INTERNATIONAL STANDARD

ISO 21866-1

First edition
2020-10

Plain bearings — Automotive engine bearing test rig using actual connecting rods —

Part 1: Test rig

Reference number
ISO 21866-1:2020(E)

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Published in Switzerland

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Foreword

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This document was prepared by Technical Committee ISO/TC 123, *Plain bearings*, Subcommittee SC 2, *Materials and lubricants, their properties, characteristics, test methods and testing conditions*.

A list of all parts in the ISO 21866 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.

Introduction

Recently, the rigidity of automotive engine bearings and their housings have been lowered due to the demand for weight reduction, and they are getting easier to be deformed. On the other hand, for achieving clean combustion with high heat efficiency, combustion pressure and bearing oil film pressure have become higher. Also, the minimum oil film thickness for bearing has been made thinner by using low-viscosity oil to reduce friction loss. The plain bearings for automotive engines have a tough situation because of all these changes.

So far, the test rig used for plain bearings has been developed with the application of elasto-hydrodynamic lubrication theory (EHL). But the serious problem stated above remains: the rigidity of a connecting rod bearing for automotive engine is lowered in comparison with other machineries because of the especial requirement of weight reduction.

Based on the abovementioned background, it is essential to evaluate the bearings for each car, using the actual engines. Also, not only the magnitude and pattern of the load on a bearing but also the engine speed are different between gasoline engine bearings and diesel engine bearings, so the different bearings need to be developed accordingly. As a consequence, it has become essential to conduct a final test with the engine of an actual car because the conventional test rig could not meet such requirements.

The aim of this document is to shorten the time and reduce the costs needed on engine bearing testing in order to satisfy the requirements of automotive engine bearings at present and in future by using connecting rods of actual cars.

Plain bearings — Automotive engine bearing test rig using actual connecting rods —

Part 1:
Test rig

1 Scope

This document specifies the requirements for an engine bearing test rig that uses an actual connecting rod to determine plain bearing performance in automotive engines, evaluating fundamental bearing properties such as seizure resistance, wear resistance, fatigue resistance and resistance to the impact of foreign material.

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 4378-1, *Plain bearings — Terms, definitions, classification and symbols — Part 1: Design, bearing materials and their properties*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 4378-1 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 http://www.electropedia.org/

4 Classification of bearing tests

Three stages of functional evaluation test methods of plain bearings using various kinds of test rigs are shown in Table 1.

Table 1 — Examples of stages for bearing evaluation tests

Stage	Purpose	Bearing housing	Test method
Stage 1	screening of material properties	—	— pin on disc — block on ring — other
Stage 2	evaluation of the bearing function	high rigidity connecting rod connecting rod similar to the actual connecting rod	own test rig by bearing manufacturer
Stage 3	validation of the actual engine	actual connecting rod	— actual engine — actual car

At stage 1, primary screening is conducted at the earliest stage of bearing material development, selection or evaluation using fundamental test rigs such as pin on disc or block on ring.

At stage 2, the tests are conducted to evaluate the bearing material and design, using an actual plain bearing constructed from material that has shown excellent performance during stage 1 testing. In this stage, the operating conditions and assessment procedure provided in ISO 6281 are considered. Test rigs appropriate for each testing purpose are used and the damage of the bearing is judged as described in ISO 7146-1 and ISO 7146-2.

At stage 3, engine or vehicle testing of the actual bearing that has passed stage 2 is conducted as the final verification before market launch.

Unexpected bearing damage can occasionally occur due to differences between actual application operating conditions and test conditions at stage 2 and stage 3. Rectification late in the product development timeframe can incur expense and delay. Therefore, it is imperative to develop an alternative, more effective evaluation method at stage 2 and stage 3 by using an actual connecting rod to improve the reliability of automotive engine bearings.

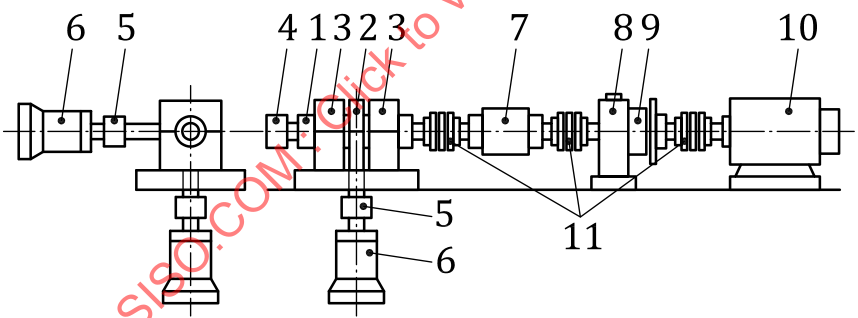
Examples of bearing seizure and fatigue tests using the test rigs specified in this document are shown in Annex A and Annex B.

It is important to understand that connecting rod rigidity affects the housing deformation and oil pressure distribution. For information, an example of the oil film calculation is shown in Annex C.

5 Test rig

5.1 Test rig construction

Figure 1 shows an example of the overall configuration of the test rig.



Key

1 test shaft
2 test connecting rod
3 support bearing housing
4 oil feed equipment
5 load cell
6 dynamic servo actuator
7 torque metre
8 gear box
9 torque limit clutch
10 drive motor
11 flexible coupling

Figure 1 — Overview of bearing test rig construction

One particular test rig that meets the requirements mentioned in the scope is described as follows.

To emulate mechanical conditions within the engine, an actual connecting rod is used. The test bearing is assembled into the big end or small end of the connecting rod, and a dynamic load is applied. Figure 1 shows the overall structure of the test rig. A test bearing in the test connecting rod (2) is mounted on the test shaft (1) which is driven by a speed-variable motor (10) via a torque metre (7) and a torque limit clutch (9). Friction of the test bearing is measured by the torque metre and the test rig is protected from damage due to bearing failure by an emergency stop. A servo actuator (6) is capable of producing dynamic loads with a frequency higher than the engine speed, measured by a load cell (5). Oil is supplied to the test bearing in the test connecting rod (2) by the oil supply equipment (4) to simulate the oil supply through the engine crankshaft. The dynamic load pattern is synchronized to the shaft oil-hole pattern. Stable temperature measurement of the test bearing is shown in Figure 7, accomplished by the constant pressure on the thermocouple to maintain contact with the bearing back. Figure 8 shows that the test rig is able to measure the effects of axial misalignment on bearing back temperature.

Dimensions and rigidity of the test connecting rod assembly components may be freely chosen within an appropriate range. Dynamic load elements that may be freely chosen within an appropriate range are wave form, amplitude, frequency and load step magnitude. Examples of variables that are related to bearing properties to be measured during testing are temperature, bearing hardness, polishing method, bearing geometry (roundness, roughness, waviness, concavity and straightness), lubricant viscosity and lubricant additives. These variables may be specified within an appropriate range. Several bearing properties may be tested concurrently.

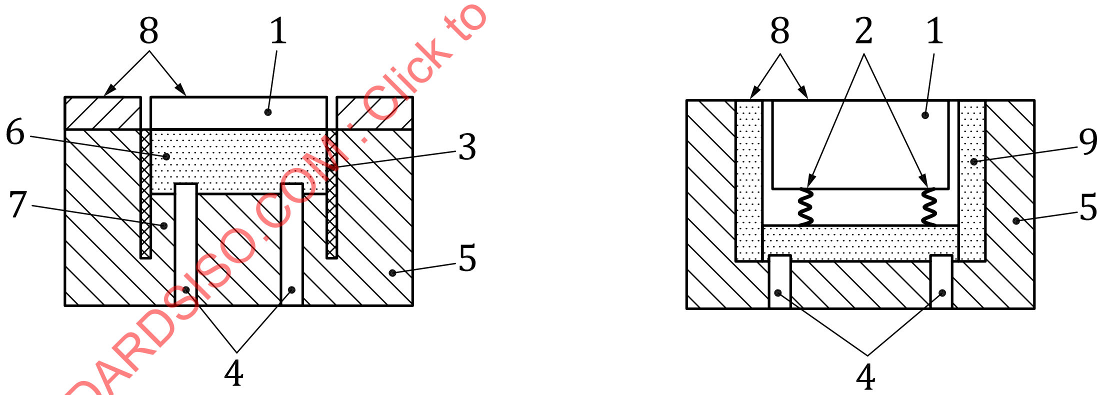
5.2 Rig frame construction

When the bearing is tested under a dynamic load, it is important to avoid the resonant vibrations of the test rig frame. The resonance frequency of the test rig frame shall be higher than the dynamic load frequency.

5.3 Foundation structure

It is necessary to pay attention to the structure and weight of the foundation for the test rig in order to ensure the reliability of the test.

Figure 2 shows two types of foundation for the test rig.



a) Edge cutting foundation

b) Floating foundation

Key

1 surface plate mass
2 damper spring
3 separator filler
4 construction anchor pile
5 ground
6 concrete mass
7 ground mass
8 floor
9 concrete sand stopper

Figure 2 — Examples of the foundation for a test rig

In Figure 2, a), a separator filler (3) is provided around the surface plate mass (1) and the concrete mass (6) in order to cut off the vibration from the floor. In Figure 2, b), the surface plate mass (1) is supported by damper springs (2) which cut off the vibration. Generally, Figure 2, b) shows an excellent vibration isolation performance while Figure 2, a) can reduce the expense.

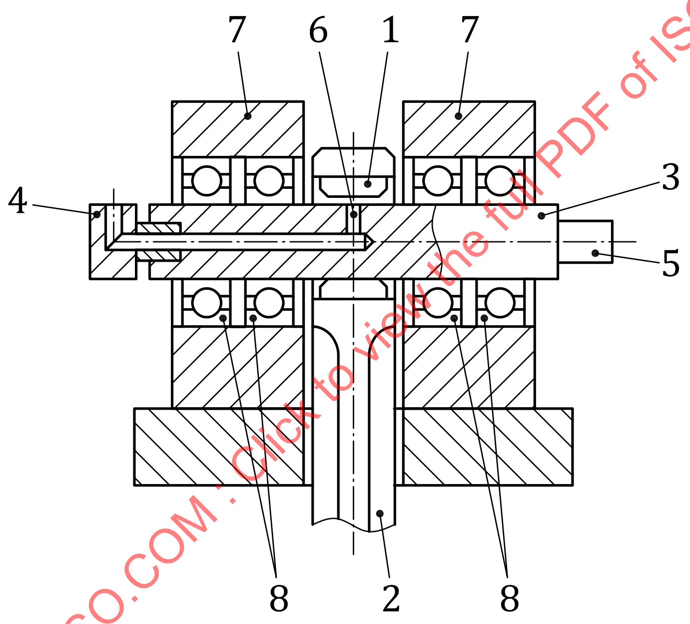
In Figure 2, a), the foundation weight is the total weight of (1), (6) and (7). In Figure 2, b), it is the weight of (1). In both types, the foundation weight should be 10 times to 20 times heavier than the maximum vibration load given as the product of maximum acceleration and accelerated mass.

5.4 Test using actual engine connecting rod

5.4.1 Structure around the test bearing

Figure 3 shows the structure of the main part of the test rig in which the test bearing and the test shaft are installed.

As mentioned in Clause 4 and illustrated in Figure 3, the support bearing housing (1) in the connecting rod (2) is mounted on the rotating test shaft (3) which is supported by support bearings (8) and housings (7). Lubricating oil is supplied to the test bearing (1) through oil supply equipment (4) and an oil supply hole (6), simulating an actual crankshaft.



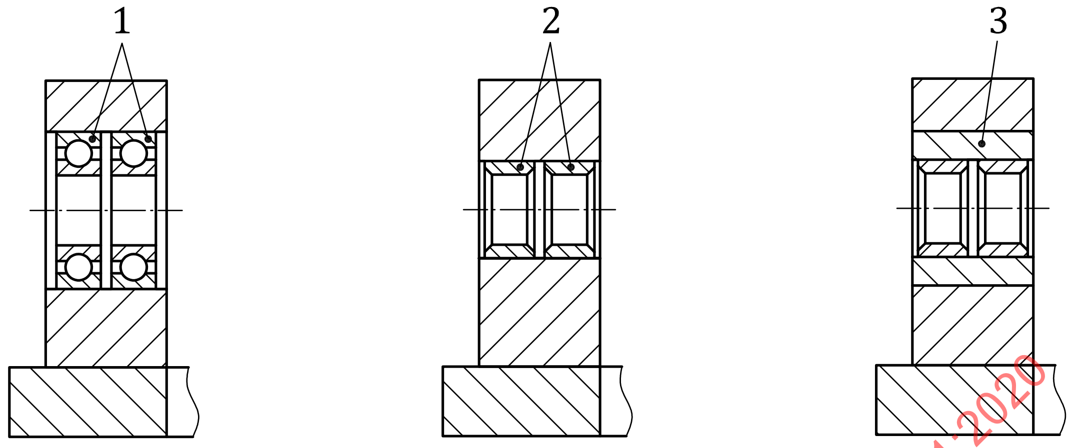
Key

1	support bearing housing	5	connecting shaft to coupling
2	connecting rod	6	oil supply hole
3	test shaft	7	housing
4	oil supply equipment	8	support bearing

Figure 3 — Test section and the support bearing (sketch)

5.4.2 Structure around the support bearing

Figure 4 shows three types of support bearings: a) rolling bearings, b) plain bearings and c) plain bearings with a cylindrical sleeve mounted in a housing for rolling bearings.



a) Rolling bearing type

b) Plain bearing type

c) Plain bearing with cylindrical sleeve type

Key

1 rolling bearings

2 plain bearings

3 cylindrical sleeve

Figure 4 — Principle types of support bearing

A support bearing is installed close to each side of the test bearing. The temperature of support and test bearings is influenced by frictional heating, thermal conduction of the test shaft and running in and/or wear. The support bearings arrangement shall be chosen with attention to the operating conditions such as oil temperature, oil flow rate and bearing clearance.

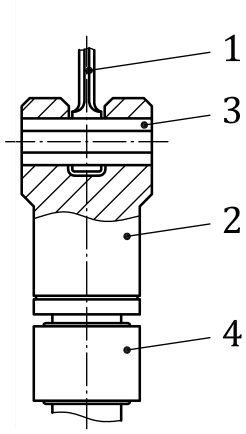
The characteristic features of the support bearings types are given below. An appropriate support bearing should be selected depending on the application.

Rolling bearings have less effect on the test bearing temperature, however, greater vibration noise can occur.

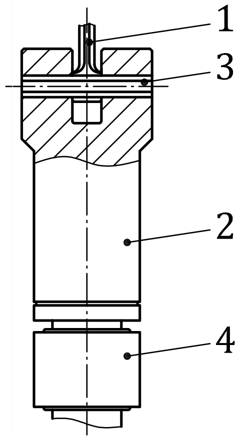
The temperature of the test bearing is influenced by plain support bearing clearance, oil-flow rate and additional conditions. Vibration noise is small.

5.4.3 Connection of the connecting rod with dynamic servo actuator

The length of the connecting rod has various dimensions depending on the type of the engine, and an adjustable connecting rod joint as shown in Figure 5 should be applied to connect the connecting rod to the actuator. It is not appropriate to use a long stroke actuator for adjusting the length of the connecting rod, because it causes performance degradation of the actuator.



a) Short joint for long connecting rod



b) Long joint for short connecting rod

Key

1 connecting rod

2 connecting rod joint

3 joint pin

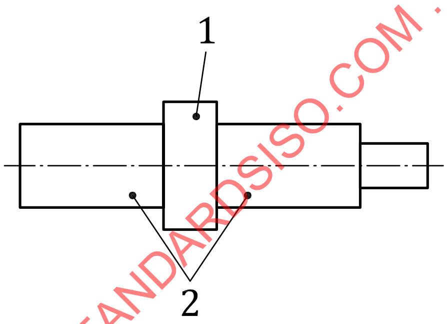
4 load cell

Figure 5 — Adjustable connecting rod joint

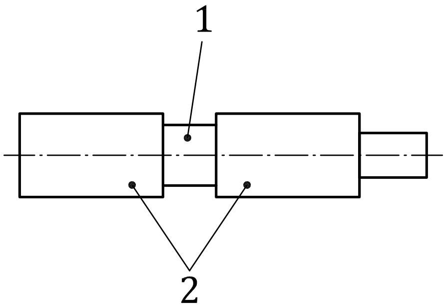
The short joint in Figure 5, a) should be used for a long connecting rod, and the long joint in Figure 5, b) should be used for a short connecting rod.

5.4.4 Test shaft for different diameter of test bearings

The diameter of the test bearing can vary depending on the size of the engine. A test shaft as shown in Figure 6 shall be used. The shaft diameter of the support bearings shall be constant, only the test bearing shaft section diameter shall be changed. Maintaining a constant support bearing shaft diameter, ensures that the support bearing contribution to the thermal environment remains constant.



a) For test bearing with large diameter



b) For test bearing with small diameter

Key

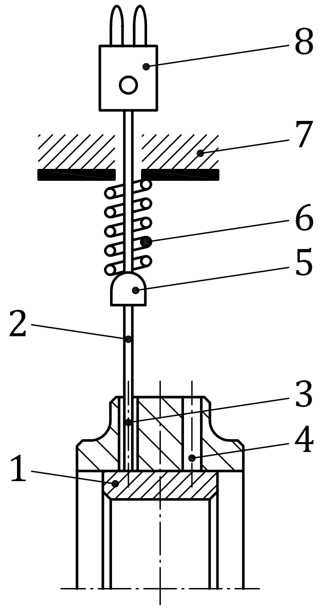
1 corresponding part to test bearing

2 corresponding part to support bearings

Figure 6 — Test shaft with different diameters

5.4.5 Temperature measurement for the test bearing

The temperature of the bearing shall be measured during the test as this indicates the tribological condition. Figure 7 shows an example to mount the thermocouple.



Key

1 test bearing
2 thermocouple
3 hole 1
4 hole 2
5 stopper
6 compression spring
7 spring seat
8 thermocouple connector

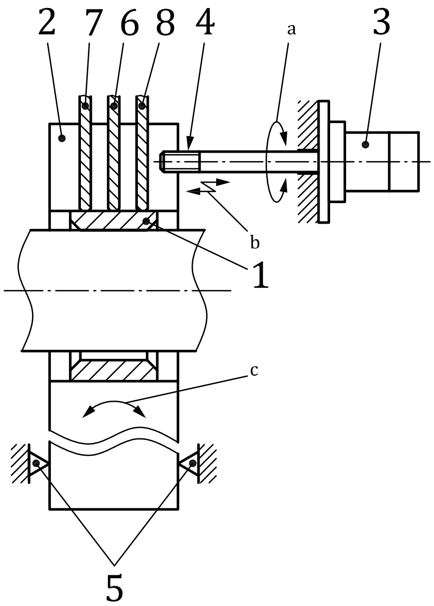
Figure 7 — An example to mount the thermocouple

Sheath type thermocouple (2) is set in one of the holes. In order to ensure contact between the thermocouple and the bearing back, the stopper (5) attached to the thermocouple (2) should be pressed down by a spring (6) and the thermocouple is constantly pressed onto the bearing back. A sheath thermocouple diameter of 1,0 mm to 2,0 mm is preferable for automotive test bearings to prevent bending. Heat conductive paste is applicable between test bearing and thermocouple.

5.4.6 Adjustment of the misalignment of the test bearing and the shaft

To obtain representative temperatures, the bearing temperature shall be measured at the circumferential point where the load is the maximum. In the axial direction, the temperature should also be measured near both bearing ends, although it is usually measured only in the middle of the bearing in the axial direction. This is to detect the misalignment. When misalignment occurs, the axial temperature distribution becomes unsymmetrical, revealing the misalignment. The misalignment causes large errors of measurement and shall therefore be avoided.

Figure 8 shows the tilting control test system used for the bearing temperature measurement. Thermocouple [6], [7] and [8] are installed in the bearing at the circumferential position of the maximum bearing load. The rotation of the screw [4] by the stepping motor [3] shifts axially the connecting rod [2] as indicated by the arrow [a], and the connecting rod [2] tilts about the fulcrum [5] as indicated by the arrow [c]. The stepping motor [3] is so controlled that equal temperature of [7] and [8] is achieved. As a feature, the temperature of [6] shows a relatively higher temperature than [7] and [8].



Key

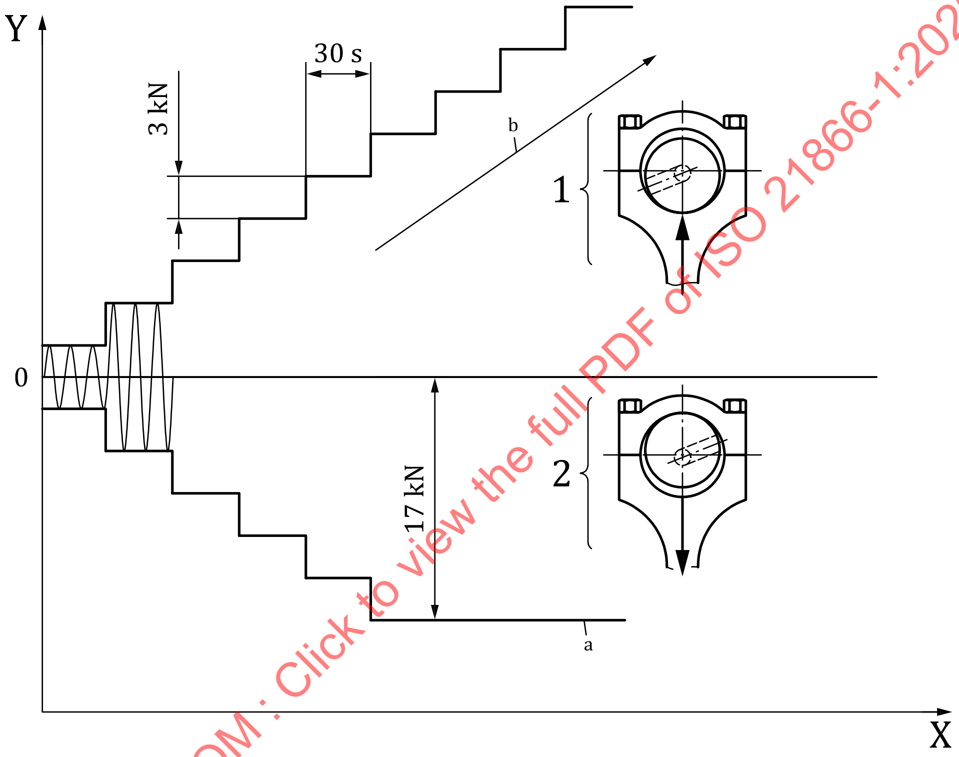
1 test bearing
2 connecting rod
3 tilting control motor
4 screw
5 pivot stopper
6 bearing centre thermocouple
7 bearing edge thermocouple 1
8 bearing edge thermocouple 2
[a] Turning motion of the screw.
[b] Axial motion of connecting rod.
[c] Tilting motion of connecting rod.

Figure 8 — Tilting control system using bearing temperature measurement

Annex A
(informative)

Example for bearing seizure test

Figure A.1 shows an example of a typical bearing load pattern used to evaluate the bearing seizure resistance using the test rig as given in Figure 1.



Key

X time

Y bearing load

1 rod direction load

2 cap direction load

[a] Constant.

[b] Step increase in rod-half load magnitude to achieve seizure.

Figure A.1 — Bearing load pattern for seizure test, principle

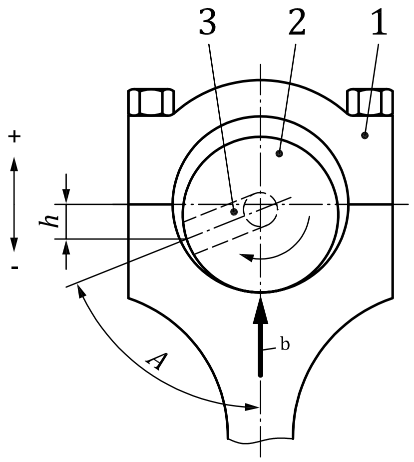
The rod-half bearing load is increased in a stepwise pattern until bearing seizure occurs, or until the maximum specified bearing load has been reached. The connecting rod tensile strength is lower than the compressive strength, therefore the maximum load of 30 kN is applied in the cap direction to prevent connecting rod failure.

An example of the test conditions is given in Table A.1.

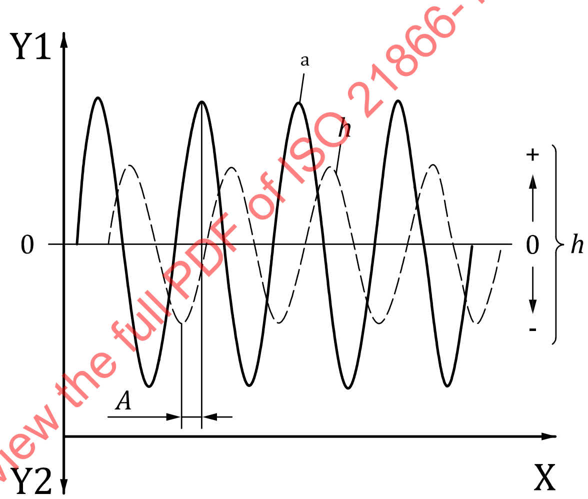
Table A.1 — Seizure test condition

Test condition	Value	Unit
shaft rotation speed	3 000	min^{-1}
actuator excitation frequency	50	Hz
bearing diameter	50	mm
excitation waveform	Sine	—
oil supply temperature	120	° C
oil supply pressure	300	kPa
diametral clearance	30	µm

Figure A.2 shows the relationship between the bearing load and oil supply hole. The bearing load and oil supply hole in the test rig shall be synchronized just as in an actual engine.



a) Geometry of oil supply hole



b) Synchronization of load and rotation angle

Key

X test shaft rotation angle
Y1 rod direction
Y2 cap direction
1 connecting rod
2 shaft
3 oil supply hole
A advance angle of oil supply hole
h height of oil supply hole
a Transient bearing load amplitude.
b Bearing load direction.

Figure A.2 — Synchronization of the oil supply hole and bearing load

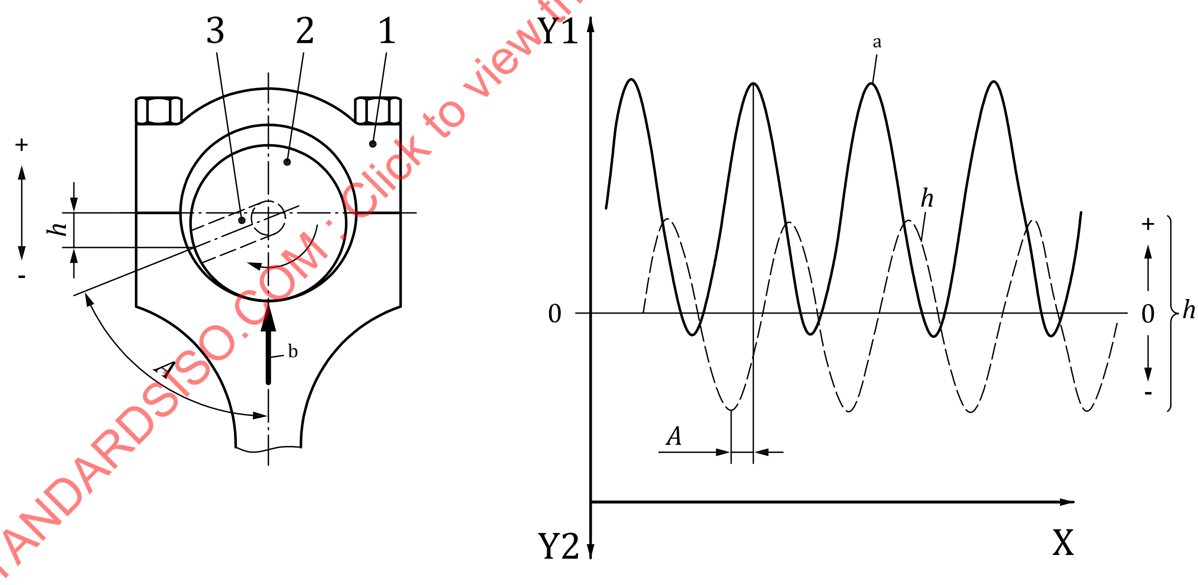
Annex B
(informative)

Example for bearing fatigue test

Figure B.1 shows an example for bearing fatigue test under test condition given in Table B.1.

Table B.1 — Fatigue test condition

Test condition	Value	Unit
shaft rotation speed	3 000	min^{-1}
actuator excitation frequency	50	Hz
bearing diameter	50	mm
bearing width	18	mm
excitation waveform	Sine	—
oil supply temperature	120	°C
oil supply pressure	300	kPa
diametral clearance	30	µm



a) Geometry of oil supply hole **b) Synchronization of load and rotation angle**

Key

X test shaft rotation angle
Y1 rod direction
Y2 cap direction
1 connecting rod
2 shaft
3 oil supply hole
A advance angle of oil supply hole
h height of oil supply hole
a Transient bearing load amplitude.
b Bearing load direction.

Figure B.1 — Load for fatigue test