



BSI Standards Publication

## **Metallic materials — Rotating bar bending fatigue testing**

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**INTERNATIONAL  
STANDARD**

**ISO  
1143**

Third edition  
2021-07

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**Metallic materials — Rotating bar  
bending fatigue testing**

*Matériaux métalliques — Essais de fatigue par flexion rotative de  
barreaux*



Reference number  
ISO 1143:2021(E)

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Published in Switzerland

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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](http://www.iso.org/directives)).

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This document was prepared by Technical Committee ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 4, *Fatigue, fracture and toughness testing*.

The third edition cancels and replaces the second edition (ISO 1143:2010), which has been technically revised.

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

- A new [Clause 13](#), Measurement uncertainty, has been added;
- a new [Annex B](#), Example of a test report, has been added.

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](http://www.iso.org/members.html).

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**3.3**  
**S-N diagram**  
diagram that shows the relationship between stress and *fatigue life* (3.2)

**3.4**  
**bending moment**  
 $M$   
multiplication between force and length of lever arm at test temperature

**3.5**  
**section modulus**  
 $W$   
ratio of the moment of inertia of the cross-section of a beam undergoing flexure to the greatest distance of an element of the beam from the neutral axis

**3.6**  
**machine lever ratio**  
 $M_{lr}$   
ratio between the force applied to the weight hanger and the *bending moment* (3.4) applied to the specimen

**3.7**  
**length of lever arm**  
 $L$   
distance between the supporting point and the loading point

Note 1 to entry: See [Figures 1 to 7](#).

Note 2 to entry: Since these distances are length of level arm,  $L_1 = L_2 = L$ .

## 4 Symbols

Symbols and corresponding designations are given in [Table 1](#)

**Table 1 — Symbols**

Symbol	Designation	Unit
$D$	Diameter of gripped or loaded end of specimen	mm
$d$	Diameter of specimen where stress is maximum	mm
$L$	Length of lever arm	mm
$M$	Bending moment	N·mm
$M_{lr}$	Machine lever ratio	/
$N_f$	Fatigue life, cycles to failure	cycle
$r$	Radius at ends of test section that starts transition from test diameter, $d$	mm
$W$	Section modulus	mm <sup>3</sup>

## 5 Principle of test

Nominally identical specimens are used, each being rotated and subjected to a constant bending moment. The forces giving rise to the bending moment do not rotate. The specimen may be mounted as a cantilever, with single-point or two-point loading, or as a beam, with four-point loading. The test is continued until the specimen fails or until a pre-determined number of stress cycles have been achieved, a stress cycle corresponds to a complete rotation of the specimen.

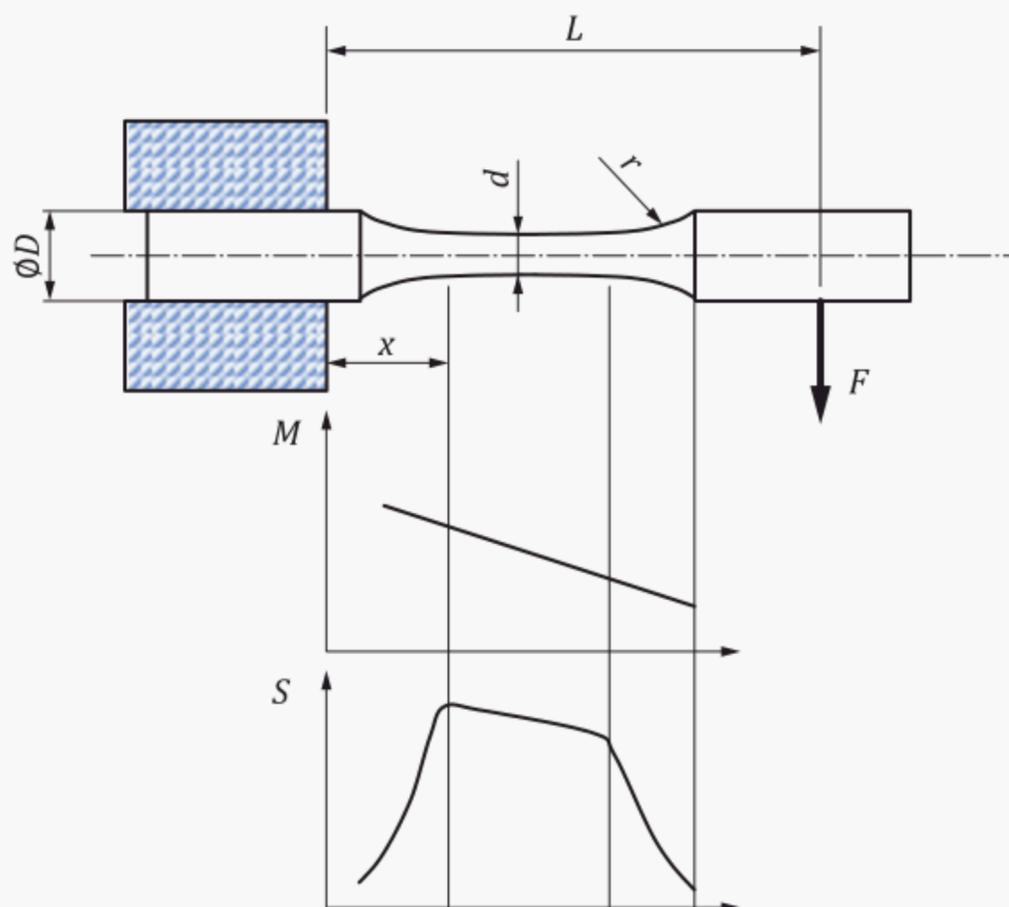
## 6 Shape and size of specimen

### 6.1 Forms of the test section

The test section may be

- cylindrical, with tangentially blending fillets at one or both ends (see [Figures 1, 4 and 5](#)),
- tapered (see [Figure 2](#)), or
- hourglass-type (see [Figures 3, 6 and 7](#)).

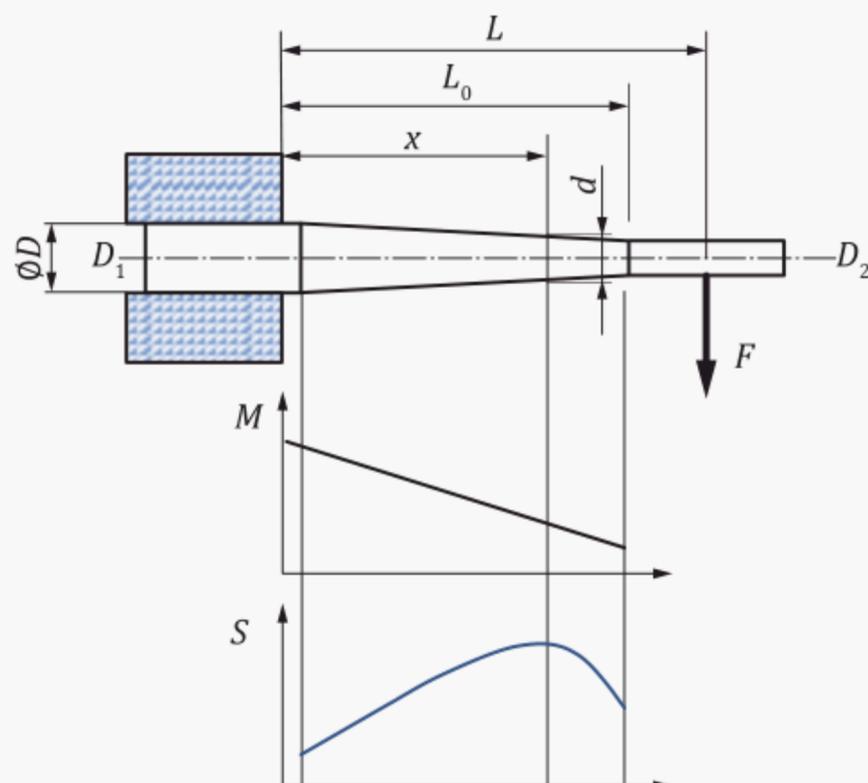
**NOTE** A volume of material is tested in the gauge portion of a parallel specimen in two-point and four-point loading conditions. This volume is equally under maximum stress. For all other loading conditions and for both parallel and hourglass specimens, only a thin planar element of material is submitted to the maximum stress at the minimum cross-section.



#### Key

$D$	diameter of gripped or loaded end of specimen	$M$	bending moment
$d$	diameter of specimen where stress is maximum	$r$	radius (see <a href="#">Table 1</a> )
$F$	applied force	$S$	stress
$L$	length of lever arm	$x$	distance along specimen axis from fixed bearing face to maximum stress plane

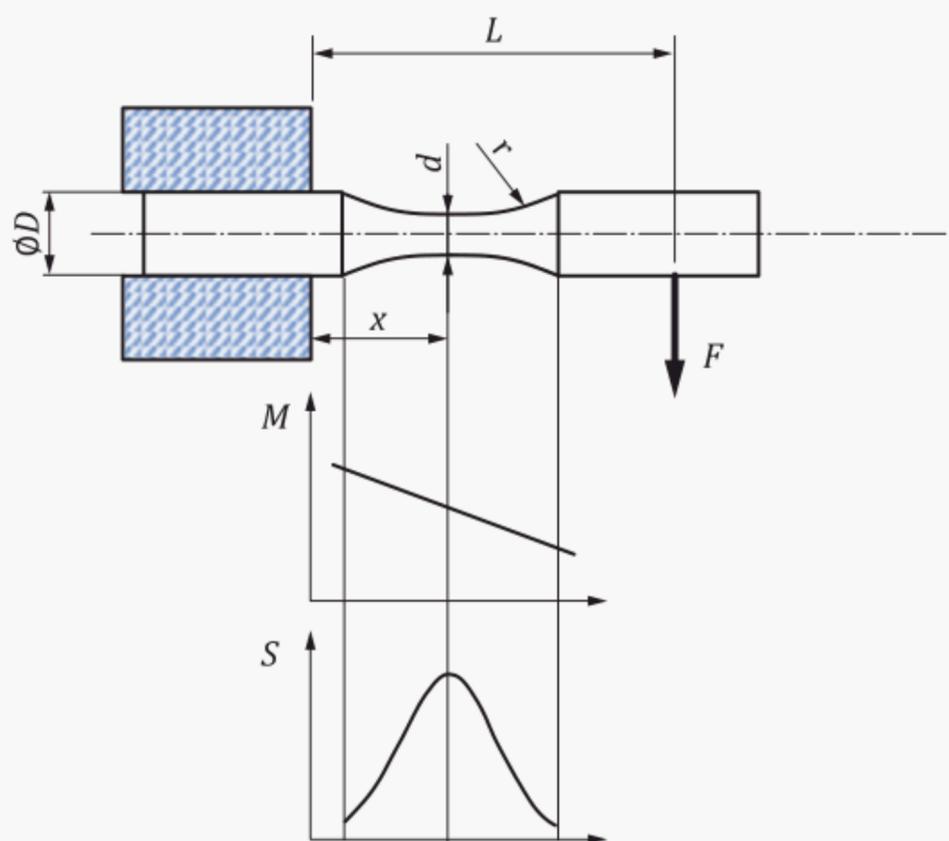
**Figure 1 — Parallel specimen — Single-point loading**



**Key**

- |     |   |     |  |
|-----|---|-----|--|
| $D$ | diameter of gripped or loaded end of specimen | $M$ | bending moment   |
| $d$ | diameter of specimen where stress is maximum  | $S$ | stress   |
| $F$ | applied force                                 | $x$ | distance along specimen axis from fixed bearing face to maximum stress plane |
| $L$ | length of lever arm                           |     |  |

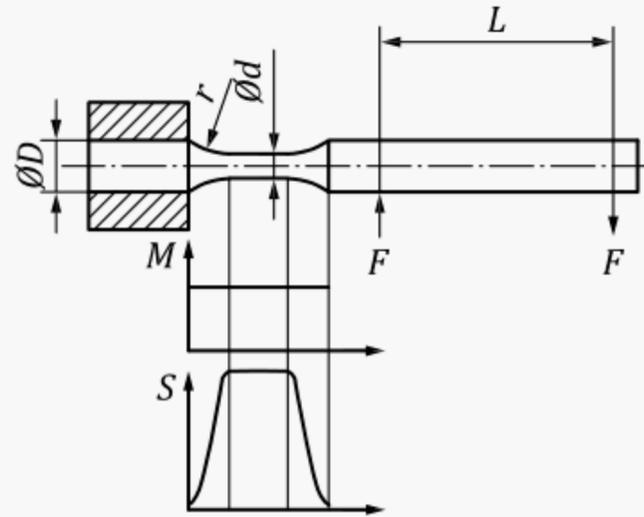
**Figure 2 — Tapered specimen — Single-point loading**



**Key**

- |     |   |     |  |
|-----|---|-----|--|
| $D$ | diameter of gripped or loaded end of specimen | $M$ | bending moment   |
| $d$ | diameter of specimen where stress is maximum  | $S$ | stress   |
| $F$ | applied force                                 | $x$ | distance along specimen axis from fixed bearing face to maximum stress plane |
| $L$ | length of lever arm                           |     |  |
| $r$ | radius (see <a href="#">Table 1</a> )         |     |  |

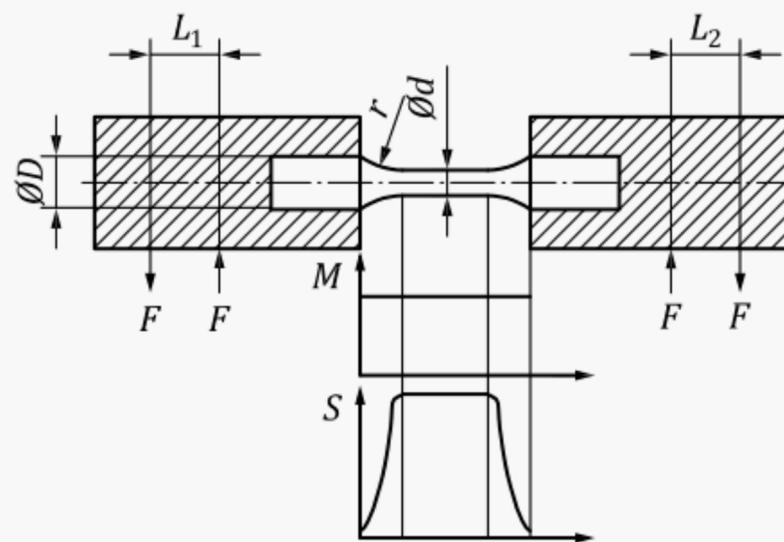
**Figure 3 — Hourglass specimen — Single-point loading**



**Key**

- |     |   |     |                                       |
|-----|---|-----|---------------------------------------|
| $D$ | diameter of gripped or loaded end of specimen | $M$ | bending moment                        |
| $d$ | diameter of specimen where stress is maximum  | $S$ | stress                                |
| $F$ | applied force                                 | $r$ | radius (see <a href="#">Table 1</a> ) |
| $L$ | length of lever arm                           |     |                                       |

**Figure 4 — Parallel specimen — Two-point loading**

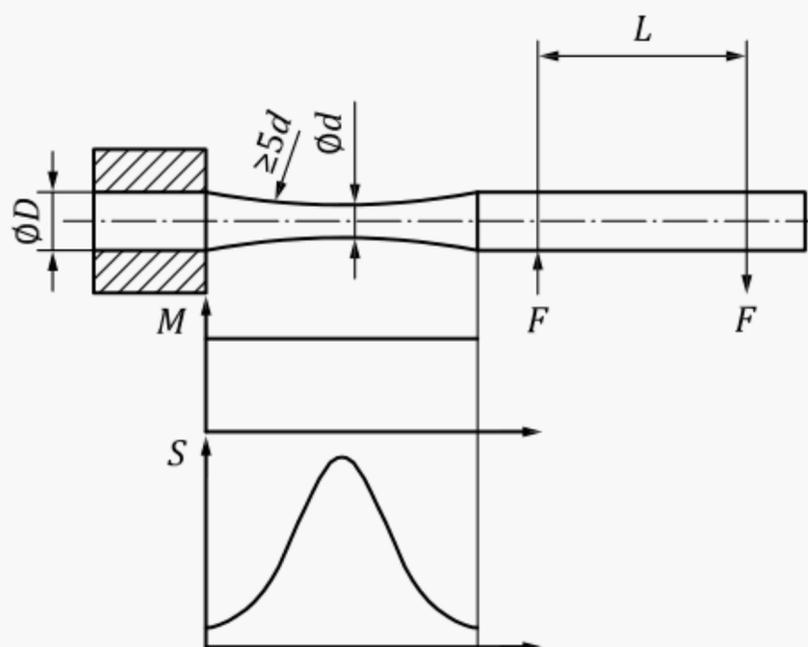


**Key**

- |            |   |     |                                       |
|------------|---|-----|---------------------------------------|
| $D$        | diameter of gripped or loaded end of specimen | $M$ | bending moment                        |
| $d$        | diameter of specimen where stress is maximum  | $S$ | stress                                |
| $F$        | applied force                                 | $r$ | radius (see <a href="#">Table 1</a> ) |
| $L_1, L_2$ | length of lever arm                           |     |                                       |

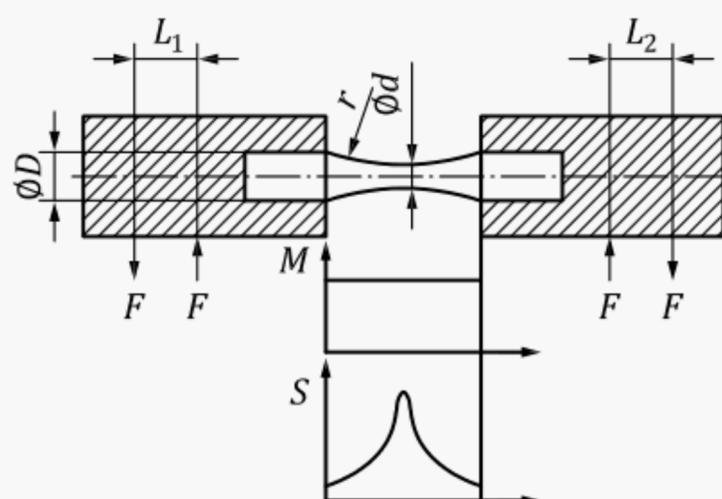
NOTE  $L_1 = L_2 = L$

**Figure 5 — Parallel specimen — Four-point loading**



- Key**
- |     |   |     |                     |
|-----|---|-----|---------------------|
| $D$ | diameter of gripped or loaded end of specimen | $L$ | length of lever arm |
| $d$ | diameter of specimen where stress is maximum  | $M$ | bending moment      |
| $F$ | applied force                                 | $S$ | stress              |
| $r$ | radius (see <a href="#">Table 1</a> )         |     |                     |

**Figure 6 — Hourglass specimen — Two-point loading**

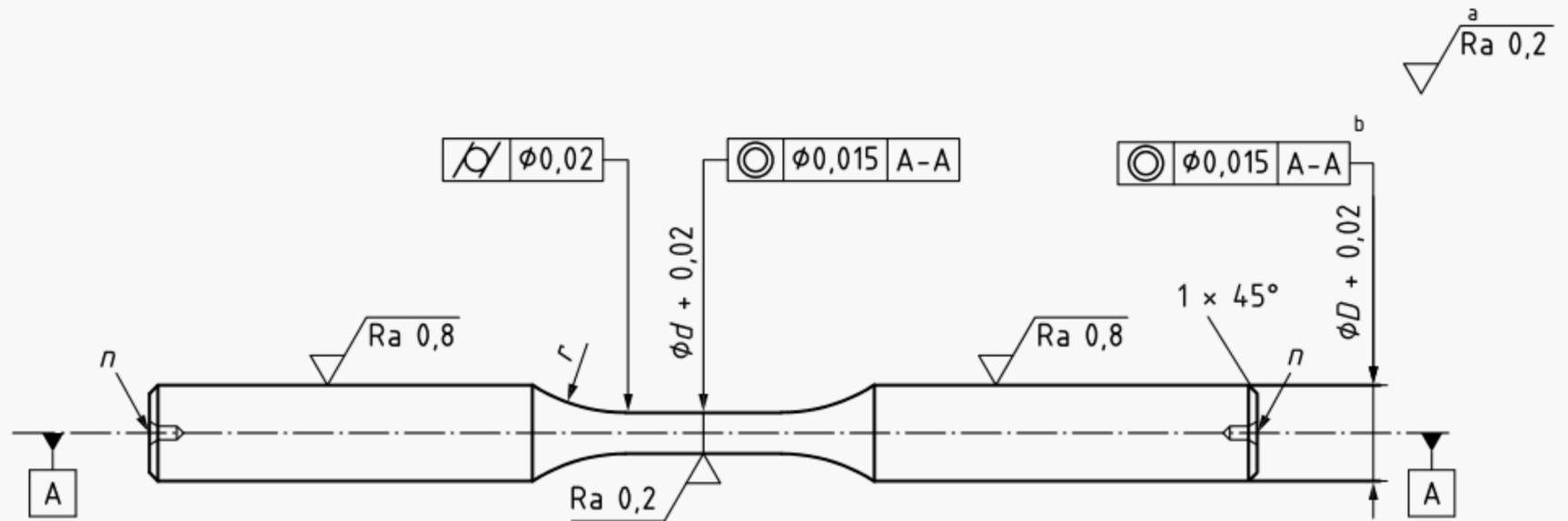


- Key**
- |            |   |
|------------|---|
| $D$        | diameter of gripped or loaded end of specimen |
| $d$        | diameter of specimen where stress is maximum  |
| $F$        | applied force                                 |
| $L_1, L_2$ | length of lever arm                           |
| $M$        | bending moment                                |
| $r$        | radius (see <a href="#">Table 1</a> )         |
| $S$        | stress  |

NOTE  $L_1 = L_2 = L$ .

**Figure 7 — Hourglass specimen — Four-point loading**

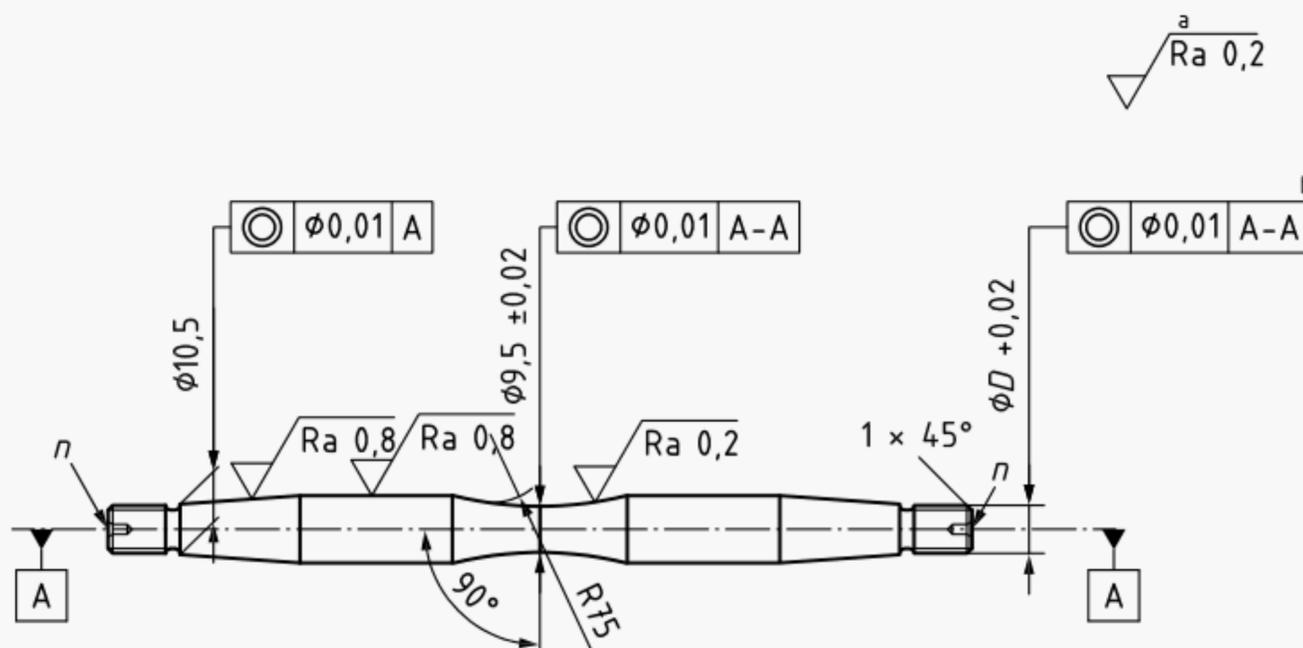
In each case, the test section shall be of circular cross-section. Typical parallel and hourglass specimen shapes and related dimensions are shown in [Figures 8](#) and [9](#), respectively.



**Key**

- $n$  specimen code
- $a$  others
- $b$  two tops

**Figure 8 — Cylindrical smooth specimen**



**Key**

- $n$  specimen code
- $a$  others
- $b$  two tops

**Figure 9 — Cylindrical hourglass specimen**

The form of test section can be dependent on the type of loading to be employed. While cylindrical or hourglass-type specimens may be loaded as beams, or as cantilevers with either single-point or double-point loading, the tapered form of specimen is used only as a cantilever with single-point loading. Figures 1 to 7 show, in schematic form, the bending moment and nominal stress diagrams for the various practical cases.

The volumes of material subjected to greatest stresses are not the same for different forms of specimen, and they may not necessarily give identical results. The test in which the largest volume of material is highly stressed is recommended.

The use of single point loading machines should be done with great caution. One of the main drawbacks is that the bending moment is not constant along the specimen. The section where the stress is maximum

and the corresponding stress depend not only on the specimen geometry but also on the length of level arm. For this type of machines, cylindrical hour glass specimen geometry is recommended because the higher stress is close to the one calculated for the minimum diameter section.

Experience has shown that a ratio of at least 2:1 between the cross-sectional areas of the gripping regions and the test portion of the specimen is recommended. The grips which do not lead up to large stress-concentration area are recommended.

In tests on certain materials, a combination of high stress and high speed may cause excessive hysteresis heating of the specimen. This effect may be reduced by subjecting a smaller volume of the material or by decreasing the test frequency (see [10.3](#)). If the specimen is cooled, the test medium should be reported.

## 6.2 Dimensions of specimens

All the specimens employed in a test series for a fatigue-life determination shall have the same size, shape and tolerance of diameter.

For the purpose of calculating the force to be applied to obtain the required stress, the actual minimum diameter of each specimen shall be measured to an accuracy of 0,01 mm. Care shall be taken during the measurement of the specimen prior to testing to ensure that the surface is not damaged.

On cylindrical specimens subject to constant bending moment (see [Figures 4](#) and [5](#)), the parallel test section shall be parallel within 0,025 mm. For other forms of cylindrical specimen (see [Figure 1](#)), the parallel test section shall be parallel within 0,05 mm. For material property determination, the transition fillets at the ends of the test section should have a radius not less than  $3d$ . For hourglass-type specimens, the section formed by the continuous radius should have a radius not less than  $5d$ .

[Figure 8](#) shows the shape and dimensions of a typical cylindrical specimen. The recommended values of  $d$  are 6 mm, 7,5 mm and 9,5 mm. The tolerance of diameter should be  $0,005d$ . [Figure 9](#) shows a typical hourglass specimen suitable for fatigue testing at elevated temperature.

## 7 Preparation of specimens

### 7.1 General

In any rotating bar bending fatigue test program designed to characterize the intrinsic properties of a material, it is important to observe the following recommendations in the preparation of specimens. A possible reason for deviation from these recommendations is if the test program aims to determine the influence of a specific factor (surface treatment, oxidation, etc.) that is incompatible with the recommendations. In all cases, any deviation shall be noted in the test report.

### 7.2 Selection of the specimen and marking

The sampling of test materials from a semi-finished product or a component may have a major influence on the results obtained during the test. It is therefore necessary for this sampling to be recorded and a sampling drawing be prepared. This shall form part of the test report and shall indicate clearly

- the position of each of the specimens removed from the semi-finished product or component,
- the characteristic directions in which the semi-finished product has been worked (direction of rolling, extrusion, etc., as appropriate), and
- the unique identification of each of the specimens.

The unique mark or identification of each specimen shall be maintained at each stage of its preparation. This may be applied using any reliable method in an area not likely to disappear during machining or likely to adversely affect the quality of the test. Upon completion of the machining process, it is desirable for both ends of each specimen to be uniquely marked so that, after failure of a specimen, each half can still be identified.

## 7.3 Machining procedure

### 7.3.1 Heat treatment of test material

The heat treatment is generally performed on a rough machined specimen. Then final machining followed by polishing should be performed on the specimen to remove any deformation of the specimen due to the heat treatment process. If that is not possible, the heat treatment should be carried out in a vacuum or in inert gas to prevent oxidation of the specimen. Subsequent stress relieving is recommended in this case. The stress relieving treatment shall not alter the micro-structural characteristic of the material under study. The specifics of the heat treatment and machining procedure shall be reported with the test results.

### 7.3.2 Machining criteria

The machining procedure selected may produce residual stresses on the specimen surface likely to affect the test results. These stresses may be induced by heat gradients at the machining stage or they may be associated with deformation of the material or micro-structural alterations. Their influence is less marked in tests at elevated temperatures because they are partially or totally relaxed once the temperature is attained. However, they should be reduced by using an appropriate final machining procedure, especially prior to a final polishing stage. For harder materials, grinding rather than turning or milling may be preferred.

- Grinding: from 0,1 mm above the final diameter, at a rate of no more than 0,005 mm/pass.
- Polishing: remove the final 0,025 mm with abrasives of decreasing grit size. The final direction of polishing shall be along the test specimen axis.

The phenomenon of alteration in the microstructure of the material may be caused by the increase in temperature and by the strain hardening induced by machining. It may be a matter of a change in phase or, more frequently, of surface re-crystallization. The immediate effect of this is to make the test specimen no longer representative of the initial material. Hence, every precaution should therefore be taken to avoid this risk.

Contaminants can be introduced when the mechanical properties of certain materials deteriorate in the presence of certain elements or compounds. An example of this is the effect of chlorine on steels and titanium alloys. These elements should therefore be avoided in the products used (cutting fluids, etc.). Rinsing and degreasing of specimens prior to storage is also recommended.

### 7.3.3 Surface condition of specimens

The surface condition of specimens influences the test results. This influence is generally associated with one or more of the following factors:

- the specimen surface roughness;
- the presence of residual stresses;
- alteration in the microstructure of the material;
- the introduction of contaminants.

The recommendations below allow the influence of these factors to be reduced to a minimum.

The surface condition is commonly quantified by the mean roughness or equivalent (e.g. 10 point roughness or maximum height of irregularities). The importance of this variable on the results obtained depends largely on the test conditions, and its influence is reduced by surface corrosion of the specimen or plastic deformation.

It is preferable, whatever the test conditions, to specify a mean surface roughness,  $R_a$ , of less than 0,2  $\mu\text{m}$  (or equivalent).

Another important parameter not covered by mean roughness is the presence of localized machining scratches. A low-magnification check (at approximately  $\times 20$ ) shall not show any circumferential scratches or abnormalities.

With specimens having tangentially blended fillets, often an undercut is observed at the transition from the radius of the fillet to the cylindrical test section. This undercut may lead to a preferred failure of the specimen in this area. The undercut can't easily be measured but can be found by visible inspection of the reflections on the surface under a flat angle. No visible undercut shall be allowed.

If specimens are not manufactured according to the procedures defined in [7.3.2](#) or if there are doubts about the correct machining, it is recommended to measure or evaluate:

- residual stress state, preferably a profile of residual stress over depth;
- surface roughness profile;
- surface hardness;

and state the values observed together with the test results in order to facilitate definite interpretation of the test results.

#### 7.3.4 Dimensional checks

The diameter shall be measured on each specimen. In the case of specimens with a parallel gauge length, the diameter shall be measured at a minimum of three positions along the gauge length. The measurement shall be performed using a method that does not damage the specimen.

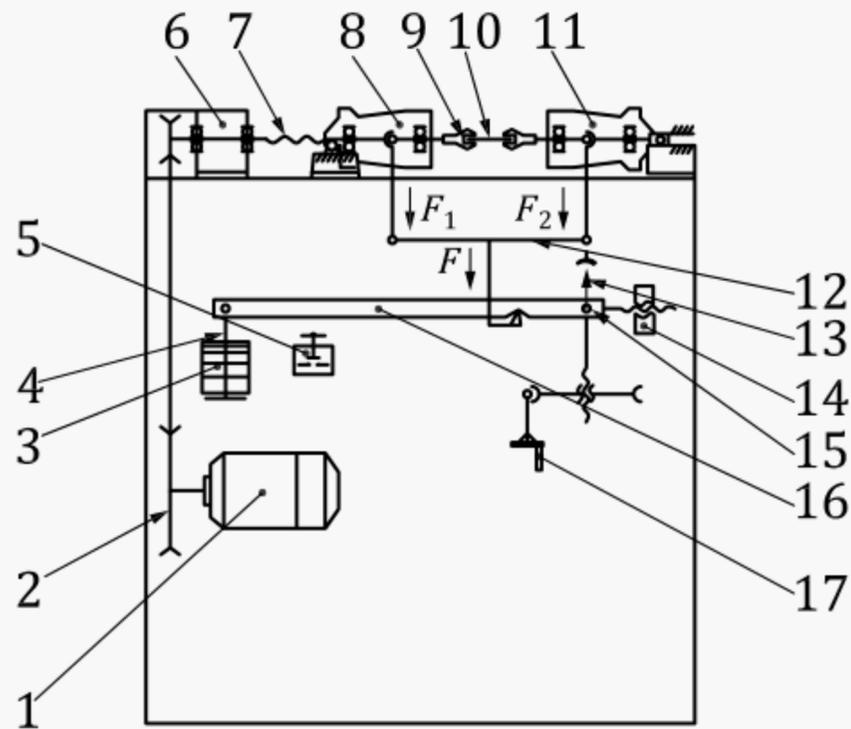
#### 7.4 Storage and handling

After preparation, the specimens shall be stored in such a way to prevent any risk of damage (scratching by contact, oxidation, etc.). The use of individual boxes or tubes with end caps is recommended. In certain cases, storage in a vacuum or in a desiccator containing silica gel may be necessary.

Handling shall be reduced to the minimum necessary. In all instances, the gauge length or test section should not be touched. However, if this happens, cleaning the specimen with alcohol is allowed.

### 8 Accuracy of the testing apparatus

A number of different types of rotating bending fatigue machine are used. [Figures 1 to 7](#) show the principles of the main types of machine. [Figure 10](#) shows the schematic of a kind of rotating bending fatigue machine. Its operation shall satisfy the following requirement: the accuracy of the applied bending moment shall be within 1 % (see [Annex A](#)).



### Key

1	motor	10	specimen
2	triangle belt	11	right main axis box
3	weight	12	hanging hook
4	boom	13	pointer
5	button	14	balance weight
6	counting accelerator	15	counter
7	soft axis	16	lever
8	left main axis box	17	hand wheel
9	split collet		

**Figure 10 — Schematic of a rotating bend fatigue machine**

## 9 Heating device and temperature measurement

**9.1** The specimen is heated with a furnace or equivalent device.

**9.2** The temperature of the specimen shall be kept uniform throughout the test, complying with the limits defined in [10.5.3](#).

**9.3** To measure or record temperature, the thermocouple, compensating wire, and controlling and measuring temperature meter that are used shall be calibrated together as a system. The calibration interval shall be in accordance with the product standard, and good metrological practice.

**9.4** The temperature indicator shall have a resolution of at least 0,5 °C and the temperature measuring equipment shall have an accuracy of ±1 °C.

## 10 Test procedure

### 10.1 Mounting the specimen

Each specimen shall be mounted in the test machine such that stresses at the test section (other than those imposed by the applied force) are avoided. If the bearings transmitting the force are secured to the specimen by means of split collets, in certain cases it may be desirable for these to be positioned and fully tightened before the specimen is mounted in the test machine, in order to prevent an initial torsion

strain being imparted. A similar practice may be necessary if the method of securing is by means of an interference fit.

To avoid vibration during the test, alignment of the specimen and the driving shaft of the test machine shall be maintained within close limits. Permissible tolerances are  $\pm 0,025$  mm at the chuck end and  $\pm 0,013$  mm at the free end for single-point and some types of two-point loading test machines. For other types of rotating bending fatigue test machines, the permissible tolerance on eccentricity measured at two places along the actual test section shall not be greater than  $\pm 0,013$  mm. The required degree of alignment shall be established before applying any force.

NOTE These measurements are typically made using a dial gauge.

## 10.2 Application of force

The lever ratio shall be calibrated according to [Annex A](#). The specific formula to calculate the force or the mass in bending conditions for a given stress is generally given in the user manual of the rotating bar bending machine. The calculated test force could be according to [Table 2](#).

The set-up of force level  $F$ :

- is direct for Direct Force systems;
- is obtained by mass equal to  $F$  divided by the level ratio  $M_{lr}$  for Fixed ratio lever;
- is obtained adjusting  $F$  on the force scale on the lever for lever and balance machines.

**Table 2 — Calculation of force to be applied to test machine loading system**

Machine type	$F$
Single-point bending – parallel specimen ( <a href="#">Figure 1</a> ) or hourglass specimen ( <a href="#">Figure 3</a> )	$F = S \frac{\pi d^3}{32(L-x)}$
Single-point bending – tapered specimen <a href="#">Figure 2</a>	$F = S \cdot \frac{27 \cdot \pi \cdot (D_1 - D_2) \cdot (D_1 L_0 - L \cdot (D_1 - D_2))^2}{128 \cdot L_0^3}$
Two-point bending ( <a href="#">Figure 4</a> , <a href="#">Figure 6</a> ) or Four-point bending ( <a href="#">Figure 5</a> , <a href="#">Figure 7</a> )	$F = S \frac{\pi d^3}{32L}$

where

$S$  is the required test stress;

$F$  is the applied force;

$L$  is the length of lever arm (see [A.4.2](#));

$d$  is the specimen diameter where the stress is maximum;

$x$  is the distance along the specimen axis from the fixed bearing face to the maximum stress plane.

The general procedure for attaining full-force running conditions shall be the same for each specimen. The test machine shall be switched “ON” and the desired speed attained before application of force is commenced. The force shall then be applied incrementally or continuously until the required value is attained, without shock or impact, and as quickly as is convenient. Small adjustments in operating speed can then be made if a particular frequency is required<sup>[3]</sup>.

## 10.3 Frequency selection

The frequency chosen shall be suitable for the particular combination of material, specimen and test machine. The testing speed should be the same for the given test series. It is necessary to avoid abnormal vibration of the specimen when testing.

For tests at high temperature, the temperature shall remain within the permissible temperature fluctuation specified in [10.5.3](#).

Tests are normally performed at a frequency between 15 Hz to 200 Hz (i.e. from 900 r/min to 12 000 r/min).

At high frequencies, self-heating of the specimen can occur and could affect the resulting fatigue life. If self-heating occurs, it is advisable to decrease the test frequency. In room temperature testing, self-heating of the specimen should be monitored and recorded. If the specimen temperature exceeds 35 °C, it shall be measured and reported. The specimen temperature should not exceed values within which there is no influence on the fatigue behaviour of the material being tested. If in doubt, reference tests with lower frequency and temperature shall be made in order to prove that there is no influence of testing frequency and temperature.

NOTE If the influence of the environment is significant, the test result is likely to be frequency-dependent.

## 10.4 End of test

The test is continued until specimen failure or until it has reached the required number of cycles (e.g.  $10^7$  or  $10^8$ ). Where the failure location is outside the specimen gauge length, the test result is considered invalid.

## 10.5 Procedure for testing at elevated temperature

**10.5.1** Due to the nature of rotating bar bending fatigue testing, direct temperature measurement may not be possible. If this is the case, it is essential to use indirect temperature measurement, calibrated in a static manner.

**10.5.2** To measure the temperature of the specimen, three approaches are possible.

The first approach, which is the preferred method, uses indirect measurement, i.e. the tip of the thermocouple is not directly in contact with the specimen surface, but kept about 1 mm to 2 mm distance from it. When using this method, the laboratory shall establish a relationship between the specimen surface temperature and that shown by the measuring thermocouple. This relationship shall be used to derive a correction factor for establishing the specimen temperature.

The second approach uses direct measurement, i.e. the thermocouple tip is directly in contact with the specimen surface. Use of this approach requires the test machine to be stopped periodically, the load to be removed and then the temperature of the specimen surface to be measured.

The third approach consists in a static calibration of the heating device. This calibration is made using a specimen to be tested (with the same geometry and material) equipped with thermocouples welded at its centre:

- one thermocouple for hourglass specimen,
- two thermocouples for cylindrical specimen with a parallel section smaller than 15 mm (placed at 1/3 and at 2/3 of the length),
- three thermocouples for cylindrical specimen with a parallel section greater than 15 mm (placed in the middle, at 1/3 and at 2/3 of the length).

The purpose of this method is to establish the relationship between the specimen temperature and the furnace temperature. The measurements shall be recorded.

During the test, the furnace temperature is observed to ensure that the specimen temperature is in accordance with the test conditions.

NOTE 1 Depending on the material, if self-heating of the specimen occurs during the test, this method is not suitable to control the test temperature.

NOTE 2 A reference thermocouple that is positioned at a fixed point inside the furnace close to the specimen surface enables the detection and measurement of temperature drifts as well as self-heating of the specimen for information.

**10.5.3** The specimen shall be heated to the specified temperature and stabilized for approximately half an hour prior to starting the test. During the entire test cycle, the fluctuation in the indicated specimen temperature shall be within 0,6 % test temperature in degree Celsius (°C) or 3 °C, whichever is greater.

The temperature (gradient) on the testing section of the specimen in the furnace body length shall not be greater than 15 °C.

Establishing the gradient along the specimen gauge length is typically machine specific. One approach is to use a specimen with three thermocouples along the gauge length, inserted into the test machine. The furnace and associated control/monitoring thermocouples are installed, and the furnace heated to the test temperature. When the furnace has stabilized at the required temperature, the temperatures are measured and a gradient derived.

**10.5.4** The temperature-measuring device should be stable within  $\pm 1$  °C overall changes in ambient temperature.

Any drift of the controlling temperature shall be detected and measured (see [10.5.2](#)). For tests during which drifts of the controlling temperature and hence of that of the specimen occur, the validity of the result shall be determined with reference to ISO 12107.

## 11 Test report

The fatigue test report shall include the mandatory items that are listed below:

- a) material tested and its metallurgical characteristics — reference can usually be made to the appropriate specifications to which the material was produced;
- b) method of stressing and the type of machine used;
- c) type, dimensions and surface condition of the specimen and the points of load application;
- d) frequency of the stress cycles;
- e) test temperatures and the temperature of the specimen if self-heating occurs (i.e. greater than 35 °C);
- f) daily maximum and minimum values of air temperature and relative humidity;
- g) criterion for the end of the test, i.e. its duration (e.g.  $10^6$ ,  $10^7$ ,  $10^8$  cycles), or complete failure of the specimen, or some other criterion;
- h) any deviations from the required conditions during the test;
- i) test result.

Optional information regarding the fatigue test may be added in the test report. The optional information shall be clearly separated from the mandatory data to avoid any confusion.

An example of a test report is given in [Annex B](#).

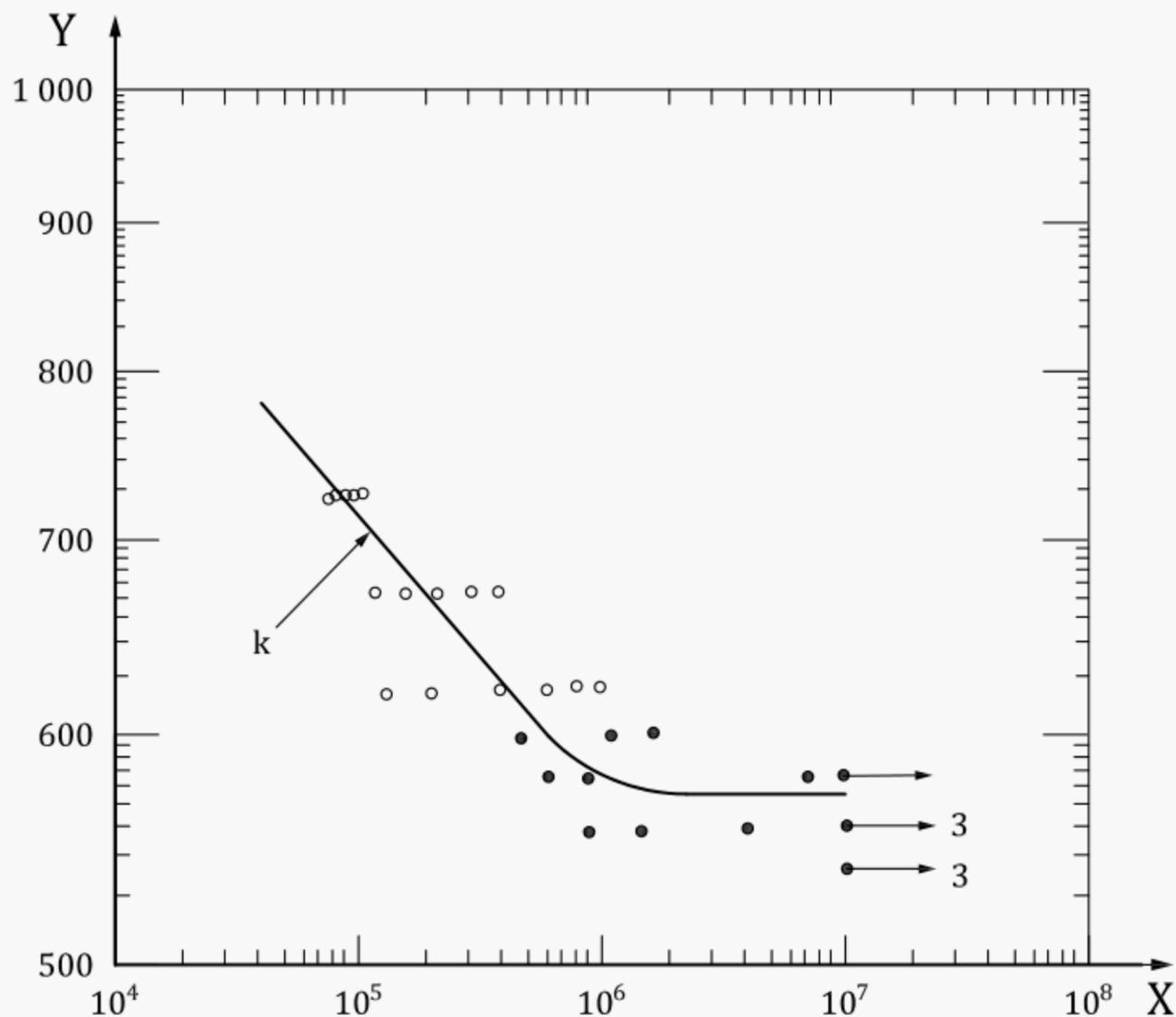
## 12 Presentation of fatigue test results

### 12.1 Tabular presentation

It is desirable but not required that the fatigue test results be reported in tabular form. When used, the tabular presentation shall include, at minimum, the specimen identification, test sequence, orientation of specimen in the original material (distance from surface, orientation with reference to surface, orientation with reference to milling direction), orientation of specimen in testing machine, location of crack initiation (length measured with reference to a defined position, angle with reference to a defined orientation of the specimen in the original block of material), testing stress range, fatigue life or cycles to end of test.

### 12.2 Graphical presentation

The most common graphical presentation of fatigue test data are the  $S-N$  (stress-life) diagram (see [Figure 11](#)). The dependent variable, fatigue life,  $N$ , in cycles, is plotted on the abscissa as a logarithmic scale. The independent variable, maximum stress, stress range, or stress amplitude, expressed in megapascals (MPa) is plotted on the ordinate, a logarithmic scale or linear scale.



#### Key

X fatigue life,  $N_f$  (log)

Y maximum stress,  $S_{max}$ , MPa (log)

k is the slope of  $S-N$  curve in the region of finite life

Circles alone ( $\bigcirc$ ) and black dots ( $\bullet$ ) correspond to failed specimens and black dots with arrows ( $\bullet \rightarrow$ ) correspond to non-failed specimens at  $10^7$  cycles (run-outs).

**Figure 11 —  $S-N$  curve diagram**

Analysis of  $S-N$  diagram is performed for the purpose of fitting an appropriate mathematical relationship to test data to generate a curve that yields approximately 50 % probability of failure. Typically, the data

exist at a number of stress and represent a continuous single distribution that is log-normal distributed with constant variance as a function of stress. For such a statistical estimation of the S-N curve, please see ISO 12107.

Minimum information to be presented on the S-N diagram should include the designation, specification or proprietary, grade of the material, tensile strength, surface condition of specimen, stress concentration factor of notch when applicable, type of fatigue test, test frequency, environment, test temperature and relative humidity.

## **13 Measurement uncertainty**

### **13.1 General**

Measurement uncertainty analysis is useful for identifying major sources of inconsistencies of measured results.

Product standards and material property databases based on this document have an inherent contribution from measurement uncertainty. It is therefore inappropriate to apply further adjustments for measurement uncertainty and thereby risk failing product which is compliant. For this reason, the estimates of uncertainty derived by following this procedure are for information only.

### **13.2 Test conditions**

The test conditions and limits defined in this document should not be adjusted to take into account measurement uncertainties.

### **13.3 Test results**

The estimated measurement uncertainties should not be combined with measured results to assess compliance to product specifications.

For consideration of uncertainty, see Reference [6] which provide guidance for standard processes for calculating uncertainty for metallic material rotating bar bending fatigue properties.

## **Annex A** (normative)

# **Verification of the bending moment of rotating bar bending fatigue machines**

### **A.1 Verification philosophies for rotating bar bending fatigue machines**

Two approaches to verification of rotating bar bending fatigue machines are in common use. The first method uses dimensional measurement and subsequent calculations; the second a strain-gauged specimen.

This annex specifies verification equipment, pre-verification inspection, verification processes (either dimensional or strain gauge methods), assessment of the verification data and subsequent acceptance criteria.

### **A.2 Verification equipment**

#### **A.2.1 General**

A range of equipment is used to verify the performance of rotating bar bending fatigue machines. Traceable forces are generated by either calibrated masses or calibrated force transducers. Where the test machine incorporates a lever and balance loading arrangement the forces are verified using a combination of both calibrated masses and force transducers. Dimensional measurements are made with calibrated measuring instruments, typically either micrometers and/or measurement callipers.

#### **A.2.2 Masses**

The masses used to apply the forces during the verification shall have an accuracy equal to or better than  $\pm 0,1$  %, verified at least every five years.

#### **A.2.3 Force transducers**

Where a force transducer(s), i.e. force transducer or cells are used to verify applied forces, these shall be calibrated in accordance with ISO 376 and shall be equal to or better than Class 1,0.

#### **A.2.4 Dimensional measurement**

The micrometer(s) or measuring calliper(s) used to establish dimensional measurements from the rotating bending test machine shall have a resolution of at least 0,01 mm and an accuracy of at least 0,03 mm.

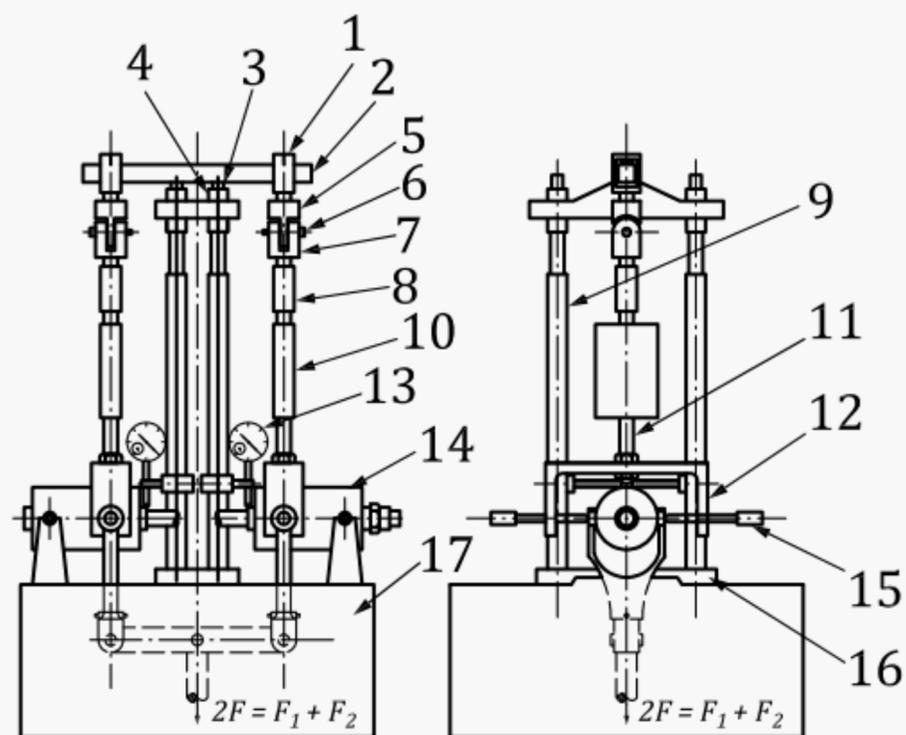
### **A.3 Inspection of the test machine prior to verification**

Prior to verification, the component parts of the machine shall be inspected for wear and replaced if necessary. Any such replacement shall be recorded in the machine maintenance record.

## A.4 Verification procedure — Verification by dimensional measurement

### A.4.1 General

Rotating bar bending fatigue machines can be verified using a combination of dimensional measurements and force measurements. The various lever arms which convert the applied force to an applied moment on the specimen need to have their lengths measured very accurately (see A.4.3). The method of verification of the applied force will be dependent upon the load application system — whether it comes from a series of masses, a steelyard and balance system or a loading system utilizing a force transducer. It can be necessary to utilize test machine specific fixtures, such as are shown in Figure A.1, to verify the applied force.



#### Key

- 1 framing
- 2 arm
- 3 former bearing rod
- 4 knurled nut
- 5 upper knuckle-joint
- 6 pin joint
- 7 lower knuckle-joint
- 8 upper connecting rod
- 9 latter bearing rod
- 10 force proving instrument
- 11 lower connecting rod
- 12 rack
- 13 micrometer
- 14 main axis box
- 15 knurled screw
- 16 frame foundation
- 17 box body

Figure A.1 — Example of calibration force measuring device on four-point bending machine

#### A.4.2 Temperature stabilization

Allow sufficient time for the verification equipment to equilibrate and attain a stable temperature. Record the temperature at the beginning and end of the verification process.

#### A.4.3 Measurement of mean force arm length

Measure, on each side of each arm, the force arm length  $L$  (or  $L_1$  and  $L_2$  in the case of four-point bending machines) using a micrometer or vernier caliper (see [Figures 1 to 7](#) and [A.2](#)). Repeat these measurements three times. Calculate the average value and record as the mean force arm length,  $L$ ; the individual measurements should not vary by more than 5 %. Where the machine applies four-point bending, the measured mean values of  $L_1$  and  $L_2$  shall be within 1 % of each other.



#### Key

A	left end pivot point
B	right end pivot point
C	left loading pivot
D	right loading pivot
$R_A$	left supporting point
$R_B$	right supporting point
$F_1, F_2$	applied forces 1, 2
$L_1, L_2$	force arm lengths

**Figure A.2 — Schematic for moment arm determination — Four-point bending machine**

The mean force arm length(s) are used in conjunction with the formula given in [Table 2](#) for calculating the forces necessary to generate the required test stresses.

#### A.4.4 Measurement of loading arm lever ratio

Some designs of machine incorporate a lever arrangement to magnify the effective load or to invert a downward force into an upward one. Where such levers form part of the test machine, their effective lever ratio shall be determined. This calibration can be achieved by either precise dimensional measurement of the lever arm(s) and pivot distances, or by determination using a force transducer and calibrated masses. The resulting magnification ratio is recorded and is used in all test load calculations.

NOTE Guidance in the use of force transducers for making lever ratio measurements can be found in ISO 7500-2.

#### A.4.5 Calculation of required characteristics — Relative force accuracy error, $q$

##### A.4.5.1 Machines incorporating force transducer(s)

The relative force accuracy error,  $q$ , expressed as a percentage of the mean value,  $F$ , of the true force is given by [Formula \(A.1\)](#):

$$q = \frac{F_i - \bar{F}}{F_i} \times 100 \quad (\text{A.1})$$

where  $F_i$  is the force applied by the test machine to be verified.

##### A.4.5.2 Machines using test masses

The relative force accuracy error,  $q$ , for machines using test masses, is the percentage error reported in the calibration certificate for the test masses.

Where the machine incorporates loading levers,  $q$  is calculated by multiplying the percentage error of the test masses by the lever magnification ratio.

##### A.4.5.3 Machines using steelyard and balance loading

The relative force accuracy error,  $q$ , for steelyard and balance machines comprises two elements. The first of these,  $c$ , relates to the percentage accuracy of the measured mass of the balance weight, obtained from its calibration certificate. The second,  $d$ , relates to the discrimination of the scale on the steelyard (and any vernier on the balance weight).

The smallest discernible mass of the lever and balance system,  $m_e$ , is established by converting 2 mm of displacement on the scale into a corresponding load increment.

Where a force vernier is incorporated into the balance weight, then  $m_e$  is equal to the vernier force increment.

Smallest discernible mass  $m_e$  is converted to input  $d$  for the relative force accuracy error calculation by dividing it by the lowest working test load for the machine, expressed as a percentage.

The two elements  $c$  and  $d$  are combined using [Formula \(A.2\)](#):

$$q = \sqrt{(c^2 + d^2)} \quad (\text{A.2})$$

#### A.4.6 Calculation of required characteristics — Relative force repeatability error, $b$

##### A.4.6.1 Machines incorporating force transducer(s); i.e. force transducer(s)

The relative force repeatability error,  $b$ , for each discrete force is the difference between the maximum and minimum values measured with respect to the mean value of true force. It is given by [Formula \(A.3\)](#):

$$b = \frac{F_{\max} - F_{\min}}{\bar{F}} \times 100 \quad (\text{A.3})$$

##### A.4.6.2 Machines using test masses

The relative force repeatability error,  $b$ , for machines utilizing test masses, is based upon the accuracy of the test masses. This is established by reviewing the calibration certificate for those test masses and establishing their metrological grading. This is then expressed as a percentage of the test mass.

#### A.4.6.3 Machines using steelyard and balance loading

The relative force repeatability error is established by experimentation, based upon the ability of the operators to set the balance weight to a defined position on the steelyard scale. To establish the repeatability error, the machine is set up to incorporate a force measurement system calibrated to ISO 376, Class 1.0, to be used to measure the applied force as indicated by the force transducer system. Each operator sets the machine, five times, to the specified load on the steelyard and a colleague records the resulting applied force. The relative force repeatability error,  $b$ , is the difference between the maximum,  $F_{\max}$ , and minimum,  $F_{\min}$ , values measured with respect to the mean value. It is given by [Formula \(A.3\)](#).

#### A.4.7 Calculation of required characteristics — Relative force arm accuracy error, $q'$

The relative accuracy error,  $q'$ , for the force arm is given by [Formula \(A.4\)](#):

$$q' = \frac{L_s - \bar{L}}{\bar{L}} \times 100 \quad (\text{A.4})$$

where

$L_s$  is the force arm nominal value;

$\bar{L}$  is the mean of the measured force arm length(s).

#### A.4.8 Calculation of required characteristics — Relative moment accuracy error, $q''$

The relative moment accuracy error,  $q''$ , is given by [Formula \(A.5\)](#):

$$q'' = q + q' = \left[ \frac{F_i - \bar{F}}{\bar{F}} + \frac{L_s - \bar{L}}{\bar{L}} \right] \times 100 \quad (\text{A.5})$$

#### A.4.9 Required performance characteristics

The maximum permissible error values are as follows:

- relative force error ( $q$ )  $\pm 1$  %;
- relative force repeatability error ( $b$ ) 1 %;
- relative force arm error ( $q'$ )  $\pm 0,3$  %;
- relative moment error ( $q''$ )  $\pm 1,3$  %.

### A.5 Verification procedure — Verification using strain-gauged specimen

#### A.5.1 General

A second approach to verifying rotating bar bending fatigue machines is to use a strain-gauged specimen similar in design to that used in testing. When preparing such a verification specimen, the critical diameter (greatest stress location) shall be measured prior to the application of strain gauges. A typical verification test piece has two axial strain gauges 180° apart (gauges No.1 and No.2). The technique may also be performed using a verification specimen with only one strain gauge (gauge no. 1). Convert strain gauge outputs to applied force using the elastic modulus of the strain-gauged, test-piece material, the measured critical diameter,  $d$ , and the appropriate formula given in [Table 2](#). From this relationship of applied force and calculated specimen force, the applied force for all subsequent tests can be determined.

## A.5.2 Temperature stabilization

Allow sufficient time for the verification equipment to equilibrate and attain a stable temperature. Record the temperature at the beginning and end of the application of each series of force measurements. Where necessary, apply temperature corrections to the deflections of the proving devices using the formula provided in the ISO 376 calibration certificate for the verification equipment.

## A.5.3 Pre-verification conditioning

In order to ensure the machine is in good working condition, it is necessary to install a strain-gauged specimen and exercise the fatigue test machine and calibration equipment/fixtures three times between the initial force and the maximum force to be verified. After the third application, return the applied force to zero. If the calibration equipment/fixtures incorporate a force-proving device, then reset the output to zero.

## A.5.4 Selection of test forces

Calculate a series of at least five, approximately equally spaced, forces between 20 % of the force range and the full force of the machine or between the minimum and maximum forces to be used.

## A.5.5 Cantilever machines

**A.5.5.1** For the single point loading machines, the use of strain gauges to verify the load application shall be done with the smallest gage size possible to avoid the averaging of the measurement.

**A.5.5.2** Install the strain-gauged specimen in the machine at the motor end, the bending arm end remaining unconnected. Connect the strain gauges to the strain-gauge conditioning box and check for continuity of signal; subsequently, allow the specimen, machine components and electronics to stabilize thermally for 30 min. After this period, zero the electronics and strain gauge output.

**A.5.5.3** Attach the bending arm to the specimen and link to the loading system. Then rotate the strain-gauged specimen until the output from the single gauge (or gauge no. 1 in a sample with two gauges) is a maximum; record the strain gauge output(s). Repeat this process at each applied force condition, rotating the strain-gauged specimen slightly to ensure the maximum bending is measured at each of the applied force conditions.

**A.5.5.4** Force increments are achieved by application of known masses; where force is applied by a “steelyard and balance” system the force increments are achieved by movement of the balance weight along the steelyard.

**A.5.5.5** When the initial force increments cycle is completed, remove the applied forces (but leave the bending arm in place); then repeat the sequence for force increment cycles No. 2 and 3. Upon completion of force increment cycle 3, rotate the strain-gauged specimen approximately 180°. Initiate a second sequence of three force increment cycles, at each measurement maximizing the output from gauge No. 2 or, in the case of a single gauge specimen, maximizing the compressive strain output.

**A.5.5.6** Upon completion of these measurements, remove the loading system and the bending arm; record a final measurement of the strain-gauge output(s). Then convert the recorded strain gauge measurements to applied specimen force using the appropriate formula in [Table 2](#) for this type of test machine, the appropriate elastic modulus,  $E$ , for the strain-gauged specimen, and the measured gauge section diameter,  $d$ , for this specific strain-gauged specimen.

## A.5.6 Four-point bending machines

**A.5.6.1** Carry out an identical process to that set out in [A.5.5](#) for the verification of four-point bending machines, with the exception of initial specimen set-up in the test machine. In this case, install one end of

the strain-gauged specimen in the test machine at the motor end, with the other end remaining free at the non-motor end. Connect the strain gauges to the strain gauge conditioning box and check for continuity of signal; subsequently, allow the specimen, machine components and electronics to thermally stabilize for 30 min. After this period, zero the electronics, as per [A.5.5.2](#).

**A.5.6.2** Connect the non-motor end of the specimen to the test machine, and link everything to the loading system. Now begin the subsequent verification process, including maximizing and recording the strain gauge output at each loading increment as per [A.5.5.3](#) to [A.5.5.5](#). Once all of the data has been recorded for each of the three repeat loading conditions, convert the recorded strain gauge measurements to applied specimen force using the appropriate formula in [Table 2](#) for this type of test machine, the appropriate elastic modulus,  $E$ , for the strain-gauged specimen, and the measured gauge section diameter,  $d$ , for this specific strain-gauged specimen, as per [A.5.5.6](#).

### **A.5.7 Machines verified using a strain-gauged specimen**

The data obtained from the verification process using strain gauges is used to establish the “tare” (minimum specimen force) when the machine has zero applied weight, and the relationship between applied force and specimen force. This relationship is subsequently used to establish the test forces required for specified test stresses, and also to determine the pertinent inputs to the machine classifications set out in [A.5.8](#) and [A.5.9](#).

### **A.5.8 Calculation of required characteristics — Relative force accuracy error, $q$**

#### **A.5.8.1 Machines incorporating force transducer(s)**

The relative force accuracy error,  $q$ , expressed as a percentage of the mean value of the true force,  $F$ , is given by [Formula \(A.1\)](#).

#### **A.5.8.2 Machines using test masses**

The relative force accuracy error,  $q$ , for machines using test masses, is the percentage error reported in the calibration certificate for the test masses, plus the tare error expressed as a percentage of the applied force.

Where the machine incorporates loading levers,  $q$  is calculated by multiplying the percentage error of the test masses by the lever magnification ratio plus the tare error expressed as a percentage of the applied force.

#### **A.5.8.3 Machines using steelyard and balance loading**

The relative force accuracy error,  $q$ , for steelyard and balance machines comprises two elements. The first of these,  $c$ , relates to the percentage accuracy of the measured mass of the balance weight, obtained from its calibration certificate. The second,  $d$ , relates to the discrimination of the scale on the steelyard (and any vernier on the balance weight). There is no tare error on this category of machine, as the steelyard and balance are balanced at zero force.

The smallest discernible mass of the lever and balance system,  $m_e$ , is established by converting 2 mm of displacement on the scale into a corresponding load increment.

Where a force vernier is incorporated into the balance weight, then  $m_e$  is equal to the vernier force increment.

Smallest discernible mass  $m_e$  is converted to input  $d$  for the relative force accuracy error calculation by dividing it by the lowest working test load for the machine, expressed as a percentage.

The two elements  $c$  and  $d$  are combined using [Formula \(A.2\)](#).

## A.5.9 Calculation of required characteristics — Relative force repeatability error, $b$

### A.5.9.1 Machines incorporating force transducer(s); i.e. force transducer(s)

The relative force repeatability error,  $b$ , for each discrete force is the difference between the maximum and minimum values measured with respect to the mean value of true force. It is given by [Formula \(A.3\)](#).

### A.5.9.2 Machines using test masses

The relative force repeatability error,  $b$ , for machines utilizing test masses, is based upon the accuracy of the test masses. This is established by reviewing the calibration certificate for the test masses and establishing their metrological grading. This is then expressed as a percentage of the test mass.

### A.5.9.3 Machines using steelyard and balance loading

The relative force repeatability error is established by experimentation, based upon the ability of the operators to set the balance weight to a defined position on the steelyard scale. To establish the repeatability error, the machine is set up to incorporate a force measurement system calibrated to ISO 376, Class 1,0, to be used to measure the applied force as indicated by the force transducer system. Each operator sets the machine, five times, to the specified load on the steelyard and a colleague records the resulting applied force. The relative force repeatability error,  $b$ , is the difference between the maximum,  $F_{\max}$ , and minimum,  $F_{\min}$ , values measured with respect to the mean value. It is given by [Formula \(A.3\)](#).

## A.5.10 Required performance characteristics

Machines are verified using a strain gauged test-piece, the maximum permissible error values are as follows:

- a) relative force accuracy ( $q$ )  $\pm 1$  %;
- b) relative force repeatability ( $b$ ) 1 %.

## A.6 Verification period

Test machines shall be verified annually or more frequently, as required. As reference value, a period of  $\leq 12$  months can be chosen following recommendations in ISO 7500-2[2].

## Annex B (informative)

### Example of a test report

Analysis of rotating bar bending fatigue testing results is listed in [Table B.1](#).

**Table B.1 — Analysis of rotating bar bending fatigue testing results**

Finished date of the test: Material tested (standardized designation) —Chemical composition; —Heat treatment; —Special specifications; Test Conditions —Method of stressing (the points of load application); —Test machine; —Stress ratio; —Specimen type; —Specimen dimensions; —Test frequency; —Test waveform; —Test temperature; —Temperature of the specimen if self-heating occurs; —Air temperature(maximum and minimum values); —Relative humidity(maximum and minimum values); —Run-out number of the test e.g. $10^6, 10^7, 10^8$ cycles; —Definition of failure; —Deviations from the required conditions during the test.					
Specimen identification	Test temperature °C	Specimen diameter at critical section mm	Maximum stress MPa	Fatigue life $N_f$ cycle	Remark

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