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Plain bearings — Testing under conditions of hydrodynamic and mixed lubrication in test rigs

Paliers lisses — Essai des paliers lisses dans les conditions de lubrification hydrodynamique et mixte dans des machines d'essai pour paliers

Reference number
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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.

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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 6281 was prepared by Technical Committee ISO/TC 123, *Plain bearings*, Subcommittee SC 2, *Materials and lubricants, their properties, characteristics, test methods and testing conditions*.

This first edition of ISO 6281 cancels and replaces ISO/TR 6281:1990, of which it constitutes a technical revision.

Plain bearings — Testing under conditions of hydrodynamic and mixed lubrication in test rigs

1 Scope

This International Standard establishes guidelines for the testing of lubricated plain journal bearings in test rigs, running under conditions of hydrodynamic or mixed lubrication, during bearing and/or material development. It deals with both static and dynamic loading in solid and multi-layer journal bearings. It is not applicable to the testing of dynamic characteristics of lubricant film in journal bearings applied in calculation of vibration and stability of turbo-rotors. Further details of test procedures will need to be established when carrying out testing based on these guidelines.

2 Symbols

See Table 1.

Table 1 — Symbols

Symbol	Description	Unit
a	Length of period	s
B	Bearing width	mm
F	Bearing load	N
F^*	Bearing load per unit bearing width	N/mm
f	Coefficient of friction of journal bearing	—
t	Time	s
U	Sliding velocity	m/s
β	Direction of bearing load	°
ω	Angular velocity	rad/s
η	Dynamic viscosity of lubricant	N·s/m^2

3 Test objectives for bearing properties

The test objectives for plain journal bearing test rigs operating under conditions of hydrodynamic or mixed lubrication are to obtain information, among others, on the following bearing properties, which can serve as critical variables when designing and applying the bearing (see ISO 4378):

a) running-in ability;

b) wear resistance;

c) compatibility between bearing and journal materials (resistance to adhesion);

d) embeddability (foreign particles absorption);

e) resistance to journal scoring and abrasion;

f) conformability;

g) deformability (compressive strength);

h) resistance to erosion (cavitation erosion, fluid erosion, particle erosion);

i) static load carrying capacity;

j) dynamic load carrying capacity (fatigue strength);

k) friction characteristics;

l) lubricant flow rate characteristics;

m) temperature increase characteristics.

Of these bearing properties, the first group, a) to h), depends primarily on the mechanical and tribological properties of sliding materials under specified conditions. The second group, i) to m), depends primarily on hydrodynamic variables, and therefore also on

— viscosity as a function of temperature, pressure and shear rate,

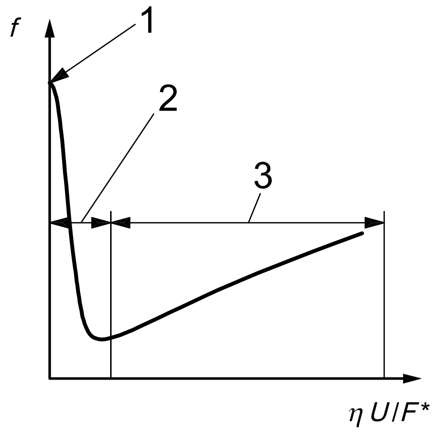
— energy dissipation in the lubricant film (shear heating and heat dissipation), and

— elastic and thermal deformation of the bearing and journal, and hence change of lubricant film thickness (thermo-elastohydrodynamic lubrication).

The determination of these bearing properties, or test objectives, requires lubrication conditions that can involve boundary, mixed or hydrodynamic lubrication — the three modes of lubrication regime. In certain cases, a repeated, time-dependent change between mixed and hydrodynamic lubrication can be required.

NOTE Specific test methods may not yet exist for all of the above-mentioned bearing properties.

Figure 1 depicts the typical relation between the dimensionless number, $\eta U/F^*$, and the coefficient, f, of friction of the journal bearing, where η, U and F^* denote dynamic viscosity of the lubricant, sliding velocity and bearing load per unit bearing width ($F^* = F/B$), respectively. It shows the three regimes of boundary, mixed and hydrodynamic lubrication and qualitatively indicates the dependence between these important parameters.



Key

1 boundary lubrication

2 mixed lubrication

3 hydrodynamic lubrication

Figure 1 — Three modes of lubrication regime

4 Test rigs

4.1 General recommendations

It is often more practical and efficient to investigate the bearing in a test rig than in an actual application. The design of the bearing test rig should be such as to simulate as far as possible all the relevant characteristic parameters (geometric, dynamic, hydrodynamic, thermal, thermodynamic, etc.) of the actual application.

In addition, the following is recommended for the test rig.

a) Simple mechanical construction.

b) Simple dismantling and assembly procedures for the test objects; with well-defined positioning of the bearing and housing; preferably it should be possible to inspect the test bearing *in situ*. In addition, the test rig should be equipped with an emergency stop mechanism, both for safety reasons and to allow the inspection of the sliding surface before the onset of catastrophic damage.

c) Well-defined dimensions for the test bearing.

d) High dimensional stability with little shaft deflection. The test rig should be as rigid as possible, with a high natural frequency. In special cases, however, it may be necessary to vary the dimensional stability or the shaft deflection in order to simulate the operating condition of the actual application.

e) Appropriate lubricant supply condition. When the lubricant flow within the bearing clearance has to be simulated exactly, the circumferential and axial position of the lubricant supply in the test rig should be the same as in the actual application.

f) Well-defined and experimentally verifiable lubrication conditions.

g) The regime of laminar or turbulent flow should be the same in the test rig and in the actual application.

h) The rig should replicate as far as possible the temperature and stress range that can occur in practice.

i) Appropriate measuring techniques or equipment should be employed.

4.2 Generic types of test rig

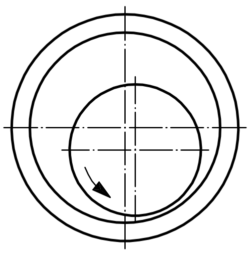
Generic types of test rig for plain journal bearings are shown in Figures 2 and 3. Figure 2 a) and b) depict the rotational motion of the journal, where a combination of both is also possible. In practice, many more patterns of journal motion other than rotation may occur, such as inclination, bending, axial, conical and their combinations. In addition, the bearing itself can rotate or oscillate or even move in space instead of, or together with, the journal, as with a crank-pin bearing. In any case, the relative motion of the journal to the bearing has to be known (measurable) exactly. However, constant rotational speed of journal and the parallel movement of journal to bearing are the simplest and most preferable for testing.

Figure 3 shows patterns of the bearing load. In the case of statically loaded journal bearing [Figure 3 a)], the magnitude, F, and the direction, β, of the bearing load are constant. In a special case of dynamically loaded bearing, F is constant, but β increases or decreases with time [Figure 3 b)]. In the general case of dynamically loaded bearing [Figure 3 c)], both or at least one of F and β change periodically, while the remaining variable can be constant. The periodic form of F (also β) is then arbitrary, such as sinusoidal with or without constant offset, curving steeply up and downwards, as, for example, in engine bearing loading.

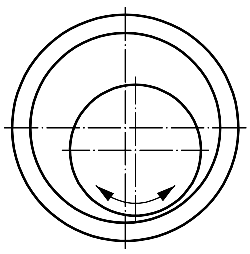
With regard to the loading of the test bearing, it is often more practical to load the test bearing directly supported by the journal [Figure 4 a)], than to load the test bearing indirectly through the journal [Figure 4 b)]. For static loading, a dead weight system, with or without lever, or hydraulic or pneumatic actuation can be used. For dynamic loading, a rotating or vibrating mass system, with or without lever, an electromagnetic exciter, hydraulic actuation, etc., can be applied. Dynamic loading by means of a mass fixed to the journal seems to be simple, but the amplitude of the bearing load is then determined primarily by the rotational speed of the journal. Therefore, it is not easy to change the load amplitude independently of the rotational speed. Furthermore, the magnitude and direction of the bearing load have to be precisely measured, and it is important to let the journal move freely inside the bearing clearance without hindrance from the loading mechanism.

Besides such bearing test rigs operating under hydrodynamic or mixed lubrication, as described above, many other kinds of test apparatus and test methods may be used to investigate the tribological or mechanical properties of bearing materials, including coefficient of friction, mechanical strength, hardness, elasticity, plasticity and bond strength. The study of the tribological properties of boundary films has also led to the development of other test apparatus and methods; these are, however, outside the scope of this International Standard (see ISO 4384-1, ISO 4384-2, ISO 4385, ISO 7148-1, ISO 7148-2, ISO 7905-2, ISO 7905-3 and ISO 7905-4).

NOTE The testing of the resistance to corrosion of bearing materials by the lubricant is the subject of ISO 10129.

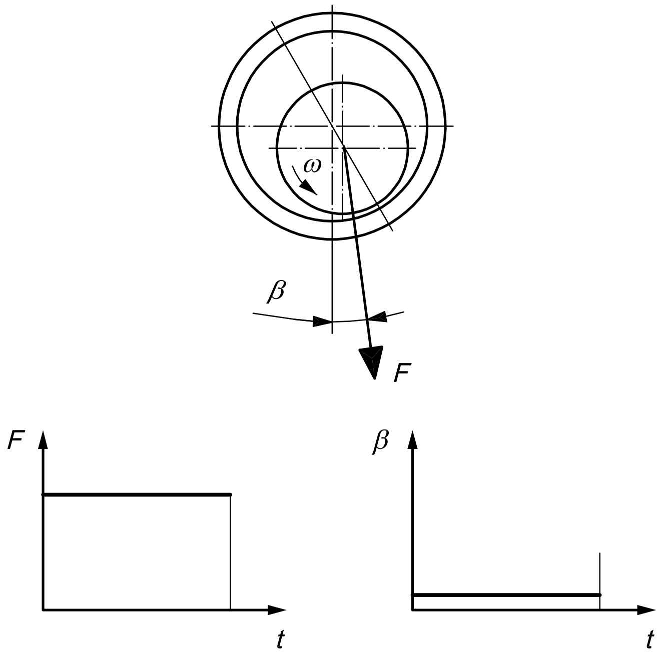


a) Rotation

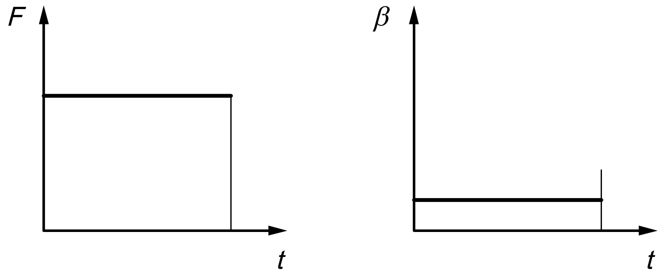


b) Oscillation

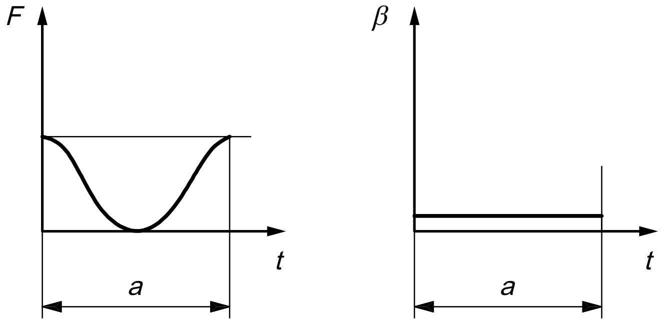
Figure 2 — Rotational motion of journal



a) Static load



b) Dynamic load (rotating load)

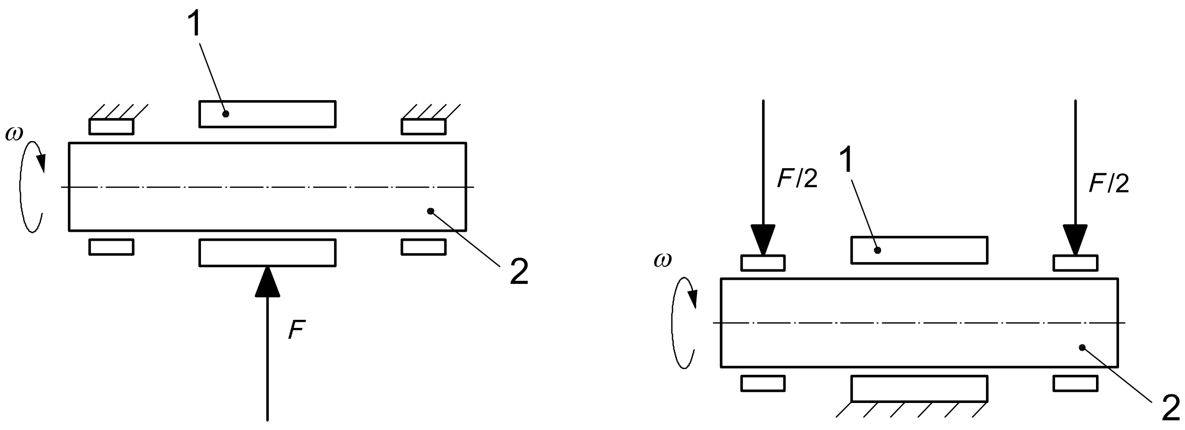


c) Dynamic load (arbitrary pattern)

Key

a length of period
F bearing load
β direction of bearing load
t time
ω angular velocity

Figure 3 — Examples of bearing load patterns



a) **Load on bearing** b) **Load on journal**

Key

F bearing load

ω angular velocity

1 test bearing

2 journal

Figure 4 — Two modes of load application

5 Test procedures

The actual test procedure depends on the property to be determined. It is important to establish the test conditions in order to ensure that test results obtained on test rigs are applicable in practice and that results obtained on different test rigs are mutually compatible.

In the following, guidelines or examples of test procedures for obtaining the bearing properties according to Clause 3, a) to m), are described together with the evaluation of the results. Bearing properties a) to h) depend primarily on mechanical and tribological characteristics of the bearing material itself, and in some cases, may be determined qualitatively by proper material testing. However, they can be evaluated quantitatively only by testing in bearing test rig. When stepwise increase or decrease of bearing load or severity of operating condition is prescribed, thermal equilibrium must be achieved in the test object at each step to assure reproducibility of the results. During the test, it is important to be aware of the eventual change of the test object itself, even under seemingly constant operating conditions, through wear, foreign particles embedding, diffusion, chemical reaction, lubricant degradation, etc. This should be verified and documented in the test report.

a) Running-in ability

The change of surface topography, roughness, friction torque, wear rate[1] or wear intensity[2] of the bearing, or the temperature of the lubricant and/or bearing should be measured from the initial state of the sliding surfaces under the specified operating condition. From the characteristic change of these variables with time, the completion of running-in process can be detected. The shorter the time until running-in is completed, the higher the running-in ability.

1) Ratio of wear extent to the time interval during which it has developed.

2) Ratio of wear extent to the specified distance on which wear developed or to the volume of the work done.

b) **Wear resistance**

The severity of the operating condition of the bearing should be increased until wear occurs. Wear can be mechanical or mechano-chemical in nature. The former can be adhesive wear, seizure, scoring or scratching, abrasion, fatigue wear, spalling, cavitation wear, erosive wear or fretting wear. The latter can be oxidative wear, fretting corrosion or electro-erosive wear. The more severe the operating condition under which wear begins to occur and the smaller the wear rate and/or the wear intensity, the higher the wear resistance.

c) **Compatibility between bearing and journal material (resistance to adhesion)**

The frictional torque and/or the temperature of the lubricant and bearing should be measured during the stepwise increase in the severity of the operating condition (i.e. increase in inlet lubricant temperature, specific bearing load, sliding velocity), and the occurrence of adhesion should be detected. The more severe the operating condition under which the adhesion begins to occur, or the less the sliding surface suffers adhesion damage, the higher the compatibility and the resistance to adhesion.

d) **Embeddability (foreign particles absorption)**

Foreign particles of known hard material (i.e. hardness, quantity and size) should be mixed with the lubricant, and the quantity and depth to which the foreign particles have embedded into the bearing surface in a specified time, together with the grade of damage of the journal surface, should be measured under the specified operating condition. The larger the quantity and the greater the depth to which the foreign particles have embedded, or the less the damage of the journal surface by the foreign particles, the higher the embeddability.

e) **Resistance to journal scoring and abrasion**

The severity of the operating condition of the bearing should be increased stepwise and the occurrence of the journal scoring (severe scratches) or abrasion verified. The more severe the operating condition under which the damage begins to occur, and the less the scoring and abrasion caused to the journal (or the smaller the wear rate and the wear intensity), the higher the resistance to journal scoring and abrasion.

f) **Conformability**

The bearing load should be increased stepwise under a specified operating condition such that a high specific local load or edge load is applied to the bearing, which in consequence deforms elastically and plastically towards the form of the journal. The more the bearing deforms without showing any other bearing damage, or the higher the grade of similarity of form of the sliding surfaces reached, the greater the conformability.

g) **Deformability (compressive strength)**

The specific bearing load should be increased stepwise under a specified operating condition until the compressive strength of the bearing material is almost reached. The higher the deformation of the bearing, the greater the deformability.

h) **Resistance to erosion (cavitation erosion, fluid erosion, particle erosion)**

The bearing should be run under a specified erosive operating condition, until a predetermined quantity of damage by erosion is detected. The longer the time or sliding distance until damage is detected and the more severe the operating condition (i.e. higher specific bearing load, temperature, sliding velocity), the greater is the resistance to erosion. The resistance to erosion may be also measured by the grade of damage caused by erosion during a given period of time or by the rate of wear by erosion.

i) Static load carrying capacity

The specific bearing load should be increased stepwise under a specified operating condition. When one of the variables, i.e. the minimum lubricant film thickness, the maximum lubricant film pressure, the maximum bearing stress or strain, the maximum bearing or lubricant film temperature and bearing damage, reaches the allowable limit, then the static load carrying capacity is obtained, the higher value of which is the more desirable.

j) Dynamic load carrying capacity (fatigue strength)

The amplitude of the dynamic bearing load should be increased stepwise under a specified operating condition and a constant cyclic load pattern. When one of the variables, i.e. the minimum lubricant film thickness, the maximum lubricant film pressure, the maximum bearing stress or strain, the maximum bearing or lubricant film temperature and bearing damages, reaches the allowable limit, then the dynamic load capacity is obtained, the higher value of which is more desirable. Compared to the case of static load carrying capacity, for which the allowable limit to the maximum bearing stress is given by the strength of the bearing material, the allowable limit to dynamic load carrying capacity is given by the fatigue strength (see ISO 7905-1).

k) Friction characteristics

The frictional torque should be measured under stepwise changed operating conditions (i.e. specific bearing load, sliding velocity, lubricant feed pressure and temperature). By multiplying the frictional torque and the angular velocity of the journal, the rate of heat generated by the friction can be calculated. The lower the frictional torque throughout the whole test range, the more desirable the friction characteristics.

l) Lubricant flow rate characteristics

The lubricant flow rate should be measured under stepwise changed operating conditions (i.e. specific bearing load, sliding velocity, lubricant feed pressure and temperature). The lubricant flow rate throughout the whole test range should lie within appropriate limits.

m) Temperature increase characteristics

The temperature increase of lubricant and bearing should be measured under stepwise changed operating conditions (i.e. specific bearing load, sliding velocity, lubricant feed pressure and temperature). The lower the temperature increase throughout the whole test range, the more desirable the temperature characteristics.

6 Testing and test report

6.1 General

In testing, the independent and dependent variables have to be clearly differentiated. The independent variables are those values that can be prescribed within some range, freely and at will, while the dependent variables are the test results. When the test rig (6.2) and measuring equipment (6.3) — which may also be regarded as independent variables in the widest sense — are given, the items specified in 6.4 to 6.6 are independent variables. These are: the test bearing and journal (6.4), the lubricant and its supply method (6.5) and the operating or test conditions (6.6). These operating conditions can be the bearing load, the sliding velocity, the lubricant supply conditions and the ambient conditions of the bearing.

The items specified in 6.7 are dependent variables or test results, i.e. the pressure, temperature and thickness of the lubricant film, the stress, strain, deformation and temperature of the bearing, the occurrence of damage, wear rate, etc.

The independent variables given in 6.2 to 6.6 should be chosen dependent on the test objectives a) to m) above. They should be documented with the test results according to 6.7 and the discussion of 6.8 in the test report.

6.2 Test rig

The following details should be given, as appropriate:

a) name or type of rig;

b) principle of operation, with a diagram of the test rig;

c) method of load application;

d) main dimensions and design limits (load, speed, etc.);

e) position and number of test bearings;

f) repeatability and reproducibility;

g) power and speed of driving motor and control method;

h) method and specification of emergency stop;

i) auxiliary equipment;

j) position of measuring points for various variables.

6.3 Measuring equipment

6.3.1 General

The measuring equipment listed below should be used where needed. The principle of operation, specification, range, accuracy and uncertainty, linearity and hysteresis, resolution, response frequency, and any other relevant performance of the equipment, should be known. The relation between input and output of the equipment should be checked immediately before and after the test and the results should be documented.

6.3.2 Measuring equipment for independent variables (which may also be time-dependent)

This equipment is as follows:

a) bearing load;

b) sliding velocity or rotational speed;

c) inlet lubricant temperature;

d) lubricant feed pressure;

e) ambient air temperature and air velocity around the bearing.

6.3.3 Measuring equipment for dependent variables (which may also be time-dependent)

This equipment is as follows:

a) lubricant film thickness (distribution, minimum);

b) lubricant film temperature (distribution, maximum and mean value);

c) lubricant outlet temperature;

d) lubricant flow rate;

e) lubricant pressure (distribution, maximum);

f) temperature of bearing and housing;

g) bearing stress or strain (maximum);

h) bearing wear and damage;

i) frictional torque.

NOTE Continuous wear measurements can be achieved by means of mechanical probes or X-ray fluorescent analysis of the lubricant. The physical change of the sliding surfaces that can occur, for example, by diffusion during testing, can be checked by metallographic examination. For investigation of the change of the sliding surfaces and their damage, not only surface topography or roughness measuring apparatus, microscopes and SEM can be used, but also other kinds of surface analyser can be applied.

6.4 Test bearing and journal

6.4.1 General

The following test bearing and journal details should be known where appropriate.

6.4.2 Test bearing

6.4.2.1 Material properties for each functional layer of the bearing

These are as follows:

a) designation;

b) chemical composition;

c) manufacturing method;

d) microstructure;

e) mechanical properties (hardness, tensile strength, shear strength, elongation, modulus of elasticity, Poisson's ratio);

f) thermal properties (coefficient of thermal expansion, thermal conductivity, coefficients of heat transfer).

6.4.2.2 Dimensions, finishing method and surface roughness (see ISO 4288)

These are as follows:

a) inside diameter;

b) outside diameter;

c) inside and outside housing diameter;

d) interference or fit in housing;

e) total wall thickness;

f) thickness of each material layer;

g) effective bearing width;

h) bearing clearance (radial or diametral) before and after test;

i) method of surface finishing and treatment of bearing inner surface;

j) surface roughness, in both axial and circumferential directions, if possible;

k) roundness and cylindricity of bearing inner surface;

l) area and properties of outer surface of bearing housing (for thermal analysis).

6.4.3 Journal

6.4.3.1 Material properties

These are as follows:

a) designation;

b) chemical composition;

c) manufacturing method;

d) heat treatment;

e) microstructure;

f) mechanical properties (hardness);

g) thermal properties (coefficient of thermal expansion, thermal conductivity).

6.4.3.2 Dimensions, finishing method and roughness

These are as follows:

a) diameter;

b) length;

c) allowable deflection during test run;

d) allowable misalignment during test run;

e) method of surface finishing, finishing direction and surface treatment;

f) surface roughness;

g) roundness and cylindricity.

6.5 Lubricant and lubricant supply method

6.5.1 Lubricant

The following items concerning the lubricant should be given as appropriate:

a) type;

b) manufacturer and product name;

c) specification;

d) additive chemistry and concentration;

e) acidity/basicity;

f) density (see ISO 3675);

g) thermal properties of lubricant (specific heat, thermal conductivity);

h) viscosity/temperature relationship (see ISO 3448);

i) viscosity/pressure relationship, when specific bearing load is high;

j) viscosity/shear rate relationship, when this dependence is not negligible (long-molecule additives);

k) contamination (foreign particles and abrasives, their material, size, hardness, strength, quantity).

6.5.2 Lubricant supply method

The following items concerning the lubricant supply method should be given as appropriate:

a) type (spray lubrication, ring lubrication, forced feed lubrication, etc.);

b) manner in which the lubricant is introduced to the bearing clearance (lubrication holes, lubrication indentations or lubrication grooves; their number, size and location);

c) filtration (mesh size);

d) heat exchanger for the lubricant, if any (capacity and other specifications).

6.6 Operating conditions (test conditions)

Depending on the test objectives, the following operating conditions for testing should be specified, as appropriate. Values for the following variables should be noted, along with allowable errors, as appropriate.

a) Bearing load:

1) static load — the magnitude and direction of the load; the incremental increase or decrease of load, the load step increment, increment time interval, test termination criteria;

2) dynamic load — the magnitude and direction of the load, the load pattern, the amplitude, maximum, average and minimum load, the load frequency, rest period, number of load cycles or test duration, test termination criteria.

b) Sliding velocity:

1) rotational speed; the incremental increase or decrease of speed, the speed step and time interval;

2) maximum and minimum sliding velocity, rest periods.

c) Lubricant supply condition:

1) lubricant supply temperature;

2) lubricant supply pressure;

3) total quantity of lubricant and retaining time in reservoir or circulation frequency;

4) bulk lubricant temperature in the reservoir (when cooling or heating).

d) **Ambient conditions:**

usually, ambient temperature, pressure, etc., are prescribed by the atmospheric conditions. In testing, however, the ambient conditions may be varied and, therefore, form part of the independent variables:

1) ambient temperature;

2) ambient pressure and humidity;

3) ambient air velocity;

4) foreign particles;

5) vibration and shock.

6.7 Test results

6.7.1 General

Depending on test objectives, the following parameters can be determined by the test procedures given in Clause 5 and, from the test results, the bearing properties should be obtained. However, with current technology, it is not possible to measure some of the variables (e.g. the maximum stress, strain and deformation of the bearing material, the temperature distribution in the lubricant film). In this case, parameters can be estimated by calculation. The calculation method used and the assumptions made shall be clearly documented. Calculation may also help to determine the range of operating conditions to be specified before testing (see ISO 4378-4, ISO 7902-1, ISO 7902-2 and ISO 7902-3).

6.7.2 Hydrodynamic parameters (including estimated results)

The following details should be given:

a) an estimate of minimum lubricant film thickness;

b) an estimate of lubricant film thickness profile in the circumferential and axial directions;

c) the variation of the estimated minimum lubricant film thickness as a function of time;

d) an estimate of maximum lubricant film pressure;

e) an estimate of lubricant film pressure profile in the circumferential and axial directions;

f) the variation of the estimated maximum lubricant film pressure as a function of time;

g) an estimate of maximum static stress, strain and deformation in the bearing material;

h) an estimate of maximum dynamic stress, strain and deformation in the bearing material, in terms of mean value and amplitude;

i) an estimate of temperature in the lubricant film (distribution, maximum and mean value);

j) an estimate of temperature in the bearing material and housing (maximum);

k) an estimate of balance between friction loss and dissipated heat;

l) lubricant flow rate;

m) frictional torque or coefficient of friction;

n) frictional torque or coefficient of friction as a function of time.

6.7.3 Assessment of bearing performance

One or more of the following quantitative and qualitative assessments of bearing performance against all forms of wear or damage may be used (other quantitative assessments based on a rating of bearing performance are also possible):

a) determination of wear or damage and its cause (see also ISO 7146);

b) degree of wear or damage by visual assessment;

c) mass or volume of material removed;

d) change in functional dimension, for example, wall thickness;

e) wear rate or wear distribution per unit of time;

f) duration of test (number of load cycles);

g) test conditions achieved (e.g. maximum specific load, maximum sliding velocity, maximum operating bearing temperature, minimum friction).

Qualitative and quantitative results from tests under different conditions should only be directly compared with great care. Because of the complexity of the operation of a hydrodynamic bearing under hydrodynamic or mixed lubricating conditions, small differences in test conditions can have a significant impact on qualitative and quantitative results, even with nominally the same test rig. Trends and material performance rankings between rigs are, however, possible, providing the different testing conditions are taken into account.

6.8 Discussion of test results and remarks

Any remarkable or abnormal test results should be highlighted and the reasons for this anomalous behaviour discussed.

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