a table on the generator or the generator may be used to excite equipment by means of studs without the use of a table.

3.2.101
vibration generator system
vibration generator and associated equipment necessary for its operation

3.2.102
electrodynamic vibration generator
electrodynamic vibration machine
vibration generator that derives its vibratory force from the interaction of a magnetic field of constant value, and a coil of wire contained in it that is excited by a suitable alternating current

Note 1 to entry: The moving element of an electrodynamic vibration generator includes the vibration table, the moving coil and all the parts of the generator that are intended to participate in the vibration.

3.2.103
electromagnetic vibration generator
electromagnetic vibration machine
vibration generator that derives its vibratory force from the interaction of electromagnets and magnetic materials

3.2.104
mechanical direct-drive vibration generator
direct-drive vibration generator
vibration generator in which the vibration table is forced, by a positive linkage, to undergo a displacement amplitude of vibration that remains essentially constant regardless of the load or frequency of operation

3.2.105
hydraulic vibration generator
vibration generator that derives its vibratory force from the application of a liquid pressure through a suitable drive arrangement

3.2.106
mechanical reaction vibration generator
unbalanced mass vibration generator
vibration generator in which the forces exciting the vibration are generated by rotating or reciprocating unbalanced masses

3.2.107
resonance vibration generator
vibration generator that contains a vibration system that is excited at its resonance frequency

3.2.108
piezoelectric vibration generator
vibration generator that has a piezoelectric transducer as its force-generating element

3.2.109
magnetostrictive vibration generator
vibration generator that has a magnetostrictive transducer as its force-generating element

3.2.110
deadweight
pure mass
lumped mass
mass having the characteristics of a perfectly rigid mass over the frequency region of concern

3.2.111
cycle, verb
repetitively operate a device through a range of a controlled variable such as frequency

Note 1 to entry: See *cycle*, noun (3.2.31).

3.2.112
cycle period
duration to cycle a device through all the controlled variables in the control range

3.2.113
cycle range
range defined by the minimum and maximum values of the controlled variable, such as frequency, between which the device is cycled

3.2.114
sweep
⟨vibration generator system⟩ the process of traversing continuously through a range of values of an independent variable, usually frequency

3.2.115
sweep rate
rate of change of the independent variable, usually frequency

EXAMPLE The sweep rate can be described as: df/dt where f is frequency and t is time.

3.2.116
uniform sweep rate
linear sweep rate
sweep rate for which the rate of change of the independent variable for a sweep, usually frequency, is constant, i.e. df/dt = constant

Note 1 to entry: See *sweep rate* (3.2.115).

3.2.117
logarithmic sweep rate
frequency sweep rate
sweep rate for which the rate of change of frequency with respect to frequency is constant, i.e. (df/f)/dt = constant

Note 1 to entry: For a logarithmic sweep rate, the time to sweep between any two frequencies of fixed ratio is constant.

Note 2 to entry: The logarithmic sweep rate should be expressed in octaves per minute.

Note 3 to entry: See *sweep rate* (3.2.115).

3.2.118
crossover frequency
⟨vibration environmental testing⟩ frequency at which a characteristic of a vibration changes from one relationship to another

EXAMPLE A crossover frequency may be that frequency at which the vibration amplitude, or rms value, changes from a constant displacement value versus frequency to a constant acceleration value versus frequency.

3.2.119
isolator
support, usually resilient, the function of which is to attenuate the transmission of shock and/or vibration

Note 1 to entry: An isolator may include collapsible parts, servo-mechanisms or other devices in lieu of, or in addition to, the resilient member.

3.2.120
vibration isolator
isolator designed to attenuate the transmission of vibration in a frequency range

3.2.121
shock isolator
isolator designed to protect a system from a range of shock motions or forces

3.2.122
elastic centre
point of intersection of three principal directions of deformation in elastic mounts

Note 1 to entry: This definition applies to the case where the mount size is small compared to the size of the machine or equipment to which it is attached.

Note 2 to entry: The principal direction of an elastic mount is the direction where the deflection occurs due to a force input.

3.2.123
centre-of-gravity mounting system
mounting system where, when the mounted equipment is displaced by translation from its neutral position, there is no resultant moment about any axis through the centre of mass

Note 1 to entry: If a piece of equipment is supported by a centre-of-gravity mounting system, all translational and rotational modes of vibration of the equipment on its mounts are decoupled.

Note 2 to entry: A centre-of-gravity mounting system is one where the centre-of-gravity of the mounted equipment coincides with the *elastic centre* (3.2.122) of the mount.

3.2.124
shock absorber
device for the dissipation of energy in order to reduce the response of a mechanical system to the applied shock

3.2.125
damper
⟨vibration applications⟩ device used for reducing the magnitude of a shock or vibration by energy dissipation methods

3.2.126
snubber
device used to restrict the relative displacement of a mechanical system by increasing the stiffness of an elastic element in the system (usually abruptly and by a large factor) whenever the displacement becomes larger than a specified amount

3.2.127
dynamic vibration absorber
device for reducing vibrations of a primary system over a desired frequency range by the transfer of energy to an auxiliary system in resonance so tuned that the force exerted by the auxiliary system is opposite in phase to the force acting on the primary system

Note 1 to entry: Dynamic vibration absorbers may be damped or undamped, but damping is not the primary purpose.

Note 2 to entry: Dynamic vibration absorbers without damping elements are also known as dynamic vibration neutralizers as they reflect the energy back towards the source and do not absorb.

3.2.128
detuner
auxiliary vibratory system with an amplitude-dependent frequency characteristic which modifies the vibration characteristics of the main system to which it is attached

EXAMPLE An auxiliary mass controlled by a nonlinear spring.

3.3 Terms for mechanical shock

3.3.1
shock
sudden change of force, position, velocity or acceleration that excites transient disturbances in a system

Note 1 to entry: The change is normally considered sudden if its duration is short compared with the fundamental periods of concern.

3.3.2
shock pulse
excitation event characterized by a sudden rise and/or sudden decay of a time-dependent parameter

Note 1 to entry: A descriptive mechanical term should be used, for example acceleration shock pulse.

Note 2 to entry: A shock pulse may also be characterized by its motion, force or velocity.

3.3.3
shock motion
transient motion causing, or resulting from, a shock excitation

3.3.4
impact
single collision of two bodies

3.3.5
impulse
integral with respect to time of a force taken over the time during which the force is applied

Note 1 to entry: In shock usage, the time interval is relatively short.

Note 2 to entry: For a constant force, it is the product of the force and the time during which the force is applied.

Note 3 to entry: Excitation due to an instant force is referred to as impulse excitation.

3.3.6
bump
form of shock that is repeated many times for test purposes

3.3.7
ideal shock pulse
shock pulse that is described by a simple time function

EXAMPLE See those defined in 3.3.8 to 3.3.14.

3.3.8
half-sine shock pulse
shock pulse for which the time-history curve has the shape of the positive (or negative) section of one cycle of a sine wave

3.3.9
final peak sawtooth shock pulse
terminal peak sawtooth shock pulse
shock pulse for which the time-history curve has a triangular shape for which the motion increases linearly to a maximum value and then drops instantaneously to zero

3.3.10
initial peak sawtooth shock pulse
shock pulse for which the motion rises instantaneously to a maximum value, after which it decreases linearly to zero

3.3.11
symmetrical triangular shock pulse
shock pulse for which the time-history curve has the shape of an isosceles triangle

3.3.12
versine shock pulse
haversine shock pulse
shock pulse for which the time-history curve has the shape of one full cycle of a versine curve beginning at zero (sine-squared curve)

3.3.13
rectangular shock pulse
shock pulse for which the motion rises instantaneously to a given value, remains constant for the duration of the pulse, then instantaneously drops to zero

3.3.14
trapezoidal shock pulse
shock pulse for which the motion rises linearly to a given value, which then remains constant during a time interval after which it decreases to zero in a linear manner

3.3.15
nominal shock pulse
nominal pulse
specified shock pulse that is given with specified tolerances

Note 1 to entry: Nominal shock pulse is a generic term. It requires an additional modifier to make its meaning specific, for example nominal half-sine shock pulse, or nominal sawtooth shock pulse.

Note 2 to entry: The tolerances of the nominal pulse from the ideal may be expressed in terms of pulse shapes (including area) or corresponding spectra.

3.3.16
nominal value of a shock pulse
specified value (such as peak value or duration) given with specified tolerances

3.3.17
duration of shock pulse
duration between the instant the motion rises above some stated fraction of the maximum value and the instant it decays to this fraction

Note 1 to entry: For measured pulses, the "stated fraction" is usually taken as 1/10. For ideal pulses, it is taken as zero.

3.3.18
rise time
pulse rise time
interval of time required for the value of the pulse to rise from some specified small fraction of the maximum value to some specified large fraction of the maximum value

Note 1 to entry: For measured pulses, the "specified small fraction" is usually taken as 1/10 and the "specified large fraction" as 9/10. For ideal pulses, the fractions are taken as 0 and 1 respectively.

3.3.19
pulse drop-off time
pulse decay time
interval of time required for the value of the pulse to drop from some specified large fraction of the maximum value to some specified small fraction of the maximum value

Note 1 to entry: See the note to *rise time* (3.3.18).

3.3.20
shock wave
shock time history (displacement, pressure or other variable) associated with the propagation of the shock through a medium or structure

Note 1 to entry: In liquids and gases, a shock wave is usually characterized by a wave front in which the pressure rises suddenly to a relatively large value.

3.3.21
shock testing machine
shock machine
device for subjecting a system to controlled and reproducible mechanical shock

3.3.22
shock response spectrum
maximum response of a series of uniformly damped single-degree-of-freedom systems to an applied shock input

Note 1 to entry: Shock response spectrum is a generic term. It requires an additional modifier to make its meaning specific, for example acceleration or velocity or displacement shock response spectrum.

Note 2 to entry: If the amount and type of damping of the systems are not given, they are assumed to be zero. Unless otherwise indicated, the responses are maximum absolute values irrespective of the sign and the time at which the maximum occurs. This is often referred to as maximax shock response spectrum. If reference is made to other types of shock response spectra, this needs to be stated.

Note 3 to entry: The shock response spectrum of a structure tested on a vibration generator system applying a specified earthquake motion of a floor is termed as floor response spectrum.

3.4 Terms for transducers for shock and vibration measurement

3.4.1
transducer
DEPRECATED: pick-up
device designed to convert energy from one form to another in such a manner that the desired characteristics of the input energy appear at the output

Note 1 to entry: The output is usually electrical.

3.4.2
electromechanical transducer
DEPRECATED: pick-up
transducer that is actuated by energy from a mechanical system (strain, force, motion, etc.), and supplies energy to an electrical system, or vice versa

Note 1 to entry: The principal types of transducers used in vibration and shock are:

a) piezoelectric accelerometer;

b) piezoresistive accelerometer;

c) strain-gauge type accelerometer;

d) capacitive accelerometer.

Note 2 to entry: The principal types of velocity transducer used in vibration and shock are:

a) electrodynamic transducer;

b) moving coil transducer;

c) moving conductor transducer;

d) induction transducer;

e) laser doppler vibrometer;

f) variable reluctance transducer.

Note 3 to entry: The principal types of displacement transducers are:

a) capacitative displacement;

b) linear variable differential transformer;

c) variable reluctance transducer;

d) electrostatic (capacitor) transducer;

e) eddy current transducer;

f) magnetostrictive transducer;

g) boonded-wire (foil) transducer.

3.4.3
seismic transducer
transducer consisting of a seismic system in which the differential movement between the mass and the base of the system produces an electrical output

Note 1 to entry: Acceleration transducers operate in a frequency range below the significant natural frequency of the seismic system. Velocity and displacement transducers operate in a frequency range above the natural frequency of the seismic system.

3.4.4
linear transducer
transducer for which the output quantity and the input quantity are linearly related within a specified set of tolerances for given ranges of frequency and amplitude

3.4.5
unilateral transducer
transducer that cannot be actuated by signals at its outputs in such a manner as to supply related signals at its inputs

3.4.6
bilateral transducer
transducer capable of transmission in either direction between its terminations

Note 1 to entry: A bilateral transducer usually satisfies the principle of reciprocity.

3.4.7
sensing element
part of a transducer that is activated by the input excitation and supplies the output signal

3.4.8
rectilinear transducer
transducer designed to be sensitive to some characteristics of a translational motion

Note 1 to entry: The modifier "rectilinear" is used only when it is necessary to distinguish this type of transducer from those sensitive to rotational motions.

3.4.9
angular transducer
transducer designed to measure some characteristic of a rotational motion

3.4.10
accelerometer
acceleration transducer
transducer that converts an input acceleration to an output (usually electrical) that is proportional to the input acceleration

3.4.11
velocity transducer
transducer that converts an input velocity to an output (usually electrical) that is proportional to the input velocity

3.4.12
displacement transducer
transducer that converts an input displacement to an output (usually electrical) that is proportional to the input displacement

3.4.13
vibrograph
instrument, usually self-contained and mechanical in operation, which can present an oscillographic recording of a vibration waveform

3.4.14
vibrometer
instrument with one or more outputs (typically voltage) that are proportional to either the displacement or velocity

3.4.15
force transducer
transducer that converts an input force to an output (usually electrical) that is proportional to the input force

3.4.16
sensitivity
<transducer> ratio of a specified output quantity to a specified input quantity

Note 1 to entry: The sensitivity of a transducer is usually determined as a function of frequency using sinusoidal excitation.

3.4.17
dynamic range
<transducer> range of values that can be measured

3.4.18
calibration factor
<transducer> average sensitivity within a specified frequency range

Note 1 to entry: See *sensitivity* (3.4.16).

3.4.19
scale factor
<transducer>nominal sensitivity within a specified frequency range

3.4.20
sensitive axis
<rectilinear transducer> nominal direction for which a rectilinear transducer has the greatest sensitivity

3.4.21
transverse axis
<transducer> nominal direction perpendicular to the sensitive axis

3.4.22
transverse sensitivity
cross axis sensitivity
<rectilinear transducer> sensitivity of a transducer to excitation in a nominal direction perpendicular to its sensitive axis

Note 1 to entry: The transverse sensitivity is usually a function of the nominal direction of the axis chosen.

3.4.23
transverse sensitivity ratio
cross axis sensitivity ratio
<rectilinear transducer> ratio of the transverse sensitivity of a transducer to its sensitivity along its sensitive axis

Note 1 to entry: The transverse sensitivity ratio is sometimes expressed as a percentage.

3.4.24
transducer phase shift
phase angle between the transducer output and input for sinusoidal excitation

3.4.25
transducer distortion
distortion which occurs when the output of the transducer is not proportional to the input

3.4.26
amplitude distortion
<transducer> distortion occurring when the ratio of the output of a transducer to its input at a given frequency varies with the input amplitude

3.4.27
frequency distortion
distortion or response occurring within a given frequency range when the amplitude sensitivity of the transducer for a given amplitude of excitation is not constant over that range

3.4.28
phase distortion
distortion occurring when the phase angle between the output of a transducer and its input is not a linear function of frequency

3.4.29
run-out
measure of a shaft's deviation from a perfectly uniform radius

Note 1 to entry: Mechanical run-out is a measure of the shaft's deviation from a perfectly uniform radius as its circumference is traversed. This can be measured by a mechanical dial indicator.

Note 2 to entry: Electrical run-out is a measure of the electrical properties of a shaft as its circumference is traversed. This is measured with a transducer that measures the electrical or magnetic properties that are not uniform.

3.5 Terms for signal processing

3.5.1
data
sampled measurements of a physical quantity

3.5.2
sampling
measurement of a varying physical quantity at a sequence of values of time, angle, revolutions or other mechanical, independent variable

Note 1 to entry: Other meanings of this term may be used in particular fields, for example in statistics.

3.5.3
sampling frequency
number of samples with respect to time for uniformly sampled data

3.5.4
sampling period
duration of time between two successive samples

3.5.5
sampling rate
number of samples with respect to time, angle, revolutions or other mechanical, independent variable for uniformly sampled data

3.5.6
Nyquist frequency
maximum usable frequency available in data taken at a given sampling rate

Note 1 to entry: The Nyquist frequency is $f_N = f_s/2$, where f_s is the sampling frequency.

3.5.7
sampling interval
number of physical or engineering units (e.g. time, angle, revolutions) between two successive samples

3.5.8
frequency resolution
difference of frequency between two adjacent spectral lines

Note 1 to entry: This is equal to the reciprocal of the total time of a block of data that is Fourier transformed.

3.5.9
Fourier transform
frequency description of a transient vibration

Note 1 to entry: The Fourier transform of a transient vibration $x(t)$ is given by:

$$X(f) = \int_{-\infty}^{\infty} x(t) e^{-2\pi i f t} dt$$

Note 2 to entry: The Fourier transform of vibration data $x(t)$ measured over an interval T is given by:

$$X(f_m) = \int_{0}^{T} x(t) e^{-2\pi i f_m t} dt$$

where $f_m = \frac{m}{T}$ and m is an integer.

3.5.10
Fourier series
frequency description of a set of sampled vibration data

Note 1 to entry: The Fourier series X of vibration data $x(n)$ sampled at times $n\Delta t$ where $0 \le n \le N - 1$ and Δt is the time interval between the samples given by:

$$X(m) = \frac{1}{f_s} \sum_{n=0}^{N-1} x(n) e^{-2\pi i n m}$$

where

$f_s = 1/\Delta t$ is the sampling frequency;

$X(m)$ is sampled at frequencies $m/(N\Delta t)$;

m is an integer $(0 \le m \le N - 1)$.

3.5.11
rms spectrum
amplitude spectrum used to quantify the components of sinusoidal, harmonic and non-harmonic signals, such as vibrations from an unbalanced rotor, gears or rolling bearings

Note 1 to entry: The rms spectrum R_{xx} of a sampled signal $x(n)$ with physical or engineering units U, $0 \le n \le N$, from a block of data measured over the interval of one period T is expressed as:

$$R_{xx}(0)=\frac{f_s}{NC_a}\left|X(0)\right|$$

$$R_{xx}(f_m)=\frac{\sqrt{2}f_s}{NC_a}\left|X(f_m)\right| \quad \left(\text{for } 1\le m\le\frac{N}{2}-1\right)$$

where

C_a is the amplitude scaling factor;

N is the number of samples in the data block;

n is the index of time;

R_{xx} is sampled at frequencies $m/(N\Delta t)$;

Δt is the time interval between time samples;

m is an integer ($0 \le m \le N - 1$).

Note 2 to entry: The physical or engineering units of the rms spectrum are U rms.

3.5.12
power spectral density
auto-spectral density
magnitude of the frequency domain description of random, continuous signals

Note 1 to entry: The power spectral density P_{xx} from blocks of sampled data measured over a time interval of duration T is the following average:

$$P_{xx}(m)=E\left\{\frac{2}{T}\left|X(m)\right|^2\right\} \quad \left(\text{for } 0\le m\le\frac{N}{2}-1\right)$$

Note 2 to entry: The physical or engineering units of the power spectral density are U^2/Hz.

Note 3 to entry: Power spectral density is a generic term used regardless of the physical process represented by the time history. The physical process involved is indicated in referring to particular data, e.g. the term "acceleration power spectral density" or the term "acceleration spectral density" is used instead of power spectral density when the acceleration spectrum is to be described.

3.5.13
energy spectral density
magnitude of the frequency description of a transient signal

Note 1 to entry: The energy spectrum e_{xx} from a block of sampled data measured over a time interval that includes the complete signal is:

$$e_{xx}(m)=2\left|X(m)\right|^2 \quad \left(\text{for } 0\le m\le\frac{N}{2}-1\right)$$

Note 2 to entry: If the data $x(n)$ are measured from a random process, the average of the preceding equation is taken.

3.5.14
cross spectral density
magnitude of the frequency domain relationship between the two signals

Note 1 to entry: For signals described by the energy spectral density, the cross spectrum is the cross energy spectral density e_{xy},

$$e_{xy}(m)=2X^*(m)Y(m) \quad \left(\text{for } 0\le m\le\frac{N}{2}-1\right)$$

where an average is taken for random signals.

Note 2 to entry: For random signals described by the power spectrum, the cross power spectral density is the cross power spectral density P_{xy},

$$P_{xy}(m) = \frac{2}{T} E\left\{X^*(m)Y(m)\right\} \quad \left(\text{for } 0 \le m \le \frac{N}{2} - 1\right)$$

3.5.15
coherence function
dimensionless measure of the relationship between two signals in the frequency domain

Note 1 to entry: For signals described by energy spectral density, the coherence function γ_{xy} is:

$$\gamma_{xy}^2(m) = \frac{\left|e_{xy}(m)\right|^2}{e_{xx}(m)e_{yy}(m)} \quad \left(\text{for } 0 \le m \le \frac{N}{2} - 1\right)$$

Note 2 to entry: For signals described by power spectral density, the coherence function γ_{xy} is:

$$\gamma_{xy}^2(m) = \frac{\left|P_{xy}(m)\right|^2}{P_{xx}(m)P_{yy}(m)} \quad \left(\text{for } 0 \le m \le \frac{N}{2} - 1\right)$$

Note 3 to entry: The value of the coherence function ranges between 0 and 1.

3.5.16
statistical degrees of freedom
number of independent variables in a statistical estimate of a probability

Note 1 to entry: The number of degrees of freedom determines the statistical accuracy of an estimate.

3.5.17
aliasing error
aliasing
false representation of the spectral energy caused by the mixing of spectral components above the Nyquist frequency with those spectral components below the Nyquist frequency

3.5.18
window function
window
pre-defined mathematical function that multiplies a data block and improves some characteristics of the frequency description

Note 1 to entry: If a window function is used, an amplitude scaling constant shall be used.

Note 2 to entry: A window function is used for reducing the errors in processing weighted data points.

3.5.19
amplitude scaling factor
constant derived from window function that corrects the amplitude of the frequency description of a narrowband signal

Note 1 to entry: Amplitude scaling factor can be described as:

$$C_a = \frac{1}{N} \sum_{n=0}^{N-1} w(n)$$

Note 2 to entry: where $w(n)$ is the window function.

3.5.20
effective noise bandwidth
bandwidth between frequency lines for a windowed signal, to be used to quantify the frequency description of a noise

3.5.21
time history
sequence of values of a physical or engineering quantity as a function of time

3.5.22
sidelobes
spurious peaks in the frequency domain caused by the use of a finite time window with the Fourier transform

3.5.23
spectral leakage
broadening of a peak in the frequency domain caused by window function with the Fourier transform

3.5.24
leakage error
error in frequency spectrum caused by a mismatch of the recording time to the frequency of interest

3.5.25
deterministic vibration
vibration for which the instantaneous value at a certain time can be predicted

Note 1 to entry: The vibration can be produced as a response to a known input, such as an impact, or predicted from another measured quantity, such as shaft position.

3.5.26
ensemble
set
collection of time histories

3.5.27
number of lines
number of spectral lines that are displayed

3.5.28
record length
<time histories> number of data points comprising a contiguous set of sampled data points

3.5.29
stationary process
ensemble of time histories such that their statistical properties are constant with respect to time

3.5.30
ergodic process
stationary process that possesses statistical properties that permit averages over time to replace averages over ensemble

Note 1 to entry: It follows that these time averages from any time history are then equal to the corresponding statistical averages over the ensemble.

3.5.31
random process
stochastic process
ensemble of time histories that is characterized through statistical properties

3.5.32
autocorrelation function
average of the product of the data's value at one time with its value at another time

Note 1 to entry: The autocorrelation function r_{xx} of random vibration $x(t)$ is the average E:

$$r_{xx}(t,\tau) = E\{x(t)x(t-\tau)\}$$

Note 2 to entry: If the vibration is stationary, the autocorrelation is a function only of the time difference τ. If the vibration is ergodic, the average can be taken over time. If it is non-ergodic, averages shall be taken over statistically independent samples.

3.5.33
cross-correlation function
average of the product of the values of two physical or engineering quantities at different times for two sets of data $x(t)$ and $y(t)$, the mean of the product of the value of one set of data at one time and the value of the other set of data at another time

Note 1 to entry: The cross-correlation function r_{xy} of random vibrations $x(t)$ and $y(t)$ is the average E:

$$r_{xy}(t,\tau)=E\{x(t)\,y(t-\tau)\}$$

Note 2 to entry: See Note 2 to entry for *autocorrelation function* (3.5.32).

3.5.34
normalized autocorrelation function
ratio of the autocorrelation function to its value with zero time delay

Note 1 to entry: The normalized autocorrelation coefficient ρ_{xx} is:

$$\rho_{xx}(t,\tau)=\frac{r_{xx}(t,\tau)}{r_{xx}(t,0)}$$

3.5.35
normalized cross-correlation coefficient
ratio of the cross-correlation function to the square root of the product of autocorrelations at zero time delay

Note 1 to entry: The cross-correlation coefficient ρ_{xy} is:

$$\rho_{xy}(t,\tau)=\frac{r_{xy}(t,\tau)}{\sqrt{r_{xx}(t,0)\,r_{yy}(t,0)}}$$

Note 2 to entry: At any delay τ, the cross-correlation coefficient satisfies $-1 \le \rho_{xy}(\tau) \le 1$.

3.5.36
effective bandwidth
<specified band pass filter> bandwidth of an ideal filter which has a flat response in its passband and transmits the same power as the specified filter when the two filters receive the same white-noise input signal

Note 1 to entry: The effective bandwidth may be measured by dividing the mean-square response of the filter to white-noise excitation by the product of the excitation spectral density and the square of the maximum transmission.

3.5.37
signal bandwidth
interval over frequency between the upper and lower frequencies of interest

3.5.38
confidence level
value of the probability associated with a confidence interval or a statistical interval estimator

3.5.39
probability
expression of the likelihood of occurrence of a vibration event

Note 1 to entry: The probability of occurrence of a particular event is generally estimated as the ratio of the number of occurrences of the particular event to the total number of occurrences of all types of events considered.

Note 2 to entry: For a stationary random vibration, the probability that the magnitude will be within a given magnitude range is taken to be equal to the ratio of the time that the vibration is within that range to the total time of observation.

Note 3 to entry: A large number of events or a long observation time shall be involved in the probability determinations.

Note 4 to entry: A unit probability means that the occurrence of a particular event is certain. Zero probability means that it will not occur.

Note 5 to entry: The probability that the magnitude of a vibration will be within a given range is equal to the integral of the probability density function of that vibration integrated over the given range. See *probability density function* (3.5.41).

3.5.40
probability density
⟨vibration theory⟩ ratio, at a specified vibration magnitude, of the probability that the vibration magnitude will be within a given incremental range, to the size of the incremental range, as the increment size approaches zero

Note 1 to entry: The probability density of vibration quantity *x* is:

$$p(x_m) = \lim_{\Delta x_m \to 0} \frac{P(\Delta x_m)}{\Delta x_m}$$

or

$$p(x) = \frac{\mathrm{d}P(x)}{\mathrm{d}x}$$

where

$p(x_m)$ is the probability density at x_m;

Δx_m is an incremental range of magnitude beginning at a magnitude x_m;

$P(\Delta x_m)$ is the probability that the vibration magnitude will have a value between x_m and $x_m + \Delta x_m$.

Note 2 to entry: The probability density, $p(x)$, is the derivative of the cumulative probability distribution function, $P(x)$, with respect to *x* (see 3.5.41).

Note 3 to entry: In general,

$$P(\infty) = 1 \text{ and } P(-\infty) = 0$$

and

$$\int_{-\infty}^{\infty} p(x)\mathrm{d}x = \int_{-\infty}^{\infty} \mathrm{d}P(x) = \left[P(\infty) - P(-\infty)\right] = 1$$

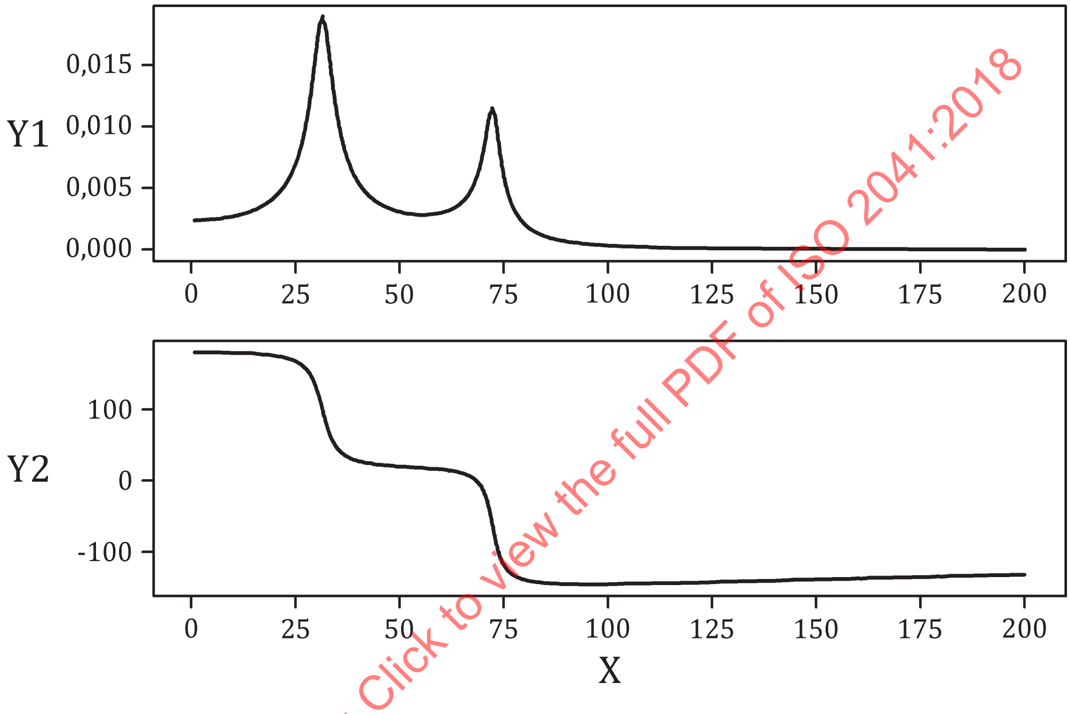
3.5.41
probability density function
⟨vibration theory⟩ expression of the probability density associated with a stated vibration

Note 1 to entry: The functions $p(x)$ given under probability density, normal distribution and Rayleigh distribution are probability density functions.

Note 2 to entry: The probability density distribution curve is a graphical representation of the probability density function. The total area under the probability density curve is equal to unity.

3.5.42
confidence interval with confidence level 100(1-α) %
interval bounded by a lower and upper statistical limit

3.5.43
Bode plot
pair of rectangular plots, one displaying the amplitude of the vibration on the vertical axis with appropriate units and frequency on the horizontal axis with appropriate units, and the other displaying the phase of the vibration on the vertical axis with units of degrees and frequency on the horizontal axis with the same units as those in the amplitude plot



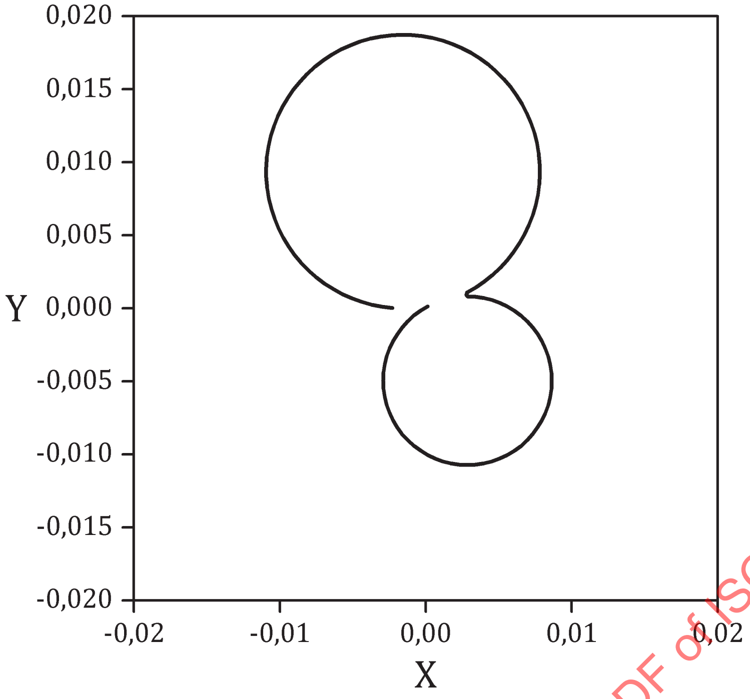
Key
Y1 displacement
Y2 angle (°)
X frequency (Hz)

Figure 4 — Bode plot

Note 1 to entry: The plots are placed so that the horizontal frequency axes are aligned to clearly display related phase and amplitude behaviour.

Note 2 to entry: In machinery assessment, a special case of the Bode plot is sometimes used which uses speed as the horizontal axis and plots corresponding vibration features such as magnitude and phase. One such use is to plot the filtered 1x turning speed vibration magnitude and phase as the machine RPM changes.

3.5.44
Nyquist plot
square plot that displays the amplitude and phase of a vibration over a range of frequencies with the imaginary components of the vibration are displayed on the vertical axis and the real components on the horizontal axis



Key

Y imaginary displacement

X real displacement

Figure 5 — Nyquist plot

Note 1 to entry: Frequency is implicitly displayed along the length of the resulting curve.

Note 2 to entry: Square Nyquist plots clearly display the phase angle along the curve.

Note 3 to entry: The Nyquist plot is particularly useful for displaying transfer functions, such as transfer compliance.

3.5.45
orbit plot
plot displaying two perpendicular displacements of a rotating shaft over one rotation

Note 1 to entry: The displacements are sometimes measured with proximity sensors.

Note 2 to entry: A third sensor is used to establish a phase reference to the angular position of the shaft.

Note 3 to entry: The average shaft centerline plot and orbit plot indicate shaft dynamics that reveal malfunctions before failure.

3.5.46
average shaft centreline plot
plot displaying the average shaft position for several frequencies

Note 1 to entry: The average shaft centerline at each frequency is determined from the orbit plot.

3.5.47
cascade plot
waterfall plot
diagram that provides a simple comparison of several frequency analyses

Note 1 to entry: It is a three-dimensional form of spectra display that clearly shows vibration signal changes related to another parameter (such as rotational speed, load, temperature, time) taken for specified parameter values, such as time.

3.6 Terms for condition monitoring and diagnostics

3.6.1
ball pass frequency, inner
f_{BPFI}
frequency of the inner race (BPFI), which appears when all the rolling elements pass on a defect on the inner race

Note 1 to entry: The frequency generated is:

$$f_{BPFI} = \frac{N}{2}\left|f_o - f_i\right|\left(1 + \frac{B}{P}\cos\varphi\right)$$

where

f_{BPFI}	is the ball pass frequency, inner, expressed in hertz (Hz);
f_o	is the outer race rotational frequency (Hz) or rotational speed (r/s);
f_i	is the inner race rotational frequency (Hz) or rotational speed (r/s);
N	is the number of balls or rollers;
B	is the diameter of ball or roller;
P	is the pitch diameter of rollers or balls;
ϕ	is the contact angle.

3.6.2
ball pass frequency, outer
f_{BPFO}
frequency of the outer race (BPFO), which appears when all the rolling elements pass on a defect on the outer race

Note 1 to entry: The frequency generated when the outer race is stationary is:

$$f_{BPFO} = \frac{N}{2}\left|f_o - f_i\right|\left(1 - \frac{B}{P}\cos\varphi\right)$$

where

f_{BPFO}	is the ball pass frequency, outer, expressed in hertz (Hz);
f_o	is the outer race rotational frequency (Hz) or rotational speed (r/s);
f_i	is the inner race rotational frequency (Hz) or rotational speed (r/s);
N	is the number of balls or rollers;
B	is the diameter of ball or roller;
P	is the pitch diameter of rollers or balls;
ϕ	is the contact angle.

3.6.3
ball spin frequency
f_{BSF}
frequency (BSF), which is the circular frequency of each rolling element as it spins

Note 1 to entry: The ball spin frequency is: