
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

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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.

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).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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 2, *Materials and lubricants, their properties, characteristics, test methods and testing conditions*.

This second edition cancels and replaces the first edition (ISO 6281:2007), which has been technically revised.

The main changes compared to the previous edition are as follows:

- editorial changes;
- reference to ISO 9045 has been replaced by ISO 4378 (all parts);
- [Clause 1](#) has been edited to be in line with ISO drafting rules;
- the unit of the dynamic viscosity in [Clause 4](#) has been modified.

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.

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

1 Scope

This document defines requirements 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.

NOTE It is intended that further details of test procedures be established when carrying out testing based on this document.

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 (all parts), *Plain bearings — Terms, definitions, classification and symbols*

3 Terms and definition

For the purposes of this document, the terms and definitions given in ISO 4378 (all parts) and the following 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

wear rate

ratio of wear extent to the time interval during which it has developed

3.2

wear intensity

ratio of wear extent to the specified distance on which wear developed or to the volume of the work done

4 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

Table 1 (continued)

Symbol	Description	Unit
f	coefficient of friction of journal bearing	—
t	time	s
U	sliding velocity	m/s
β	direction of bearing load	°
η	dynamic viscosity of lubricant	Pa · s
ω	angular velocity	rad/s

5 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 the ISO 4378 series):

- a) the running-in ability;
- b) the wear resistance;
- c) the compatibility between bearing and journal materials (resistance to adhesion);
- d) the embeddability (foreign particles absorption);
- e) the resistance to journal scoring and abrasion;
- f) the conformability;
- g) the deformability (compressive strength);
- h) the resistance to erosion (cavitation erosion, fluid erosion, and particle erosion);
- i) the static load carrying capacity;
- j) the dynamic load carrying capacity (fatigue strength);
- k) the friction characteristics;
- l) the lubricant flow rate characteristics;
- m) the temperature increase characteristics.

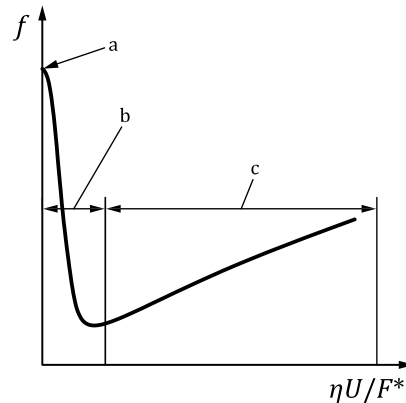
Of these bearing properties, the first group, a) to h), depends primarily on the mechanical and tribological properties of sliding materials under specified conditions. The second group, i) to m), depends primarily on hydrodynamic variables, and therefore also on

- 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 It is possible that specific test methods do not yet exist for all of the above-mentioned bearing properties.

Figure 1 depicts the typical relation between the dimensionless number $\eta U/F^*$ representing a normalized speed, 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

- a Boundary lubrication.
- b Mixed lubrication.
- c Hydrodynamic lubrication.

Figure 1 — Three modes of lubrication regime

6 Test rigs

6.1 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 (e.g. geometric, dynamic, hydrodynamic, thermal, and thermodynamic) of the actual application.

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

- a) 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) A well-defined dimensions for the test bearing.
- d) A 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 can be necessary to vary the dimensional stability or the shaft deflection in order to simulate the operating condition of the actual application.
- e) An appropriate lubricant supply condition. When the lubricant flow within the bearing clearance needs 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.

6.2 Generic types of test rig

Generic types of test rig for plain journal bearings are shown in [Figure 2](#) and [Figure 3](#). [Figure 2](#) a) and [Figure 2](#) 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 can occur, such as inclination, bending, axial, conical and their combinations. In addition, the bearing itself can rotate, 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 shall 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(s) with time, while the remaining variable can be constant. The change of 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, and hydraulic actuation, 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 shall 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 document (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.

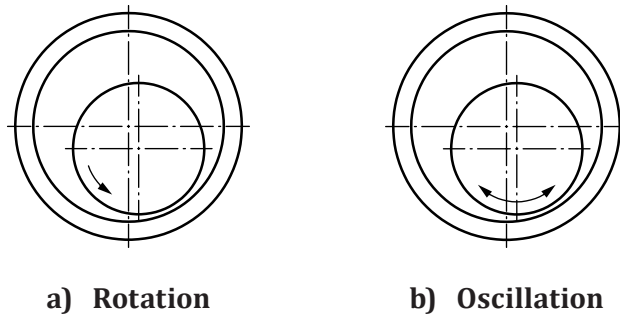
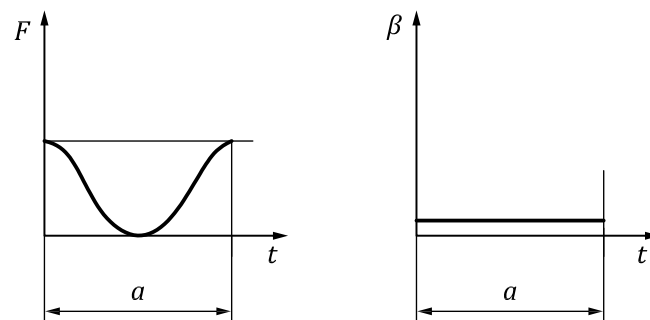
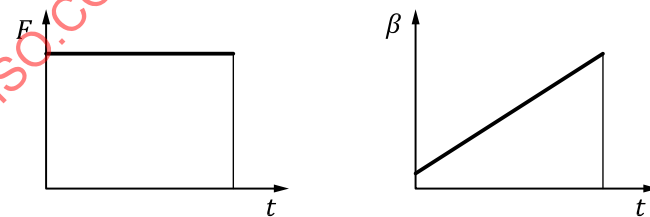
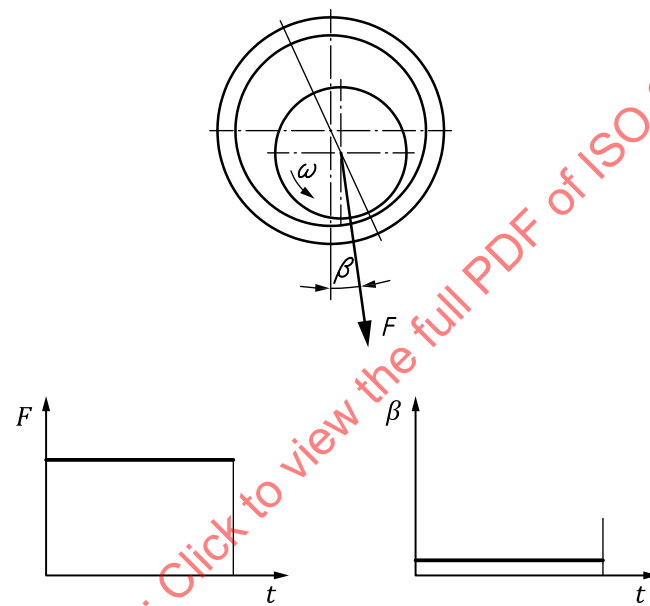


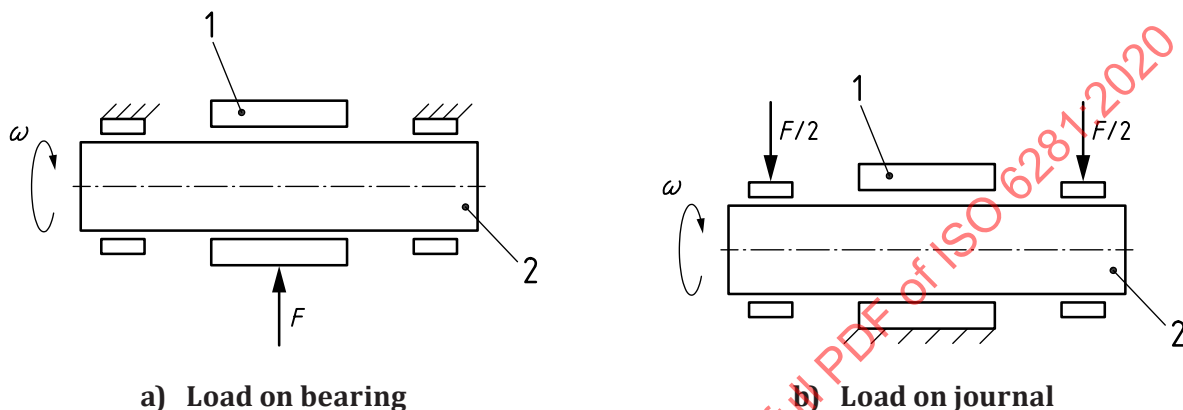
Figure 2 — Rotational motion of a journal



Key

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

Figure 3 — Examples of bearing load patterns



Key

- F bearing load
- ω angular velocity
- 1 test bearing
- 2 journal

Figure 4 — Two modes of load application

7 Test procedures

7.1 General

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, examples of test procedures for obtaining the bearing properties according to [Clause 5](#), a) to m) are described together with the evaluation of the results. Bearing properties given in [7.2](#) to [7.9](#) 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 shall be achieved in the test object at each step to ensure 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, such as through wear, foreign particles embedding, diffusion, chemical reaction, and lubricant degradation. This should be checked and documented in the test report.

7.2 Running-in ability

The change of surface topography, roughness, friction torque, wear rate or wear intensity 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.

7.3 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.

7.4 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.

7.5 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.

7.6 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 checked. 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.

7.7 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.

7.8 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.

7.9 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, and sliding

velocity), the greater 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.

7.10 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.

7.11 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).

7.12 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.

7.13 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 the appropriate limits.

7.14 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, and lubricant feed pressure and temperature). The lower the temperature increase throughout the whole test range, the more desirable the temperature characteristics.

8 Testing and test report

8.1 General

In testing, the independent and dependent variables shall 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 (8.2) and measuring equipment (8.3) — which can also be regarded as independent variables in the widest sense — are given, the items specified in 8.4 to 8.6 are independent variables. These are: the test bearing and journal (8.4), the lubricant and its supply method (8.5), and the operating or test conditions (8.6). 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 8.7 are dependent variables or test results, i.e. the pressure, temperature, and thickness of the lubricant film, the stress, strain, deformation, temperature of the bearing, and the occurrence of damage and wear rate.

The independent variables given in 8.2 to 8.6 should be chosen dependent on the test objectives a) to m) above. They should be documented with the test results according to 8.7 and the discussion according to 8.8 in the test report.

8.2 Test rig

The following details should be given, as appropriate:

- a) the name or type of rig;
- b) the principle of operation, with a diagram of the test rig;
- c) the method of load application;
- d) the main dimensions and design limits (such as load and speed);
- e) the position and number of test bearings;
- f) the repeatability and reproducibility;
- g) the power and speed of driving motor and control method;
- h) the method and specification of emergency stop;
- i) the auxiliary equipment;
- j) the position of measuring points for various variables.

8.3 Measuring equipment

8.3.1 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.

8.3.2 Measuring equipment for independent variables (which can also be time-dependent)

This equipment is as follows:

- a) the bearing load;
- b) the sliding velocity or rotational speed;
- c) the inlet lubricant temperature;
- d) the lubricant feed pressure;
- e) the ambient air temperature and air velocity around the bearing.

8.3.3 Measuring equipment for dependent variables (which can also be time-dependent)

This equipment is as follows:

- a) the lubricant film thickness (distribution and minimum);

- b) the lubricant film temperature (distribution, maximum, and mean value);
- c) the lubricant outlet temperature;
- d) the lubricant flow rate;
- e) the lubricant pressure (distribution and maximum);
- f) the temperature of bearing and housing;
- g) the bearing stress or strain (maximum);
- h) the bearing wear and damage;
- i) the 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.

8.4 Test bearing and journal

8.4.1 General

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

8.4.2 Test bearing

8.4.2.1 Material properties for each functional layer of the bearing

These are as follows:

- a) the designation;
- b) the chemical composition;
- c) the manufacturing method;
- d) the microstructure;
- e) the mechanical properties (hardness, tensile strength, shear strength, elongation, modulus of elasticity, and Poisson's ratio);
- f) the thermal properties (coefficient of thermal expansion, thermal conductivity, and coefficient of heat transfer).

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

These are as follows:

- a) the inside diameter;
- b) the outside diameter;
- c) the inside and outside housing diameter;
- d) the interference or fit in housing;
- e) the total wall thickness;

- f) the thickness of each material layer;
- g) the effective bearing width;
- h) the bearing clearance (radial or diametral) before and after test;
- i) the method of surface finishing and treatment of bearing inner surface;
- j) the surface roughness, in both axial and circumferential directions, if possible;
- k) the roundness and cylindricity of bearing inner surface;
- l) the area and properties of outer surface of bearing housing (for thermal analysis).

8.4.3 Journal

8.4.3.1 Material properties

These are as follows:

- a) the designation;
- b) the chemical composition;
- c) the manufacturing method;
- d) the heat treatment;
- e) the microstructure;
- f) the mechanical properties (hardness);
- g) the thermal properties (coefficient of thermal expansion and thermal conductivity).

8.4.3.2 Dimensions, finishing method, and roughness

These are as follows:

- a) the diameter;
- b) the length;
- c) the allowable deflection during test run;
- d) the allowable misalignment during test run;
- e) the method of surface finishing, finishing direction, and surface treatment;
- f) the surface roughness;
- g) the roundness and cylindricity.

8.5 Lubricant and lubricant supply method

8.5.1 Lubricant

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

- a) the type;
- b) the manufacturer and product name;
- c) the specification;