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

## Part 5:
## Touch-down bearings

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

*Partie 5: Paliers d'arrêt*



Reference number
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# 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.*



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

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

# Part 5: **Touch-down bearings**

## 1 Scope

This document gives guidelines for identifying:

a) The typical architectures of touch-down bearing systems to show which components are likely to comprise such systems and which functions these components provide;

NOTE Touch-down bearings are also known as “backup bearings”, “auxiliary bearings”, “catcher bearings” or “landing bearings”. Within this document, the term “touch-down bearings” is used exclusively as defined in ISO 14839-1.

b) The functional requirements for touch-down bearing systems so that clear performance targets can be set;

c) Elements to be considered in the design of the dynamic system such that rotordynamic performance can be optimized, both for touch-down bearings and active magnetic bearings (AMBs);

d) The environmental factors that have significant impact on touch-down bearing system performance allowing optimization of overall machine design;

e) The AMB operational conditions that can give rise to contact within the touch-down bearing system so that such events can be considered as part of an overall machine design. It also considers failure modes within the AMB system that can give rise to a contact event. This ensures that the specification of the touch-down bearings covers all operational requirements;

f) The most commonly encountered touch-down bearing failure modes and typical mechanisms for managing these events;

g) Typical elements of a design process for touch-down bearing systems including the specification of load requirements, the sizing process, the analytical and simulation methods employed for design validation;

h) The parameters to be taken into account when designing a touch-down bearing system acceptance test programme including the test conditions to be specified and the associated instrumentation to be used to ensure successful test execution;

i) The condition monitoring and inspection methods that allow the status of in-service touch-down bearings to be evaluated and when necessary identifying the corrective actions to be taken;

j) The factors to be considered when designing the maintenance regime for a touch-down bearing system including the actions to be taken after specified events have occurred together with any actions to be performed on a regular basis;

k) The factors to be considered regarding other life cycle topics (e.g. obsolescence management, de-commissioning and disposal).

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 2041, *Mechanical vibration, shock and condition monitoring — Vocabulary*

ISO 14839-1, *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 2041 and ISO 14839-1 apply.

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 https://www.electropedia.org/

## 4 General structure and components

Rotating machinery equipped with AMBs is typically also equipped with touch-down bearings. These touch-down bearings are intended to support the rotor when the AMB system is not activated or during a failure or overload of the AMB system. In these instances, the touch-down bearings are required to support the rotor until either levitation is recovered or the rotor is brought to zero rotational speed without damaging to other parts of the machine.



During normal operation of the machinery, the touch-down bearings have a clearance with the rotor and consequently do not apply force. The clearance at the touch-down bearings is typically the closest clearance within the rotating machine. This ensures in the event of a problem with the AMB, when the rotor moves away from its normal “centred” operating position, the first item to make contact between the rotor and stator is the touch-down bearing. Such an event occurring during rotation is referred to as a “touch-down event”, “landing event”, “contact event” or “drop event”. Such events have historically been categorized by some vendors as either “hard” landings, where a full de-levitation from high speed occurs or “soft” landings where either a partial de-levitation or a momentary contact occurs.

Touch-down bearings are required to constrain rotor movement in the degrees of freedom normally constrained by the AMB system. In the case of a rotor with two radial AMBs and one axial AMB, the touch-down bearings are required to constrain the associated five axes of movement. This is typically achieved by using:

a) two radial touch-down bearings with a separate axial touch-down bearing;

b) two radial touch-down bearings, each with a single acting thrust face; or

c) one radial touch-down bearing with a combined radial/axial touch-down bearing.

Touch-down bearings use a range of technologies, such as:

d) stator mounted rolling element bearings;

e) rotor mounted rolling element bearings;

f) dry lubricated plain bushings;

g) dry lubricated pad construction;

h) foil bearings;

i) aero-static bearings;

j) fluid-film bearings; and

k) hybrids of technologies d) to j).

In most instances on large machines the touch-down bearing comprises of a rotor part (commonly referred to as a landing sleeve) together with a stator part. The landing sleeve is intended to ensure that no damage to the core shaft occurs on touch-down and typically is a replaceable item. An alternative to the landing sleeve is to land directly on the shaft surface, which has a wear resistant coating or treatment.

The stator part typically comprises a low-friction element, which contacts the landing surface and is supported by a compliant element. The compliant element has an associated stiffness and damping which is intended to improve vibration response during a touch-down event.

The compliant element can have these characteristics:

l) preload;

m) stiffness;

n) damping;

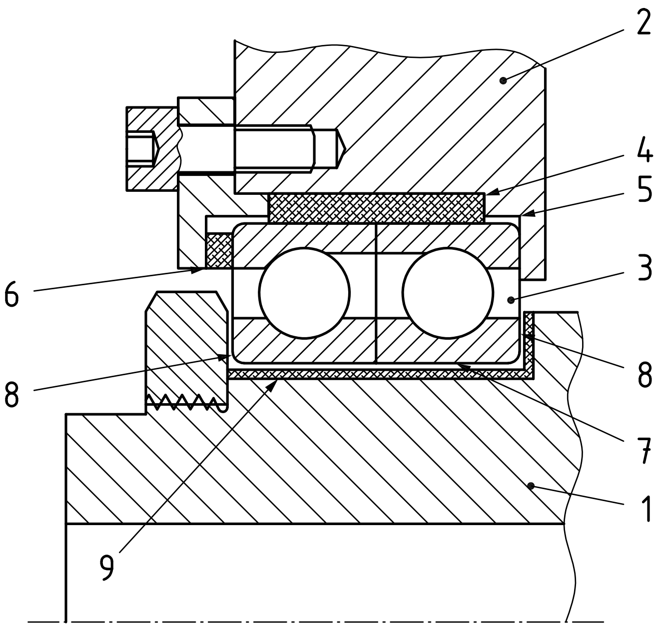
o) touch-down bearing hard-stop clearance.

When considering the minimum design clearance at any axial location, the total rotor motion at the touch-down bearings, which includes the clearance and the touch-down bearing hard-stop clearance, shall be considered together with other system stiffnesses and tolerances/concentricities. This is discussed in Clause 6.

Schematic drawings of typical configurations are shown in Figure 1 and Figure 2.






**Key**

1 core shaft
2 touch-down bearing housing
3 rolling element bearing
4 compliant element
5 hard stop clearance
6 preload spring
7 radial clearance
8 axial clearance
9 landing surfaces (or sleeve)



**Figure 1 — A typical configuration for a rolling element touch-down bearing installation**

For dry bush type radial touch-down bearings as depicted in Figure 2, the landing surface may be either a cylindrical bush (which moves as a single entity) or by articulated pads which are able to move independently of each other. In both cases the moving element(s) are supported by one or more compliant elements which provide both stiffness and damping within the hard stop clearance. In the case of the pad arrangement, the compliant elements also provide a defined pre-load force. In both cases the material of the landing surface may be optionally bonded to a backing material with suitable mechanical properties.

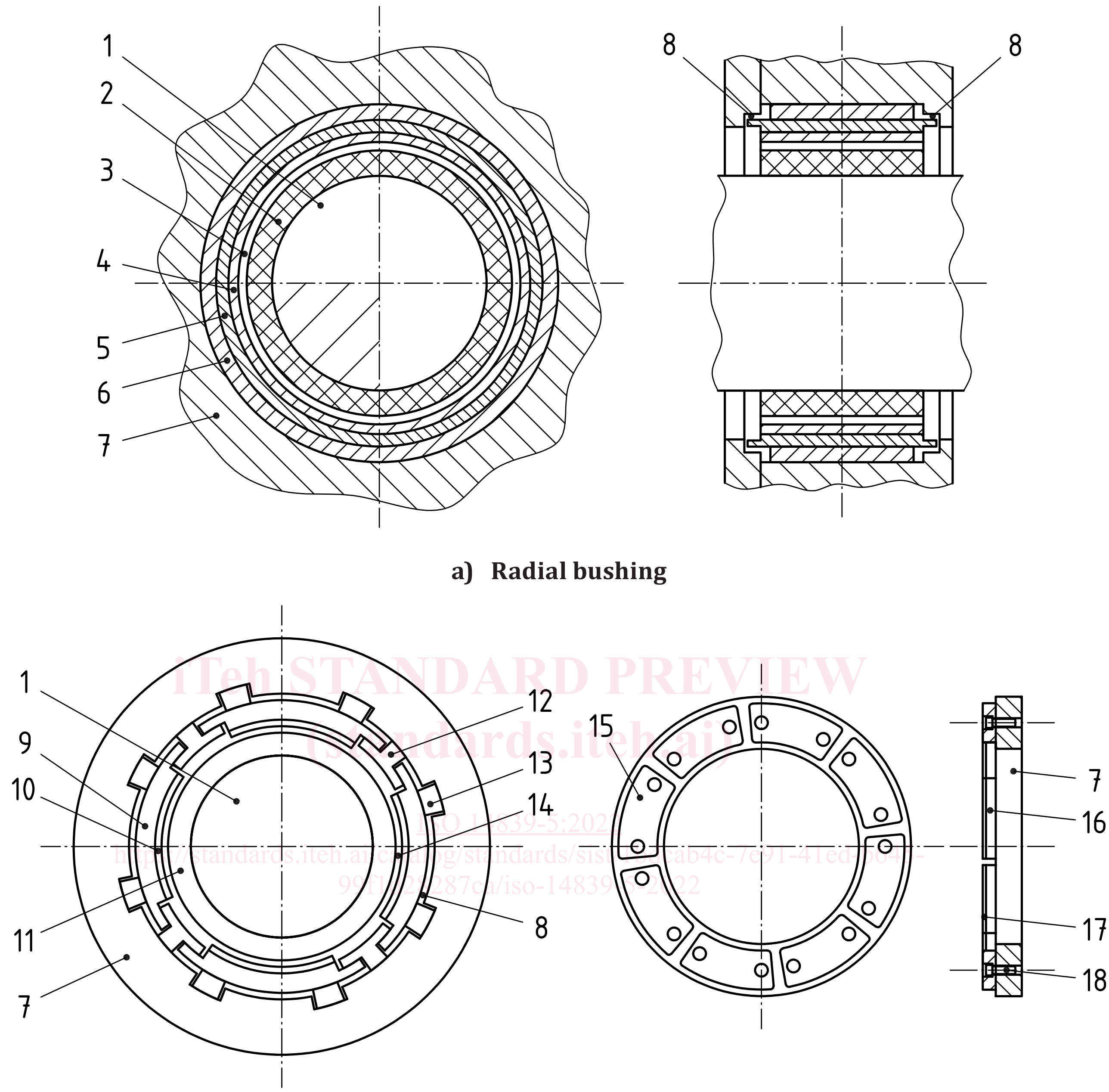
The condition of the touch-down bearings can be of utmost importance in case of an AMB failure. The touch-down bearings shall be able to safely bear the rotor during an event such as momentary contact or a full rundown to standstill. The stringent operational demands, such as high acceleration rates and high forces, lead to a very limited number of such events being allowed, thus the touch-down bearings are considered consumable parts. However, replacing touch-down bearings which have not yet reached the end of their lifetime should be avoided. Therefore, condition monitoring of touch-down bearings is essential.

## 5 Functional targets

### 5.1 General

This clause introduces the functional requirements for a touch-down bearing system that would typically be communicated by a customer of such systems to the vendor. These requirements comprise the conditions under which the touch-down bearing system shall operate, the limits to rotor excursion that the touch-down bearing shall protect, and the lifetime that the touch-down bearing shall sustain.




**a) Radial bushing**

**b) Radial articulated pads**

**c) Axial fixed pads**



**Key**

1 core shaft
2 landing sleeve (optional)
3 air gap
4 bush landing surface
5 bush backing material (optional)
6 compliant element
7 touch-down bearing housing
8 hard stop clearance
9 articulated pad (backing material)
10 articulated pad (landing surface)
11 rotor landing sleeve
12 pad stop
13 compliant element with preload
14 rotor stator clearance
15 fixed pad
16 pad backing material
17 pad landing surface
18 fixing screw

**Figure 2 — Typical configurations for dry bush touch-down bearings**

## 5.2 Design life

Touch-down bearing design life requirements shall be agreed between the customer and vendor prior to project execution and specific requirements can vary depending on the application. The touch-down bearing system shall be designed to handle a minimum number of contact events without requiring replacement or refurbishment. The agreed upon minimum number of contact events shall consider both transient contact events (momentary contacts) and sustained contact events (rundowns) and the maximum time period over which this capacity shall be sustained (effective service life of the touch-down bearing).

Additional factors that can affect touch-down bearing design life requirements include, but are not limited to:

a) the likelihood of abnormal process conditions;

b) hazardous environmental risks;

c) availability of a braking system (for sustained shutdown events);

d) power grid reliability;

e) the availability of uninterruptible power supplies (UPS) for backup power;

f) machine availability requirements (see 6.2).

It is important to recognize that the viability of the touch-down bearing can degrade over time due to environmental factors even if no hard or soft landings occur.



A means shall be provided to estimate the status of the in-service touch-down bearing system in relation to the design life requirements, without requiring a shutdown to perform the evaluation, see 8.3.

## 5.3 Clearance requirements



Permitted maximum motions within a machine depend on other close clearances within it (e.g. those in labyrinth seals). The touch-down bearings are required to limit the motions to ensure there is no unintended contact when running on the touch-down bearings.

Clearance control within the touch-down bearing will yield a maximum clearance requirement for it. This ensures that there will be no unintended contact with other parts of the machine when operating on the touch-down bearings. Clearance will depend on the assembly and manufacturing tolerances within the complete rotor and stator assembly, differential thermal effects, load cases, and other application specific forces and shall take account of the rotordynamic response when running on the touch-down bearings and during transient events.

Permitted minimum clearances in the touch-down bearing will ensure no un-intended contact with the touch-down bearing occur when the AMB is operating under specified conditions. This depends on the manufacturing concentricity tolerances of the rotor within the machine together with the nominal clearances at other locations within it. Lifetime factors such as contamination, differential thermal effects and other application specific forces need to be considered and taken into account.

Where lifetime factors are known to the machine designer, they shall be communicated to the AMB/touch-down bearing vendor as part of the AMB functional requirements.

## 5.4 Life-cycle requirements

The touch-down bearing system shall require inspection or replacement if the accumulated damage approaches or exceeds the design life requirements. The requirement for inspection or replacement shall be evaluated if the touch-down bearing system is operated outside its intended design requirements, especially for an extended period of time.

Following inspection, the touch-down bearing system can require maintenance, which can include refurbishment or replacement depending on the priorities at hand and spare parts will typically be available in advance to minimize machine downtime. The vendor shall maintain a source of touch-down bearing spare parts for an agreed period.

# 6 Touch-down bearing design considerations

## 6.1 General

This clause gives an overview of those items to be considered during the design of the touch-down bearing system by the AMB/touch-down bearing vendor and is intended to support the transformation of functional requirements into design requirements. Many requirements can be derived directly from the functional requirements where such information is known by the machine designer, but in many instances they need either to be synthesized by the vendor from the functional requirements or where this information is not known by the machine designer, estimated by the vendor based on prior experience. Touch-down bearings are included in AMB systems to provide backup or auxiliary rotor support in the rare situations where the AMBs cannot completely control the rotor. These rare situations are referred to as trigger events and are described in 6.2.

## 6.2 Trigger events

### 6.2.1 Overload due to abnormal process conditions



#### 6.2.1.1 General

AMBs have a limited peak load capability characterized by saturation in their ferromagnetic pole pieces. When loaded beyond saturation, the rotor falls out of support and needs to be retained by the touch-down bearings to prevent damage to the machine. Overload can be due to an abnormal process condition occurring or unexpected external loading source. In many cases, design margins can be included in the AMB sizing to provide extra capacity for such events; however, it is important to avoid providing substantial unneeded capacity in the AMB system. Oversized magnetic bearings can lead to poor actuator bandwidth, undesirable rotordynamic characteristics, and less robust control. Some common sources of overloading force are mentioned in 6.2.1.2 to 6.2.1.8.

#### 6.2.1.2 Compressor surge

Although compressor surge is reasonably well understood, when it occurs, the affect on the AMB control system of the amplitude of the imposed load, its excitation frequency and frequency of occurrence is difficult to predict and depends on factors that are not always in the machine designer's control. In some cases, surge results in short-term or intermittent contact with the touch-down bearings (also called touch-and-go) followed by recovery to continuous operation on the AMBs.

#### 6.2.1.3 Shock from seismic events, explosions or external impacts

These events are difficult to predict and can vary widely in magnitude and bandwidth. An AMB system can be designed to meet specific seismic requirements, but seismic events beyond the design requirements usually result in touch-down bearing impact. Occasionally, AMB systems are subjected to large shocks (e.g. resulting from explosions or external impacts), which are generally expected to be absorbed by the touch-down bearings.

If a shock load event is expected during the system lifetime, its amplitude and duration shall be defined in order that it can properly be taken account of in the AMB design analysis.

#### 6.2.1.4 Sudden rotor unbalance due to the loss of solids built-up during process flows

Some turbomachinery processes result in a build-up of solid matter on rotor surfaces. Portions of this build-up can flake off during operation resulting in a sudden unbalance. Often the resulting unbalance is small enough to be acceptable for steady-state operation of the AMB, but the impulse created can produce a short-term or intermittent contact on the touch-down bearings.

#### 6.2.1.5 Sudden rotor unbalance from loss of a turbine blade or other partial failure

A failure of this type usually results in an unbalance load that is well beyond the capability of the AMB system to tolerate and thus results in a substantial initial impact load being applied to the touch-down bearings, followed by a full-speed spin down onto the touch-down bearings. For some types of machine, a blade out failure is a design load requirement for the touch-down bearings.

#### 6.2.1.6 Abnormal motor loads – phase unbalance

For machines driven by electric motors, a phase unbalance can result in a radial load on the rotor that does not exist in normal operation. Sudden loss of a phase during operation can result in an impulse load that overloads the AMBs, resulting in touch-down bearing contact.

#### 6.2.1.7 Rub at machine close clearance

In a machine with an AMB control system, the touch-down bearing clearance shall be set such that any excursion of the rotor from its rotational axis centre shall result in touch-down bearing contact before touching any other stator element not intended to wear. Efficiency requirements in turbomachinery encourage seal clearances to be set at minimal levels in many machine designs. However, unintended rubbing contact with a seal can occur when the AMB system design has not allowed for adequate clearance margin or seal concentricity relative to the touch-down bearing. Abradable seals are designed for such contact and their use is permitted.



#### 6.2.1.8 Liquid slugging

In some processes, a slug of liquid can be introduced in the machine causing a shock or impulse load that results in touch-down bearing contact.

### 6.2.2 AMB control instability

#### 6.2.2.1 General

The nature of AMB compensator design is such that there often are frequency bands or operating scenarios where the AMB forces produce negative damping for one or more natural vibration modes of the rotor/AMB/housing system. AMB design to avoid instabilities is covered in ISO 14839-3.

#### 6.2.2.2 Inadequate control robustness to allow for process variation

Inadequate AMB control robustness can arise from a range of process variations that generate destabilizing forces, such as:

a) fluid dynamic forces in compressors, turbines and labyrinth seals can be destabilizing under certain conditions (often characterized by cross-coupled stiffness);

b) forces that are not adequately specified for the defined control scheme could not have the necessary stability margin to keep one or more modes stable under all operating conditions;

c) process fluid density much higher than predicted can result in higher destabilizing forces;

d) variation in suction pressure results in higher destabilizing forces.

#### 6.2.2.3 Lack of slew rate margin to control the dynamic loads

To respond to dynamic loads an AMB has to produce a certain control current at a required frequency. As the frequency increases, the required voltage to push the desired current through, the control increases. Since power amplifiers are sized with some specific overhead (or bus) voltage, the voltage demand of a particular load can exceed the available overhead. In this case the current is limited by the maximum d$I$/d$t$ or current slew rate. This situation almost always leads to touch-down bearing contact.

#### 6.2.2.4 Lack of power supply capacity to control the axial dynamic loads

AMBs generally impose very low real power requirements compared to other types of bearings. Additionally, in most cases it is straightforward to provide an adequately sized power supply. However, if process conditions impose unexpected axial dynamic loads, the AMB power requirements can exceed the design case due to the difficulty in predicting eddy current losses (which use real power) in the thrust bearing.

#### 6.2.2.5 Operation of a machine outside of its design case speed range

In highly gyroscopic machines, such as those with single overhung impellers, the AMB control may be gain scheduled. In this case the AMB control is adjusted based on spin speed. If the machine is operated above the design speed one or more rotor vibration modes can become unstable, resulting in touch-down bearing contact.

#### 6.2.2.6 Unexpected machine acceleration/deceleration profile



During excessive acceleration/deceleration, fluid dynamic forces can be much larger than designed for.

### 6.2.3 Loss of power

#### 6.2.3.1 General



AMB systems require an electrical power source to operate. Loss of electrical power results in deactivation of the amplifiers and shutdown of the control system. If this happens, the rotor drops onto the touch-down bearings. Generally, some type of backup electrical power is included as part of the AMB control system design, so that the AMBs will operate to allow safe spin down when external power is lost.

#### 6.2.3.2 AMB systems with no backup power source

If no backup electrical power source is provided, a loss of power results in a rotor drop onto the touch-down bearings at speed.

#### 6.2.3.3 System with an uninterruptable power supply (UPS)

Many AMB systems have a UPS sized to allow spin down of the AMBs in the event of power loss. In these systems, power loss should not be an issue unless there is a defect or failure of the UPS.

#### 6.2.3.4 Systems that incorporate a motor/generator having a regenerative backup system

Such a system can generate enough electrical power to supply the AMB in the event of power loss; however, the electrical power generator can drop out below a certain speed, often 20 % to 25 % of maximum speed. Such systems generally have a relatively benign low-speed drop (e.g. without incurring measurable system damage) as part of a system power loss event.