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Foil bearings — Performance testing of foil journal bearings — Testing of static load capacity, friction coefficient and lifetime

Paliers-feuilles — Essais de performance des paliers radiaux à feuilles non lubrifiés — Essais de la capacité de charge statique, du coefficient de frottement et de la durée de vie

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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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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 123, *Plain bearings*, Subcommittee SC 7, *Special types of plain bearings*.

This second edition cancels and replaces the first edition (ISO 13939:2012), which has been technically revised. The main changes compared to the previous edition are as follows:

— The content of Scope has been changed to a clearer expression.

— Table 1, Table 2, all figures and all formulae have been reviewed.

— The wording of definitions has been reviewed for consistency with ISO rules.

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.

Foil bearings — Performance testing of foil journal bearings — Testing of static load capacity, friction coefficient and lifetime

1 Scope

This document describes a method for comparing the performance test results of foil journal bearings, which are lubricated by air (gas) and supported by the gas-dynamic force generated via the rotations of the rotating shaft. The test procedure proposed in this document aims to predict and evaluate the static load capacity, friction coefficient and lifetime of foil journal bearings and compare the results of these parameters under different test conditions, i.e. at varying dimensions of foil bearing, rotational speed of a shaft, pressure and humidity of the surroundings. The magnitude of the static load capacity can change according to the test setting, as the test conditions can be changed.

The test method described in this document has the following application coverage.

a) The criterion for evaluating the static load capacity is the steady-state condition; i.e. the method is applicable under limited operating conditions with uniform magnitude, load direction and rotational speed.

b) The evaluation procedure can be applied only if the foil journal bearing is under a uniform rotating inertia at an arbitrary rotational speed.

c) The dynamic load with time-variant magnitude and direction is not considered.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions 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 http://www.electropedia.org/

3.1
take-off
stage aimed to secure the distance between the rotating shaft and the top foil by developing aerodynamic pressure between them

3.2
clearance
shortest distance between the rotating shaft and the top foil when the axis of the shaft coincides with the axis of the housing

3.3
bearing torque
torque developed by rotational friction between the rotating shaft and the top foil

Note 1 to entry: The measurement of the bearing torque is described in 6.4.

3.4
load
load capacity
weight that can be delivered by a bearing under steady-state conditions

3.5
initial load
load (3.4) exerted on the rotating system in the beginning

Note 1 to entry: The initial load should be lower than the static load capacity and the load at which the lifetime of the bearing is determined, as explained in 7.3 and 10.2.

3.6
static load capacity
maximum *load* (3.4) of a bearing in static state

Note 1 to entry: The measurement of the static load capacity is explained in 7.4.

3.7
friction coefficient
flow resistance caused by rotational friction between the rotating shaft and the top foil

Note 1 to entry: The measurement of the friction coefficient is described in Clause 9.

3.8
lifetime of bearing
total number of start–stop test cycles of the bearing until the first failure is observed

Note 1 to entry: The measurement of the lifetime of bearing is described in Clause 10.

4 Symbols

For the purposes of this document, the following symbols apply.

4.1 Basic characters — Roman alphabet

Table 1 — Symbol — Basic characters — Roman alphabet

Symbol	Description	Unit
C	Clearance	Micrometre
d	Diameter	Millimetre
e	Eccentricity	Micrometre
F	Force	Newton
F_w	Weight, load	Newton
H	Height	Millimetre
h	Humidity	Percentage
K	Coefficient	Newton-minute per cubic millimetre
L	Length	Millimetre
M	Torque	Newton-millimetre
N	Lifetime	Number of start–stop cycles
p	Pressure	Newton per square millimetre
R	Surface roughness	Micrometre
r	Distance	Millimetre

Table 1 *(continued)*

Symbol	Description	Unit
T	Temperature	Degree Celsius

4.2 Basic characters — Greek alphabet

Table 2 — Symbol — Basic characters — Greek alphabet

Symbol	Description	Unit
δ	Thickness	Millimetre
ε	Eccentricity ratio	Non-dimensional
μ	Friction coefficient	Non-dimensional
ω	Rotational speed	Revolution per minute

4.3 Additional signs — Subscripts

Table 3 — Symbol — Additional signs — Subscripts

Subscript	Description
a	Air (surrounding), average, applied
ah	Air in the bearing housing
b	Bump foil, bearing
f	Top foil, friction
fs	Top foil surface
h	Housing
max	Maximum
n	Net
r	Radial, radius
R	Relative
to	Take-off
s	Steady-state, static, shaft

4.4 Additional signs — Overline (shown on X)

Table 4 — Symbol — Additional signs — Overline

Overline	Description (shown on X)
$\overline{X}$	Non-dimensional quantity

5 Purpose of the test

The test mainly aims to measure and evaluate the static load capacity, friction coefficient and lifetime of foil journal bearings. These primary performance metrics of the foil journal bearing as a mechanical element with a specific dimension are closely related to the performance of the mechanical systems to which the bearings are applied.

The configuration of a typical foil journal bearing is shown in Annex A.

6 Test conditions

6.1 General

To compare the static load capacity, the test should be performed after the ambient pressure, temperature and humidity of the environment in which the bearing operates have reached a state of equilibrium. Bearing performance is obtained by measuring the bearing torque and rotational speed of the shaft. In this case, the take-off speed, at which the shaft floats on the top foil without contact, can be observed. For measuring and comparing the bearing performance, the rotational speed shall be higher than the take-off speed.

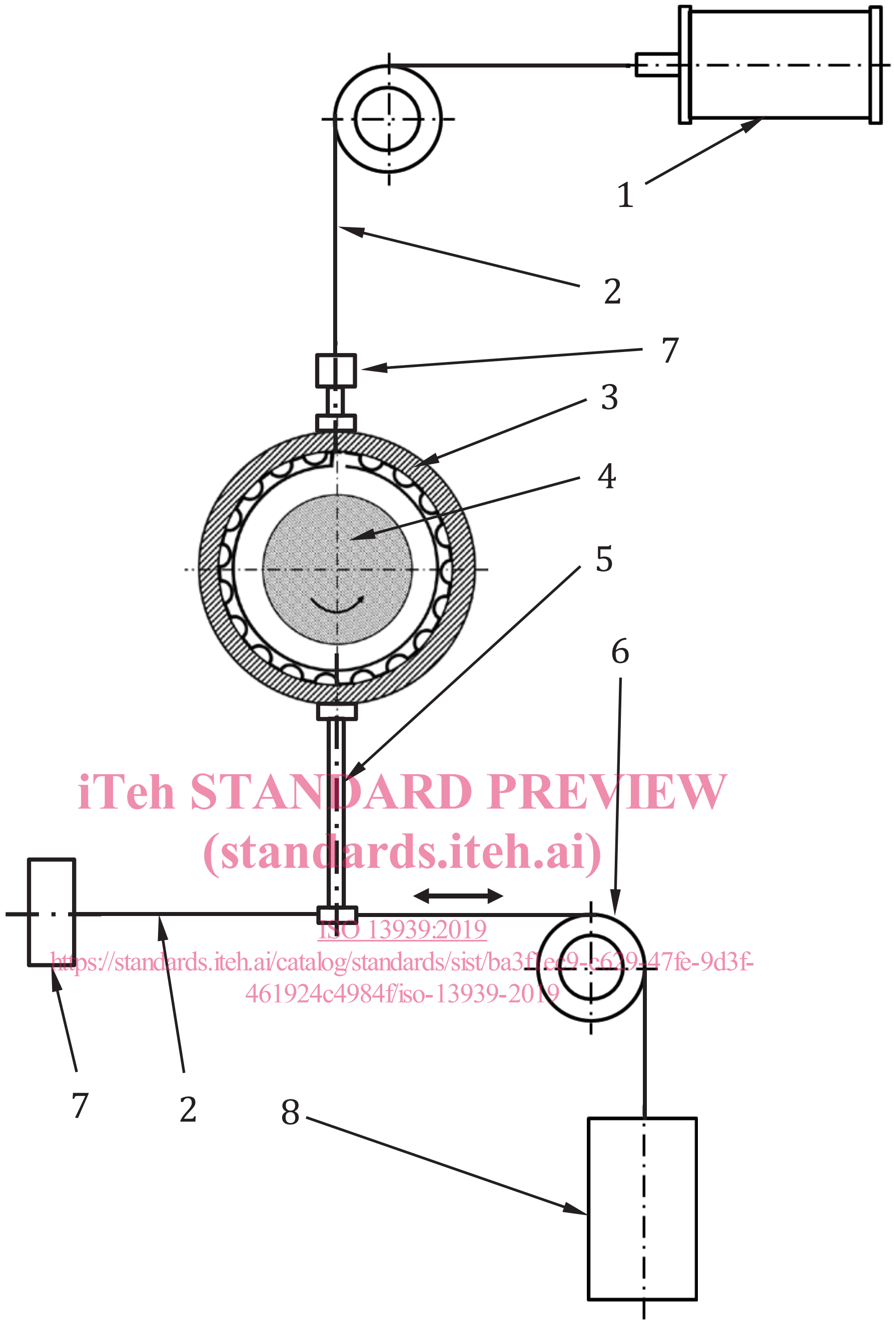
6.2 Design of test facility

The bearing test facility should be designed to control the relative position of the bearing in relation to the shaft. The bearing housing can be connected to a separate supporter, such as a spring or springs. Otherwise, a vibration-proof facility can be applied to prevent perturbation, which can severely affect the test results. Moreover, excessive friction can cause misalignment of the bearing and thus significantly affect the test results.

6.3 Installation of sensors

Figure 1 illustrates the installation of the equipment to measure the bearing torque and static load capacity of the foil journal bearings. Using the measurement system shown in Figure 1, the bearing torque and applied load can be measured and calculated as explained in 6.4.

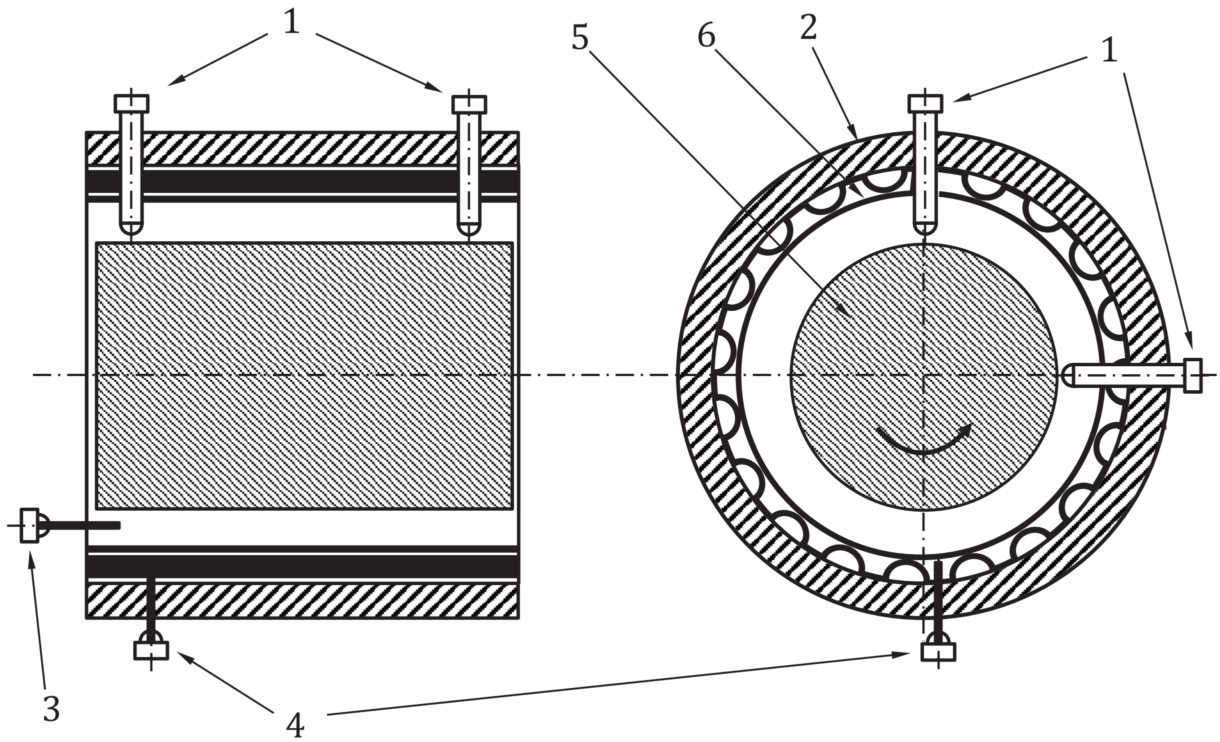
As shown in Figure 2, the displacement sensors are installed at right angles to each other at both ends of the bearing housing. The displacement of the shaft axis is observed by measuring and comparing the obtained values. To measure the rotational speed of the shaft, a fast Fourier transform (FFT) algorithm is applied to the measured displacement data or a rotational speed meter is used. A thermocouple is installed inside the bearing housing to measure the temperature of surrounding air (gas). To measure the surface temperature of a top foil, the thermocouple should be welded to the top foil surface.



Key

1 loading apparatus
2 cable
3 deadweight housing
4 shaft
5 torque rod
6 pulley
7 load cell
8 counterweight pre-load

Figure 1 — Measurement system for the bearing torque and applied load



Key

1 displacement sensor
2 deadweight housing
3 thermocouple for measuring air temperature
4 thermocouple for measuring top foil surface temperature
5 shaft
6 top foil

Figure 2 — Installation of sensors

6.4 Calculation of bearing torque and loads

The friction force, F, can be measured using a load cell linked to the torque rod installed on the outside of the housing. Then, the bearing torque, M, generated by the rotation of the shaft is obtained as the product of the friction force, F, and distance, r, between the two axes of the housing and load cell, as represented by Formula (1):

$$M = F \times r \tag{1}$$

where

M is the bearing torque, expressed in newton-millimetres (N·mm);

F is the friction force, expressed in newtons (N);

r is the distance between the housing axis and the sensor-linked location of the torque rod, expressed in millimetres (mm).

The net load, $F_{w,n}$, exerted vertically downward on the foil journal bearing, as shown in Figure 1, is obtained by subtracting the weight of the housing, $F_{w,h}$, from the applied load, $F_{w,a}$, where $F_{w,a}$ is measured by the load cell installed between the housing and loading apparatus.

6.5 Test specimens

The foil journal bearing comprising the housing, bump foil, top foil and shaft can be designed and fabricated according to the purpose of use.

7 Test methods

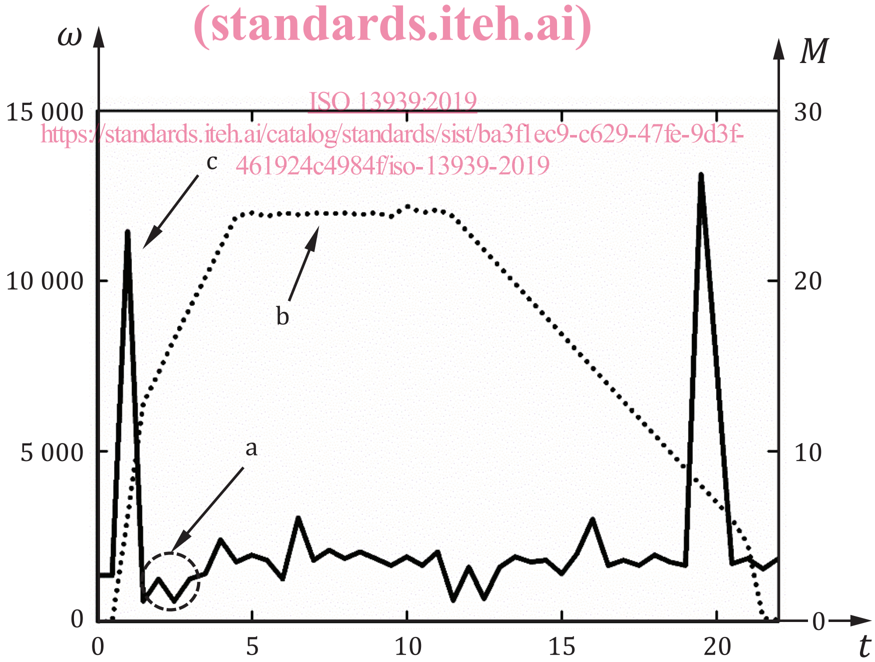
7.1 Principle

To operate and test the foil journal bearing, the take-off speed is measured and the load-carrying capacity is evaluated after sufficient pre-heating. The test report presents the variables required for test and estimation (see Annex B).

7.2 Start–stop test cycle and evaluation of the take-off speed

The foil journal bearing starts operating when the shaft is rotated using a driver. The bearing torque should be measured when the shaft begins its rotation as the speed of rotation gradually increases.

Figure 3 shows a typical example of variation in the bearing torque measured using the rotational speed of the shaft from the start–stop test. As the rotational speed increases, the bearing torque suddenly increases at a certain rotational speed and then decreases to maintain the steady-state condition with a relatively constant torque value. When the bearing torque decreases to meet its steady value, the rotational speed is determined as the take-off speed of the foil journal bearing and should be recorded in the test report (see Annex B). As the rotational speed decreases to zero, the bearing torque suddenly increases again and then decreases.



Key

- t time, expressed in seconds (s)
- ω motor speed, expressed in revolutions per minute (min^{-1})
- M torque, expressed in newton-millimetres (N·mm)
- [a] Take-off.
- [b] The dotted line represents the motor speed, ω.
- [c] The solid line represents the torque, M.

Figure 3 — Rotational speed versus bearing torque

