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

Part 4:

Technical guidelines

Vibrations mécaniques — Vibrations de machines rotatives équipées de paliers magnétiques actifs — Partie 4: Lignes directrices techniques

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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

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

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

ISO 14839-4 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*.

ISO 14839 consists of the following parts, under the general title *Mechanical vibration — Vibration of rotating machinery equipped with active magnetic bearings:*

— *Part 1: Vocabulary*

— *Part 2: Evaluation of vibration*

— *Part 3: Evaluation of stability margin*

— *Part 4: Technical guidelines*

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

Part 4:
Technical guidelines

1 Scope

This part of ISO 14839:

a) indicates a typical architecture of an active magnetic bearing (AMB) system so that users can understand which components are likely to comprise such systems and which functions these components provide;

b) identifies the primary similarities and differences between AMB systems and conventional mechanical bearings;

NOTE This information helps AMB system users better to understand the selection process and implications of transition to AMB technology.

c) identifies the environmental factors that have significant impact on AMB system performance;

d) identifies the operating limitations that are unique to AMB systems and defines standardized methods of assessing these limitations;

e) identifies typical mechanisms for managing these limitations, especially rotor unbalance;

f) provides considerations for the design and performance of touchdown bearing systems;

g) defines a typical signal set for provision in an AMB system for proper system/process interface as well as condition and diagnostic monitoring;

h) details current best practices for monitoring, operation and maintenance to achieve highest operational system reliability;

i) identifies typical fault-handling practices;

j) recommends inspection and preventive maintenance processes for AMB systems.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 1940-1, *Mechanical vibration — Balance quality requirements for rotors in a constant (rigid) state — Part 1: Specification and verification of balance tolerances*

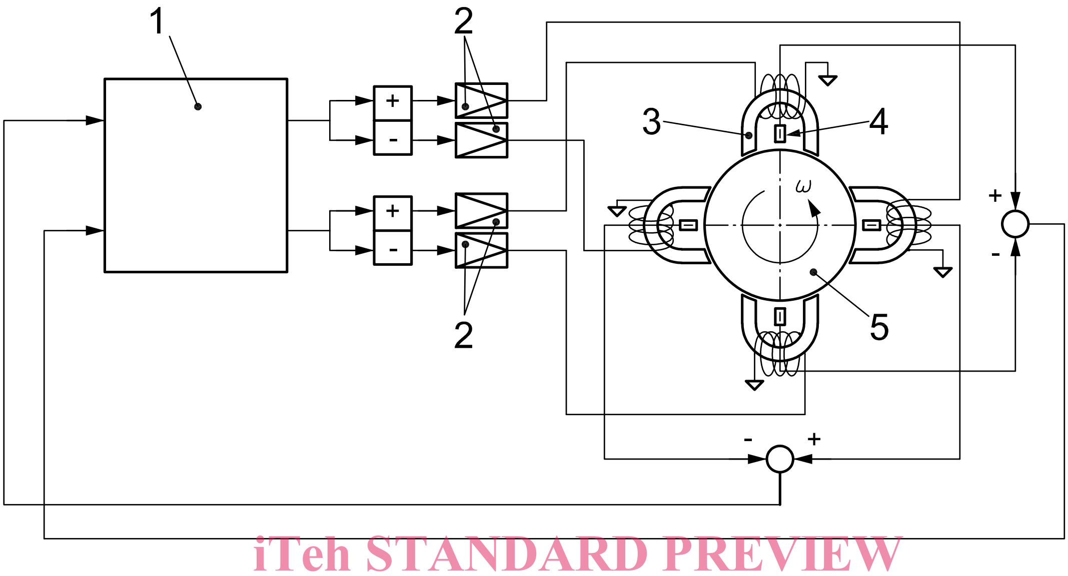
ISO 14839-1:2002 + Amd.1:2010, *Mechanical vibration — Vibration of rotating machinery equipped with active magnetic bearings — Part 1: Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 14839-1 apply.

4 Active magnetic bearing system architecture

Active magnetic bearings (AMBs) can be used as suspension elements in rotating machines in lieu of conventional types of bearings such as rolling element bearings and sleeve/journal bearings. AMBs support or levitate a shaft using an electromagnetic force controlled by a position feedback loop. A typical radial magnetic bearing actuator consists of electromagnets arranged at four directions around a rotating shaft as shown in Figure 1. In this case, there are two orthogonal control axes.



Key

1	controller
2	power amplifier
3	magnetic coil
4	displacement sensor
5	rotor with rotational angular frequency ω

Figure 1 — Schematic drawing of a magnetic bearing system

Key elements of the AMB are:

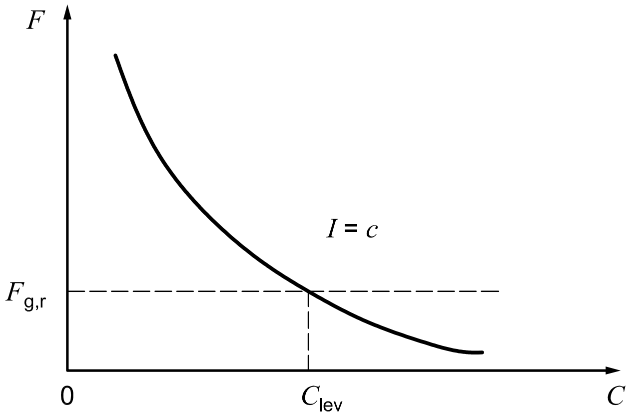
a) a displacement transducer that detects the displacement of the shaft from a reference position or setpoint;

b) a processor or controller that produces a control command signal based on the position error;

c) a power amplifier to convert the low level command signal to a control current;

d) an electromagnetic actuator that applies a control force to the shaft based on the use of a magnetic field.

Rotational drag losses are quite low in an AMB because the shaft is supported by a magnetic field without mechanical contact. The only drag losses are from eddy currents generated in the rotor and from windage. These losses are small compared with the friction drag of rolling element bearings and very small compared to the losses in sliding bearings. On the other hand, control of shaft position is not trivial. The magnetic force acting on the shaft from each electromagnet is an attractive force that becomes larger as the shaft gets closer to the actuator (see Figure 2). Thus it is passively unstable since a displacement from the equilibrium position results in a force pulling the shaft further from its equilibrium position. This force/displacement relationship is characterized by a negative stiffness.



Key

F	attractive force	$F_{g,r}$	rotor weight
C	clearance	C_{lev}	levitation point
$I = c$	current is constant		

Figure 2 — Relationship between attractive force and clearance when the current is constant

AMBs are operated with a bias flux produced either by the electromagnet or by a permanent magnet. This bias flux linearizes the force/control current relationship of the magnetic bearing making position control easier. Historically, magnetic bearings were controlled by analogue control hardware executing single input single output (SISO) proportional, integral and differential actions (PID) control or simple multi-input multi-output (MIMO) PID schemes. Digital controllers are used almost exclusively in new installations at the time of publication. Digital control provides all functionality available with the analogue control along with easier implementation and calibration.

Further, many features became more practical with digital control, including robust control techniques, unbalance response control, as well as monitoring and diagnostic functions. Generally, a digital controller for a magnetic bearing has a software control program running in a digital signal processor (DSP) that is essentially the same for all machine applications. Additionally, for a given machine application, there are parameters that define the control law and other application-specific characteristics. Magnetic bearings are typically accompanied by touchdown bearings that support the shaft when power is turned off, in the event of an equipment failure during operation, or in case an overload is applied to the bearing. The touchdown bearings are also commonly referred to as back-up bearings, auxiliary bearings, catcher bearings, and retainer bearings.

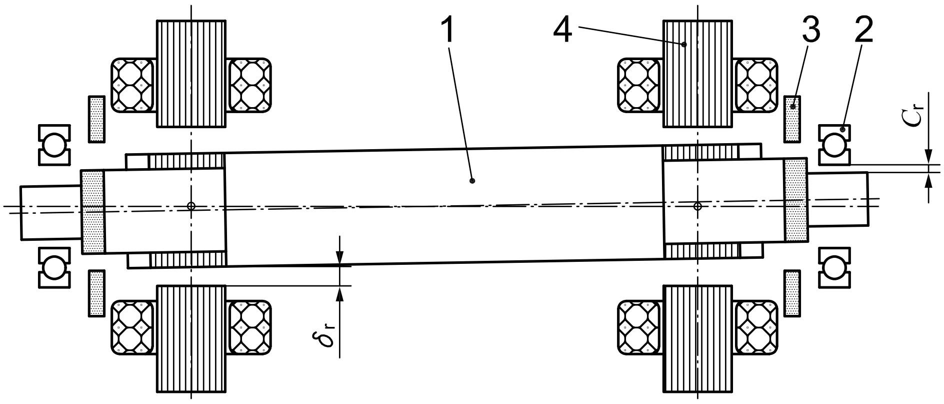
The clearance between a touchdown bearing and the shaft is commonly set to less than or equal to half of the clearance between a magnetic bearing and the shaft. The magnetic bearing that controls shaft position in the radial direction is called a radial magnetic bearing. A common arrangement of a magnetic bearing with displacement transducers and touchdown bearings is shown in Figure 3.

On the other hand, a magnetic bearing that controls shaft position in the axial direction is called a thrust magnetic bearing, and a common configuration of this bearing, displacement transducer, and touchdown bearing is shown in Figure 4.

5 Important differences between magnetic bearings and conventional bearings

5.1 Some advantages of active magnetic bearings

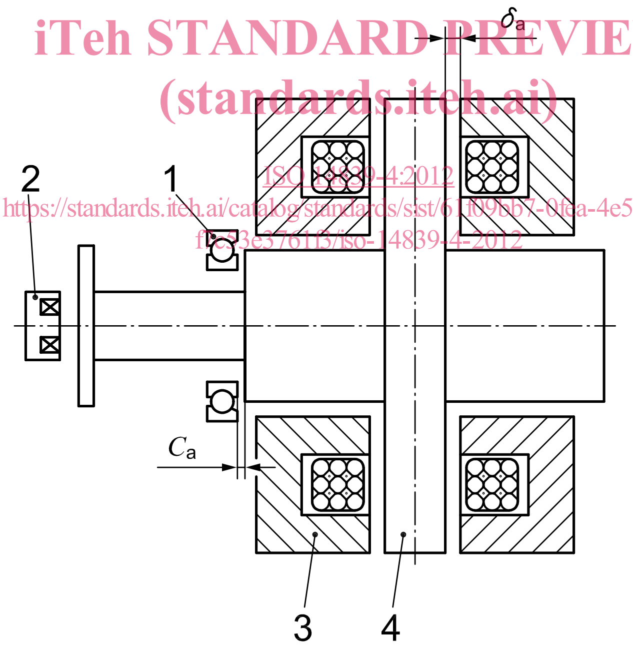
5.1.1 A magnetic bearing system has many special features that differ from conventional bearings because it functions by supporting or levitating a shaft in a magnetic field controlled by position feedback.



Key

1	shaft	$C_r \approx 0{,}5\delta_r$	
2	radial touchdown bearing	C_r	radial clearance
3	displacement sensor	δ_r	radial magnetic gap
4	radial magnetic bearing		

Figure 3 — Typical arrangement of radial magnetic bearings, displacement transducers and touchdown bearings (ISO 14839-1:2002, Figure 6)



Key

1	thrust touchdown bearing	$C_a \approx 0{,}5\delta_a$	
2	thrust displacement sensor	C_a	axial clearance
3	thrust magnetic bearing	δ_a	axial magnetic gap
4	thrust disc		

Figure 4 — Typical arrangement of thrust magnetic bearings, thrust displacement transducers and thrust touchdown bearings

5.1.2 The following functions arise because the AMB uses an active control system:

a) AMBs have high static stiffness and lower dynamic stiffness;

b) AMBs typically use unbalance control techniques which can:

   1) minimize unbalance loads and transmitted vibration (using inertial axis rotation) or,

   2) minimize harmonic displacement;

c) AMB control can be used to increase damping when passing a critical speed;

d) AMBs can be used for monitoring and diagnostic purposes due to built-in instrumentation.

5.1.3 The following advantages of AMBs relative to conventional bearings arise because of the non-contact nature of the AMB.

a) There are no mechanical friction losses and only small electrical losses due to eddy currents, allowing AMB machines to have higher efficiency.

b) Higher peripheral speeds are possible, typically limited only by rotor lamination stresses.

c) There is no wear on the machine components (actuator and transducer), therefore there is no maintenance required for these components.

5.1.4 There are the following advantages on the grounds that AMBs are used without lubrication.

a) AMBs eliminate oil contamination problems.

b) AMBs can be used in a vacuum.

c) AMBs can be used in a cryogenic environment.

d) Auxiliary lubricating systems, such as a hydraulic pump, an oil cooler, an oil filter, and piping of a hydraulic system, are unnecessary.

e) The system can be made simpler and installation space can be saved since the magnetic bearing control hardware is smaller and more easily placed than an auxiliary lubrication system.

f) Maintenance is reduced substantially.

5.2 Some disadvantages of active magnetic bearings

AMB has many features and advantages specified in 5.1. Nevertheless, there are also the following disadvantages.

a) AMBs require electrical power.

b) The maximum load capacity of AMBs mainly depends on the maximum magnetic flux capacity of the actuator materials preventing the AMB from having an overload capacity.

c) The specific load limit imposed by the magnetic saturation limits of available materials results in a specific load (load per unit area) considerably lower than oil film and rolling element bearings.

d) Since the control circuit can be complex, sufficient verification to establish reliability is required.

e) Time and cost are needed to establish the control system reliability when the system is out of order.

f) Control of many modes is required, even beyond the operating speed range.

g) Advanced knowledge that fuses concept of mechanical engineering and electrical engineering is needed for designing the magnetic bearing/rotor system.

h) Touchdown bearings have to be installed near the magnetic bearing to avoid unexpected contact between the rotor and stator of the magnetic bearing in cases of overload, failure of the magnetic bearing controller or power supply.

5.3 Comparison among rolling, fluid film and magnetic bearings

Table 1 summarizes and shows the differences among rolling bearing, fluid film bearing and magnetic bearing types.

The development of a dynamic model for an AMB system requires techniques beyond those used for a conventional bearing system. The dynamic coefficients concept known for conventional bearings cannot generally be applied directly due to the inherent characteristics of AMB systems. Examples include actuator and transducer non-collocation, high-order control characteristics, MIMO control, dynamics of power and transducer electronics. Thus, AMB vendors and their customers should agree on suitable analysis models covering all required system dynamics.

6 System condition monitoring

6.1 General

Since an AMB relies on transducers for control, the position signals can be applicable for monitoring the working condition. For this reason, it is possible to perform condition monitoring of the rotor more delicately, and the function of a failure diagnosis can be easily given. Since rotation of a rotor without levitation is harmful, a rotation request, e.g. of the motor inverter, is denied by the AMB system as long as the rotor is not levitated.

For AMB-equipped machines, it is common practice to establish operational condition limits. These limits take the form of ALARMS and TRIPS. An ALARM is set to provide a warning that a defined value of condition has been reached or that a significant change has occurred, at which remedial action may be necessary. In general, if an ALARM situation occurs, operation can continue for a period while investigations are carried out to identify the reason for the change and to define any remedial action. A TRIP is set to specify the value of condition beyond which further operation of the machine can cause damage. If the TRIP limit is exceeded, immediate action should be taken to reduce the change or the machine should be shut down.

Other commonly used names for ALARM are WARNING and ALARM1. Other commonly used names for TRIP are ALARM2, FAULT, EMERGENCY STOP and EMERGENCY SHUTDOWN (ESD) (this ESD should not be confused with PLANT ESD for petrochemical applications).

What can be considered as TRIP or ALARM items which detect abnormalities in the diagnostic equipment during operation is explained in 6.2 to 6.10.

6.2 Excess rotor shaft displacement (radial x, y, and axial z)

In ISO 14839-2, typical evaluation zones are defined to permit a qualitative assessment of the shaft displacement.

ALARM limits may vary considerably for individual machines. The values chosen are normally set relative to a baseline value determined from experience for the measurement position or direction for that particular machine. It is recommended that the ALARM limit be set higher than the baseline by an amount equal to 25 % of the zone boundary B/C. If the baseline is low, the ALARM may be below zone C. Where there is no established baseline (e.g. with a new machine) the initial ALARM setting should be based either on experience with other similar machines or relative to agreed acceptance values. After a period of time, the steady-state baseline value is established and the ALARM setting should be adjusted accordingly. If the steady-state baseline changes, e.g. after machine overhaul, the ALARM setting should be revised accordingly.

The TRIP limits generally relate to the mechanical integrity of the machine and are dependent on any specific design features which have been introduced to enable the machine to withstand abnormal dynamic forces. The values used are therefore generally the same for all machines of similar design and are not normally related to the steady-state baseline value used for setting ALARMS. There can, however, be differences for machines of different design and it is not possible to give more precise guidelines for absolute TRIP limits. In general, the TRIP limit is within zone C or zone D.

Table 1 — Comparison of rolling element bearing, fluid-film bearing and magnetic bearing

Parameter	Rolling bearing	Fluid-film bearing	Magnetic bearing
Specific bearing load	Radial bearing: 1 MPa to 3 MPa Thrust bearing: 0.2 MPa to 2,0 MPa	Radial bearing: 2 MPa to 5 MPa Thrust bearing: <7 MPa	Radial bearing: 0,5 MPa to 0,7 MPa Thrust bearing: <0,8 MPa
Friction	Medium	High	Low
General speed limit	Depending upon component and lubrication, 90 m/s to 150 m/s	~120 m/s	~200 m/s (radial AMB) ~400 m/s (axial AMB)
Stiffness	High	Medium	Low to medium, controllable and frequency dependent
Damping	Low	High	High, controllable, and frequency dependent
Lubricant	Required	Required	Not required
Operation life	Short	Long	Long
Maintenance	Periodic replacement or periodic greasing or oil system maintenance are required	Oil filter replacement and oil replacement/ disposal are required	Electromagnets and transducers are maintenance free. Controller hardware needs periodic maintenance
Interchange standardization	Yes	In progress (in ISO/TC 123)	No
Temperature range	Wide	Narrow	Wide
Monitoring	By another instrument	By another instrument	Built-in