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Second edition
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Mechanical vibration — Vibration of rotating machinery equipped with active magnetic bearings —

Part 1: **Vocabulary**

Vibrations mécaniques — Vibrations de machines rotatives équipées de paliers magnétiques actifs —

Partie 1: Vocabulaire

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Contents

Page

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*, Subcommittee SC 2, *Measurement and evaluation of mechanical vibration and shock as applied to machines, vehicles and structures*.

This second edition cancels and replaces the first edition (ISO 14839-1:2002), which has been technically revised. It also incorporates the Amendment ISO 14839-1:2002/Amd. 1:2010.

The main change compared to the previous edition is as follows:

— the terms have been updated and revised to reflect how they are used in practice.

A list of all parts in the ISO 14839 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Mechanical vibration — Vibration of rotating machinery equipped with active magnetic bearings —

Part 1: Vocabulary

1 Scope

This document defines terms relating to rotating machinery equipped with active magnetic bearings.

NOTE General terms and definitions of mechanical vibration are given in ISO 2041; those relating to balancing are given in ISO 21940-2; those relating to geometric characteristics such as coaxiality, concentricity and runout are explained in ISO 1101.

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

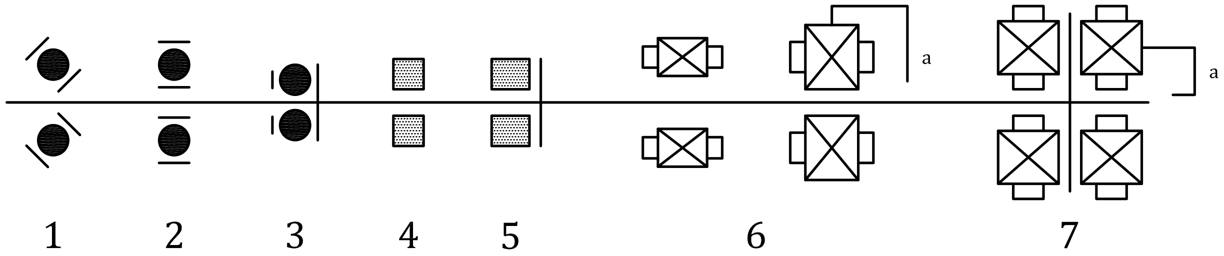
3.1.1
levitation
maintaining the position of a rotor by attractive or repulsive magnetic forces without mechanical contact

3.1.2
magnetic bearing
bearing which utilizes either attractive or repulsive magnetic forces for the *levitation* (3.1.1) and dynamic stabilization of a rotor

3.1.3
active magnetic bearing
AMB
means of supporting a rotor, without mechanical contact, using only attractive magnetic forces based upon servo feedback technology which normally consists of transducers, electromagnets, *power amplifiers* (3.5.3), power supplies and controllers

Note 1 to entry: For rotating machinery equipped with active magnetic bearings, the graphical symbols for bearings are shown in Figure 1.

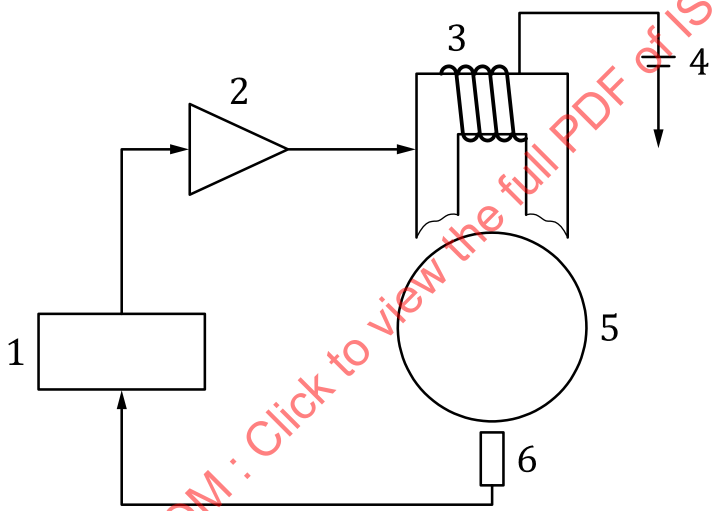
Note 2 to entry: The principle of an active magnetic bearing is shown in Figure 2.



Key

1 angular ball bearing
2 deep groove ball bearing
3 thrust ball bearing
4 radial bushing
5 thrust bushing
6 radial active magnetic bearing
7 axial active magnetic bearing
a With transducer.

Figure 1 — Graphical symbols for bearings



Key

1 controller
2 power amplifier
3 electromagnet
4 power supply
5 rotor
6 displacement transducer

Figure 2 — Principle of active magnetic bearing

3.1.4
passive magnetic bearing
means of supporting a rotor, without mechanical contact, using magnetic forces without feedback control

EXAMPLE *Permanent magnetic bearing* (3.1.5), *super-conducting magnetic bearing* (3.1.6).

3.1.5
permanent magnetic bearing
PMB
passive magnetic bearing (3.1.4) using one or several pairs of permanent magnets without feedback control

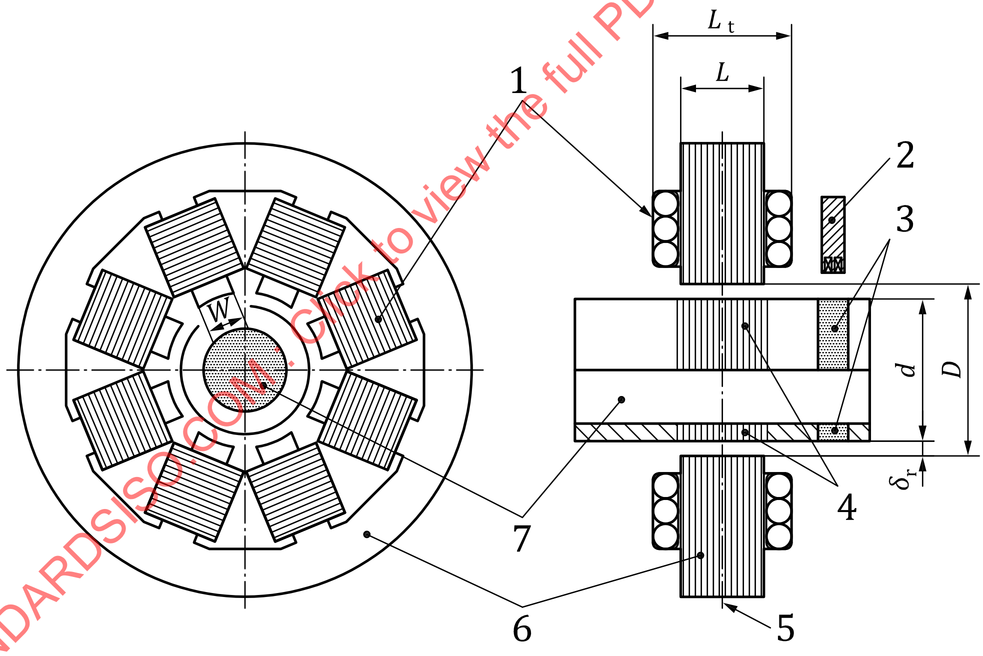
3.1.6
super-conducting magnetic bearing
SMB
passive magnetic bearing (3.1.4) using a pair of (high-temperature) super conductors and permanent magnets without feedback control, utilizing the so-called pinning force (attractive and repulsive forces)

3.1.7
hybrid magnetic bearing
HMB
bearing consisting of any combination of an *active magnetic bearing* (3.1.3) and *passive magnetic bearing* (3.1.4)

3.1.8
permanent-magnet-biased AMB
active magnetic bearing (3.1.3) in which the nominal (non-zero) or bias magnetic fluxes are established by one or more permanent magnets

3.1.9
radial magnetic bearing
magnetic bearing (3.1.2) which levitates a rotor in the radial direction and supports it against disturbances in the radial direction, such as unbalance forces, fluid forces or gravity

Note 1 to entry: See Figure 3.



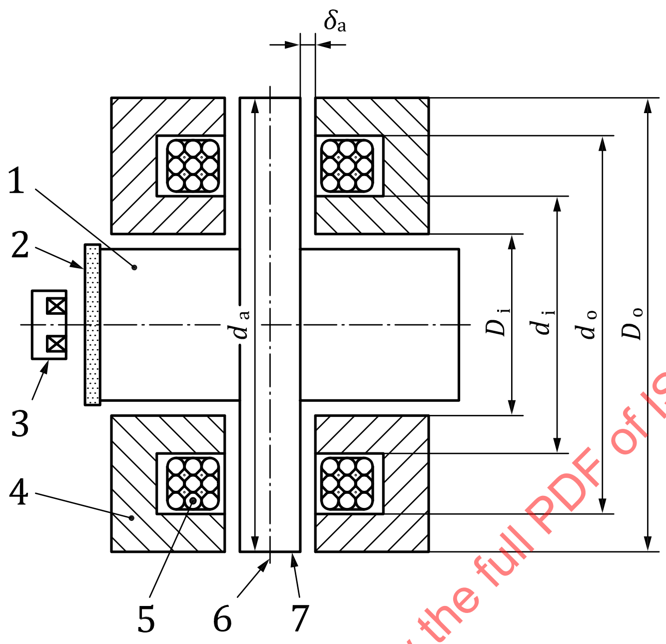
Key

1	radial coil	D	inner diameter of radial stator core
2	radial transducer	d	outer diameter of radial rotor core
3	radial transducer target	δ_r	nominal magnetic gap $(D - d)/2$
4	radial rotor core	L_t	total bearing length (including coil windings)
5	axial centre of radial AMB	L	effective length of radial bearing
6	radial stator core	W	width of a magnetic pole
7	shaft	A_r	area of magnetic pole ($A_r = WL$)

Figure 3 — Radial AMB assembly

3.1.10
axial magnetic bearing
thrust magnetic bearing
magnetic bearing (3.1.2) which levitates a rotor in the axial direction and supports it against disturbances in the axial direction, such as fluid forces or gravity

Note 1 to entry: See Figure 4.



Key

1	rotor	d_a	outer diameter of axial rotor disc
2	axial transducer target	D_o	outer diameter of outer pole of axial stator
3	axial transducer	d_o	inner diameter of outer pole of axial stator
4	axial stator core	d_i	outer diameter of inner pole of axial stator
5	axial coil	D_i	inner diameter of inner pole of axial stator
6	(clearance) centre of axial AMB	δ_a	nominal magnetic gap
7	axial rotor disc	A_a	area of the magnetic pole pair

$$A_a = \frac{\pi}{4}\left(D_o^2 - d_o^2 + d_i^2 - D_i^2\right)$$

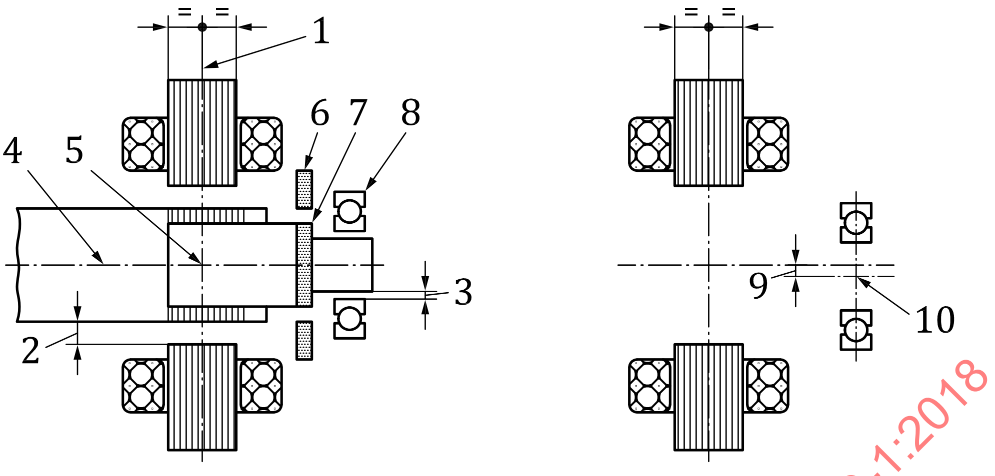
Figure 4 — Axial AMB assembly

3.1.11
nominal magnetic gap
distance between the magnetic materials of the rotor and the stator inside the *AMB* (3.1.3) when the journal centre of the rotor is located in the clearance centre of the bearing stator

Note 1 to entry: See δ_r in Figure 3 for radial AMB, and δ_a in Figure 4 for axial AMB.

3.1.12
clearance centre of a radial AMB
geometric centre of a radial bearing stator

Note 1 to entry: See Figure 5.



Key

1 axial centre of radial AMB
2 magnetic gap of radial AMB
3 radial clearance of touch-down bearing
4 journal (rotor) centreline of radial AMB
5 clearance centreline of radial AMB
6 radial transducer
7 radial transducer target
8 touch-down bearing
9 radial centre offset between radial touch-down bearing and AMB centre
10 radial centre of radial touch-down bearing

NOTE Similar consideration applies to a radial homopolar AMB.

Figure 5 — Centres and centrelines of radial heteropolar AMB

3.1.13
magnetic centre of a radial AMB
position of a rotor in a radial *AMB* (3.1.3) at which the net radial attractive forces exerted on the rotor go to zero for nominal currents or fluxes, and without any magnetic excitation or compensation forces

3.1.14
axial centre of a radial AMB
axial directional position of geometric centre of *stator core* (3.3.1)

Note 1 to entry: See Figure 5.

3.1.15
clearance centre of an axial AMB
clearance centre of a thrust AMB
axial position of the geometric centre of an (axial) thrust *AMB* (3.1.3) stator

Note 1 to entry: See Figure 4.

3.1.16
axial magnetic centre of an axial AMB
position of an *axial rotor disc* (3.2.2) in an axial *AMB* (3.1.3) at which the net axial attractive forces exerted on the rotor disc go to zero for nominal currents or fluxes, and without any magnetic excitation or compensation forces

3.1.17
clearance centreline of a radial AMB
line between the clearance centres of two radial *AMBs* (3.1.3) specified by the bearing stator configuration

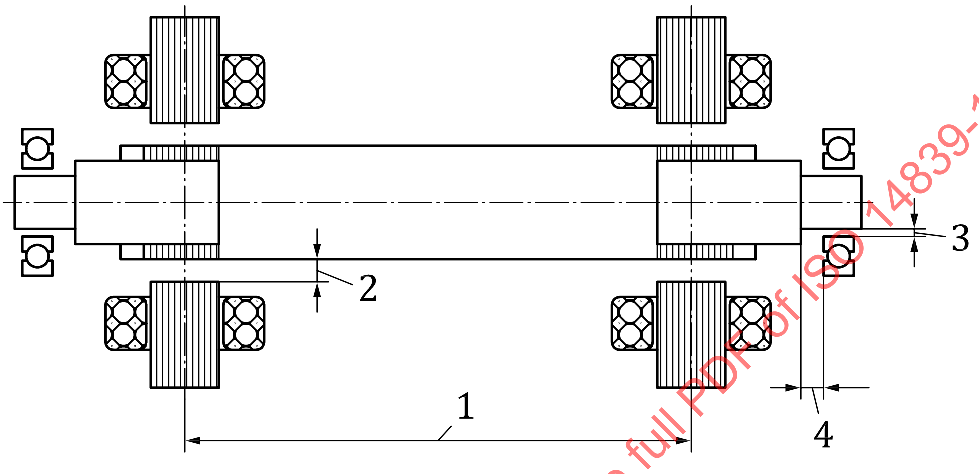
Note 1 to entry: See Figure 5.

3.1.18
journal centreline of a radial AMB
geometric centreline between the journal centres of a radial *AMB* (3.1.3) rotor

Note 1 to entry: See Figure 5.

3.1.19
bearing span between radial AMBs
axial distance between the axial centres of two radial *AMBs* (3.1.3)

Note 1 to entry: See Figure 6.



Key
1 bearing span between radial AMBs
2 magnetic radial clearance of radial AMB
3 radial clearance of touch-down bearing
4 axial clearance of touch-down bearing

Figure 6 — Heteropolar-type radial AMB

3.1.20
number of poles
sum of the south and north magnetic gap poles of an *AMB* (3.1.3)

Note 1 to entry: See Figure 7.

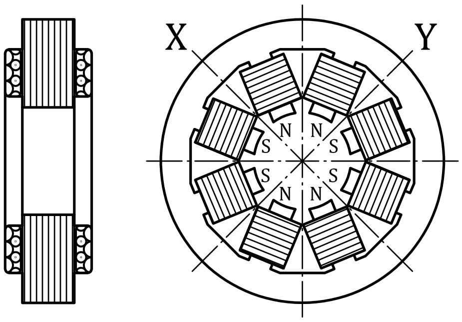
3.1.21
heteropolar-type radial AMB
radial *AMB* (3.1.3) in which the electromagnetic cross section has poles of different polarity, and the poles may have different polarity arrangements

Note 1 to entry: Polarity arrangements can be (N, S, N, S, ...), (N, S, S, N, ...), etc.

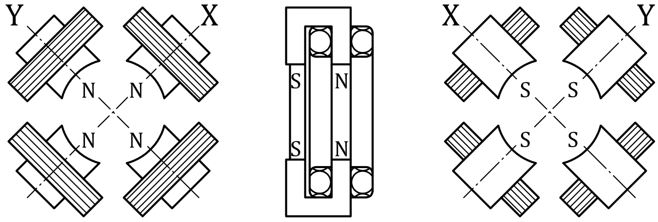
Note 2 to entry: See Figure 7 a).

3.1.22
homopolar-type radial AMB
radial *AMB* (3.1.3) whose electromagnet has more than one axial cross section, each having poles of a single polarity

Note 1 to entry: See Figure 7 b).



a) Heteropolar type (8 poles)



b) Homopolar type (8 poles)

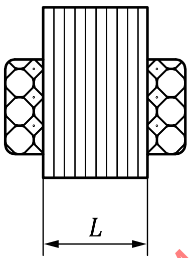
Key

X, Y control axes

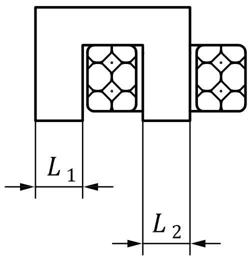
Figure 7 — Number of poles of radial AMB

3.1.23
effective length of a radial magnetic bearing
pole face axial length of a radial bearing stator for which the radial electromagnet is able to generate an attractive force exerted on the rotor

Note 1 to entry: See Figure 8.



a) Heteropolar type



$$L = L_1 + L_2$$

b) Homopolar type

Figure 8 — Effective length of radial magnetic bearing, L

3.1.24
projection area of a radial AMB
product dL of the radial bearing *journal diameter* (3.2.3), d, and the effective bearing length, L

Note 1 to entry: See Figure 3.

3.1.25
area of one magnetic pole
cross-sectional area, A, of a magnetic pole which can generate an attractive force exerted on the rotor

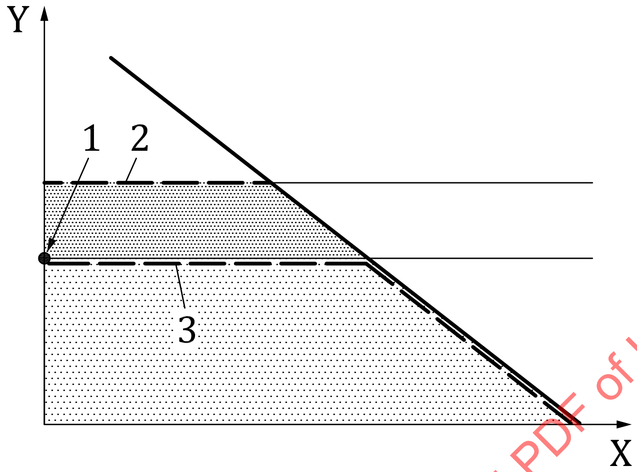
Note 1 to entry: This is different from the projection area as defined in 3.1.24.

Note 2 to entry: See A_r in Figure 3 for radial AMB, and A_a in Figure 4 for axial AMB.

3.1.26
load capacity of an AMB
maximum force that an *AMB* (3.1.3) can generate on the rotor at its fixed centred position

Note 1 to entry: This is usually limited by the magnetic saturation of the ferromagnetic material of stator and rotor core, the maximum coil current available from the *power amplifier* (3.5.3) that drives the *magnetizing coil* (3.3.4) and the maximum driving voltage of the power amplifier.

Note 2 to entry: See Figure 9.



Key

X frequency of magnetic force

Y force

1 static load capacity: usually given by AMB temperature limit (or coil temperature limit)

2 peak transient load capacity: usually given by current limitations of the AMB

3 dynamic load capacity: given by the amplifier voltage limit and eddy current effects

Figure 9 — Load capacity of an AMB

3.1.26.1
static load capacity of an AMB
F_{max}
maximum load capacity for constant load over an unlimited time period of continuous operation

3.1.26.2
peak transient load capacity of an AMB
maximum load capacity over a limited time period

3.1.26.3
dynamic load capacity of an AMB
maximum allowed amplitude value for a periodic force generated by an *AMB* (3.1.3) as a function of frequency

3.1.27
load pressure of a radial AMB
static load capacity (3.1.26.1), F_{max}, divided by the *projection area* (3.1.24), dL, of the bearing, defined as

$$p = F_{max}/(dL)$$

3.1.28
number of control axes of an AMB
number of degrees of freedom of the rotor motion which are controlled by the *AMB* (3.1.3)

EXAMPLE

a) 1-axis-controlled AMB: an AMB which actively controls vibration and motion only for one degree of freedom of the rotor;

b) 2-axis-controlled AMB: an AMB which actively controls vibration and motion for two degrees of freedom of the rotor;

c) 3-axis-controlled AMB: an AMB which actively controls vibration and motion for three degrees of freedom of the rotor.

3.1.29
total AMB loss
sum of iron loss due to eddy currents and hysteresis in the rotor and the stator, copper loss (ohmic loss) in coils, windage loss on the bearing rotor surface and circuit loss in the electrical equipment (cable, electronic cabinet)

3.1.30
self-sensing AMB
active magnetic bearing (3.1.3) which includes the function of rotor position detection without the use of direct *displacement transducers* (3.4.3)

3.1.31
rise time
time required for an *AMB* (3.1.3) force to change from 10 % to 90 % of the *peak transient load capacity* (3.1.26.2)

3.1.32
dwell time
time that the peak transient force can remain at the peak level

3.1.33
non-collocation
situation in which radial transducers and electromagnets are not placed at the same axial location

Note 1 to entry: Figures 3 and 4 show the typical cases, and non-collocation often affects the plant dynamics.

3.1.34
coaxiality
geometric line positioning characteristic between *AMB* (3.1.3) and *touch-down bearing* (3.6.1) as well as between the AMBs

Note 1 to entry: Coaxiality is explained in ISO 1101.

3.1.35
concentricity
geometric point positioning characteristic between *AMB* (3.1.3) and *touch-down bearing* (3.6.1) as well as between the AMBs

Note 1 to entry: Concentricity is explained in ISO 1101.

3.2 Terms relating to rotors

3.2.1
radial rotor core
radial rotor journal
ferromagnetic portion of the rotating shaft on which the radial magnetic control forces are exerted, which is typically laminated

3.2.2
axial bearing disc
axial disc
axial rotor disc
thrust bearing disc
thrust disc
thrust rotor disc
ferromagnetic portion of the rotating shaft on which the axial magnetic forces are exerted

3.2.3
journal diameter
diameter of the *radial magnetic bearing* (3.1.9) rotor

Note 1 to entry: See d in Figure 3.

3.2.4
geometrical runout
mechanical runout
measured fictitious displacement of the rotating shaft due to the effect of the non-circularity and non-coaxiality of the shaft shape

3.2.5
electrical runout
position transducer runout
measured fictitious displacement of the rotating shaft due to the magnetic or electrical non-homogeneity of the position *transducer target* (3.4.6)

3.2.6
DN value
product dN of the diameter d (mm) and the rotor speed N (r/min)

Note 1 to entry: The diameter, d, is defined as:

a) the outer diameter of the rotor of a radial AMB if the stator is external to the rotor (see d in Figure 3);

b) the inner diameter of the rotor of a radial AMB if the rotor is external to the stator;

c) the outer diameter of the rotor of an axial AMB (see d_a in Figure 4).

3.3 Terms relating to stators

3.3.1
stator core
core of the stationary *AMB* (3.1.3) components made of ferromagnetic or other magnetically permeable materials

3.3.2
radial stator core
stationary section of the *radial magnetic bearing* (3.1.9) around which the *magnetizing coil* (3.3.4) is wound

3.3.3
axial stator core
thrust stator core
stationary section of the *axial magnetic bearing* (3.1.10) around which the *magnetizing coil* (3.3.4) is wound

3.3.4
magnetizing coil
coil used to generate the magnetic flux in the core material

3.3.5
radial coil
magnetizing coil (3.3.4) wound around the core of the radial bearing or the radial electromagnetic pole itself

3.3.6
axial coil
thrust coil
magnetizing coil (3.3.4) of an axial *AMB* (3.1.3)

3.3.7
allowed operating temperature
coil and lamination temperatures which allow for specified normal *AMB* (3.1.3) operation

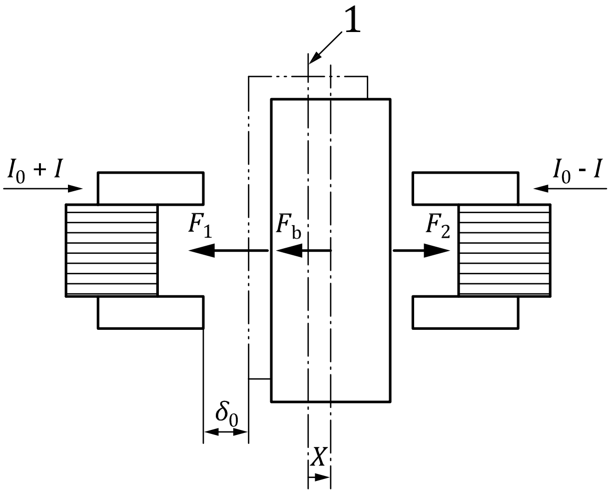
3.4 Terms relating to position transducers

3.4.1
position measuring system
composition of devices comprising a sensor that responds to changes in the rotor/stator gap, an amplifier to excite the sensor and apply a gain to the response signal, and a signal post processing unit

3.4.2
shaft displacement
rotor centre displacement in the radial or axial direction measured from the nominal position, indicating a change of rotor position

Note 1 to entry: Shaft displacement is sometimes called shaft vibration, shaft movement or shaft motion.

Note 2 to entry: See Figure 10.



$$F_b = F_1 - F_2 = K\left(\frac{I_0 + I}{\delta_0 + X}\right)^2 - K\left(\frac{I_0 - I}{\delta_0 - X}\right)^2$$

$$\approx 4K\frac{I_0}{\delta_0^2}I - 4K\frac{I_0^2}{\delta_0^3}X$$

$$= K_i I + K_s X$$

$$K_i = 4K\frac{I_0}{\delta_0^2}$$

$$K_s = -4K\frac{I_0^2}{\delta_0^3}$$

where

F_1, F_2	is the attractive force generated by one electromagnet;
F_b	is the total attractive force;
I	is the control current;
I_0	is the bias current;
K	is the coefficient of the electromagnet;
K_i	is the force/current gain;
K_s	is the negative position stiffness;
X	is the radial shaft displacement;
δ_0	is the nominal magnetic gap.

Key

1 clearance centreline

NOTE Linearization of the total attractive force F_b is shown in terms of an AMB bias current I_0, which could be set, typically, using a 2-quadrant power amplifier.

Figure 10 — Current-force characteristic

3.4.3
displacement transducer
position transducer
transducer for the detection of shaft position without any mechanical contact

Note 1 to entry: See Figures 3 and 4.

EXAMPLE Eddy current transducer, inductive transducer, capacitive transducer, optical transducer, Hall effect transducer.

3.4.4
radial displacement transducer
radial position transducer
transducer for the detection of radial shaft position

Note 1 to entry: See Figures 3 and 5.

3.4.5
axial displacement transducer
axial position transducer
thrust displacement transducer
thrust position transducer
transducer for the detection of axial shaft position

Note 1 to entry: See Figure 4.

3.4.6
transducer target
area of rotating shaft where the *position transducer* (3.4.3) detects the displacement

Note 1 to entry: See Figures 3 and 4.

3.4.7
radial transducer target
radial target
area of rotating shaft where the *radial position transducer* (3.4.4) detects the displacement in the radial direction

Note 1 to entry: See Figure 3.

3.4.8
axial transducer target
axial target
area of rotating shaft where the *axial position transducer* (3.4.5) detects the displacement in the axial direction

Note 1 to entry: See Figure 4.

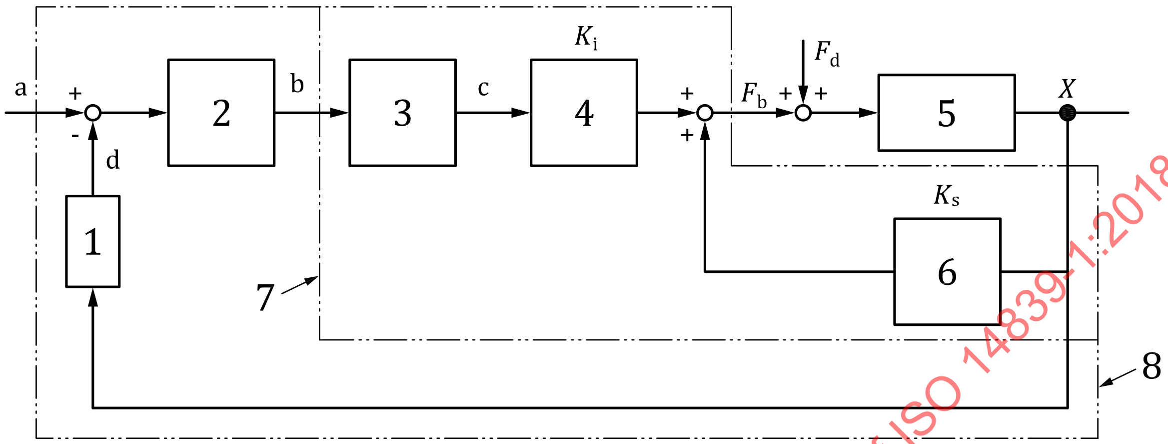
3.5 Terms relating to dynamics, control and electronics

3.5.1
AMB system
system consisting of a rotor, *position transducers* (3.4.3) or other means to detect rotor position, controller(s), *power amplifiers* (3.5.3) and electromagnets to levitate and support the rotor by attractive magnetic forces

Note 1 to entry: See Figures 2 and 11.

3.5.2
AMB controller
device which detects and processes the transducer signal and transfers it to the *power amplifier* (3.5.3) in order to regulate the magnetic attractive force to levitate the rotor

Note 1 to entry: It can be realized by an analogue and/or digital device (analogue controller, digital controller).



Key

1	position transducer	F_b	AMB force
2	AMB controller	F_d	disturbance force
3	power amplifier	X	displacement
4	force/current gain	K_i	force/current gain
5	mechanical plant rotor	K_s	negative position stiffness
6	negative position stiffness	a	Reference signal.
7	AMB actuator	b	Control signal.
8	AMB (including AMB actuator)	c	Control current.
		d	Transducer signal.

Figure 11 — Block diagram of an AMB system with a reference signal

3.5.3
power amplifier
power output device which generates *magnetizing coil* (3.3.4) current in order to generate a magnetic control force

EXAMPLE Typical types of power amplifiers are linear power amplifier, analogue amplifier, pulse width modulating (PWM) amplifier, switching amplifier.

3.5.4
AMB current control
method of controlling *AMB* (3.1.3) using voltage input/current output *power amplifiers* (3.5.3) for the feedback actuator from power amplifier to electromagnetic current

3.5.5
AMB voltage control
method of controlling *AMB* (3.1.3) using voltage input/voltage output *power amplifiers* (3.5.3)

3.5.6
AMB bias current
I_0
fixed d.c. coil current used to linearize the attractive force in relation to the current and the clearance of the *AMB* (3.1.3)

Note 1 to entry: See formulae in Figure 10.

3.5.7
negative position stiffness
K_s
<in the bias-linearized AMB actuator> position stiffness of the electromagnet due to *bias current* (3.5.6) at the nominal rotor position without an external load

Note 1 to entry: K_s is negative.

Note 2 to entry: See Figures 10 and 11.

3.5.8
closed-loop dynamic system stiffness
transfer function(s) of the F_d/X ratio of the *AMB(s)* (3.1.3) closed-loop system with the disturbance input force F_d and output displacement X

Note 1 to entry: See Figure 11.

3.5.9
closed-loop dynamic system compliance
reciprocal of the *closed-loop dynamic system stiffness* (3.5.8), i.e. X/F_d

Note 1 to entry: See Figure 11.

3.5.10
open-loop AMB dynamic stiffness
transfer function of the F_b/X ratio of the *AMB* (3.1.3) open-loop system with the displacement input X and the bearing output force F_b, through the transducer, controller, *power amplifier* (3.5.3) and electromagnet

Note 1 to entry: The frequency-dependent bearing spring force is obtained by the real part of the complex ratio F_b/X, and the frequency-dependent bearing damping force is obtained by the imaginary part of the complex ratio F_b/X.

Note 2 to entry: See Figure 11.

3.5.11
AMB centralized control
control structure that has internal connections between the controller inputs and controller outputs for different degrees of freedom of the rotor

EXAMPLE The following control methods are in this category:

— gyroscopic effects compensator;

— cross stiffness control;

— multi-input multi-output (MIMO) controller.

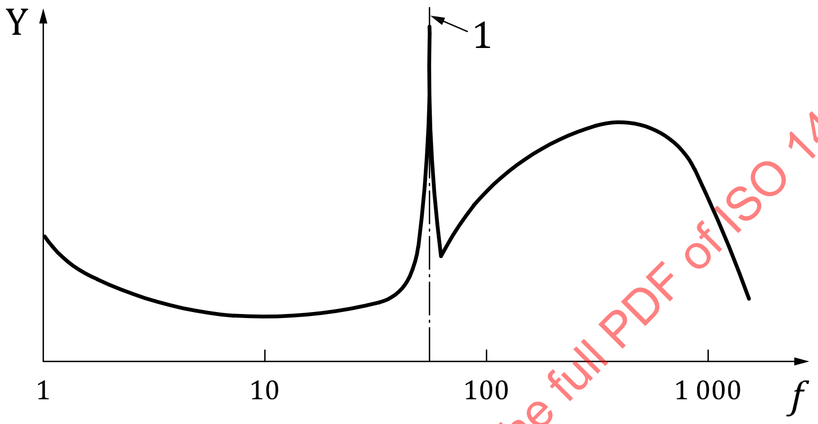
3.5.12
AMB decentralized control
control structure that has no internal connections between the controller inputs and controller outputs for different degrees of freedom of the rotor

EXAMPLE Multiple single-input single-output (SISO) controllers.

3.5.13
AMB tuning process
process of adjusting the controller's transfer function so that a rotor is in a desired operating condition within a *magnetic bearing* (3.1.2) system

3.5.14
peak-of-gain control
unbalance force counteracting control
control method which automatically detects and compensates unbalance forces of the rotor to minimize relative rotor to housing vibration due to unbalance

Note 1 to entry: The counteracting force is transmitted through the *AMB* (3.1.3) to the foundation (see Figure 12). As a result, absolute housing vibration is likely to increase while relative rotor to housing vibration is minimized.



Key
f frequency, Hz
Y controller gain, dB
1 frequency of rotation

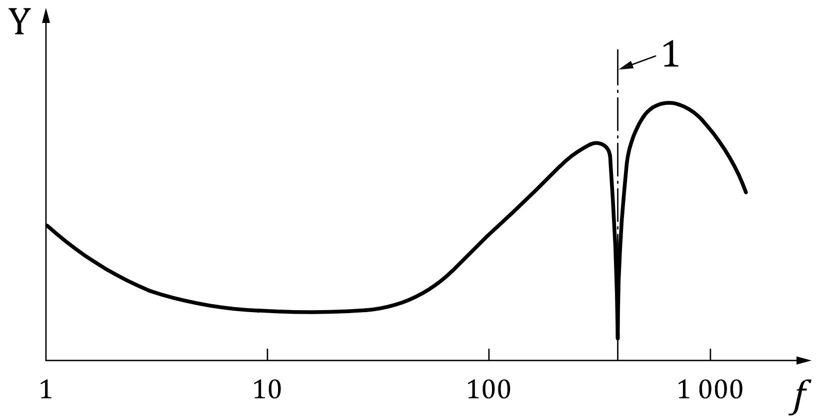
Figure 12 — Example of a controller transfer function for unbalance force counteracting control

3.5.15
unbalance force rejection control
control method which allows the rotor to rotate around its principal axis of inertia while the transmitted unbalance force through the *AMB* (3.1.3) is minimized, which leads to minimized resulting vibration of the bearing casing

Note 1 to entry: Shaft vibration can increase.

Note 2 to entry: The "ABS" (automatic balancing system) or "N-cut" have the same function as the *unbalance force rejection control* (3.5.15).

Note 3 to entry: See Figure 13.



Key

f frequency, Hz

Y controller gain, dB

1 frequency of rotation

Figure 13 — Example of a controller transfer function for unbalance force rejection control

3.6 Terms relating to auxiliary equipment

3.6.1
touch-down bearing

bearing installed in the *AMB system* (3.5.1), which is designed to limit the rotor motion and to prevent contact with the AMB stator or rotor surface due to overload, failure or deactivation of the AMB system

Note 1 to entry: Other designations include auxiliary bearing, back-up bearing, catcher bearing, emergency bearing and retainer bearing.

3.6.2
touch-down bearing clearance

half of the difference between the inner diameter of the touch-down radial bearing bore and the outer diameter of the rotor shaft, or the axial clearance between the thrust face of an axial *touch-down bearing* (3.6.1) and the shaft shoulder

Note 1 to entry: These touch-down bearing clearances need to be smaller than the gap between the rotor and stator in the *AMB system* (3.5.1).

Note 2 to entry: For radial clearance of touch-down bearing, see key 3 in Figure 5 or Figure 6.

3.6.3
touch-down test

test where a rotor rotating at the designated speed is dropped intentionally on the *touch-down bearings* (3.6.1) in order to evaluate their performance

Note 1 to entry: Other designations include drop test, landing test, back-up bearing test.

3.6.4
uninterruptible power supply system
UPS system

source of stored energy that can be used to power the *AMB system* (3.5.1) during a mains power supply failure

3.6.5
touch-down bearing compliant mount
flexible element which provides a defined stiffness and damping support for a mounted radial *touch-down bearing* (3.6.1)

Note 1 to entry: This support is required in order to improve vibration response when running on touch-down bearings.

3.6.6
touch-down bearing hard-stop clearance
travel distance to a hard stop which limits the movement of the compliant mount of a radial *touch-down bearing* (3.6.1)