SLOVENSKI STANDARD
SIST EN 3987:2009

01-december-2009

Aeronavtika - Preskusne metode za kovinske materiale - Visokociklịi no utrujanje (HCF) z nespremenljivo amplitudo

Aerospace series - Test methods for metallic materials - Constant amplitude force-controlled high cycle fatigue testing

Luft- und Raumfahrt - Prüfverfahren für metallische Werkstoffe - Schwerlastwechselermüdung (HCF) im kraftgesteuerten Versuch

Série aérospatiale - Méthodes d'essais applicables aux matériaux métalliques - Essais de fatigue mégacyclique en contrainte imposée

Ta slovenski standard je istoveten z: EN 3987:2009

ICS:

49.025.01	Materiali za letalsko in vesoljsko gradnjo na splošno	Materials for aerospace construction in general

SIST EN 3987:2009 **en,de**

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 3987

October 2009

ICS 49.025.01; 49.025.05

English Version

Aerospace series - Test methods for metallic materials - Constant amplitude force-controlled high cycle fatigue testing

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Ref. No. EN 3987:2009: E

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Foreword

This document (EN 3987:2009) has been prepared by the Aerospace and Defence Industries Association of Europe - Standardization (ASD-STAN).

After enquiries and votes carried out in accordance with the rules of this Association, this Standard has received the approval of the National Associations and the Official Services of the member countries of ASD, prior to its presentation to CEN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by April 2010, and conflicting national standards shall be withdrawn at the latest by April 2010.

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1 Scope

This document applies to constant amplitude force-controlled high cycle fatigue (HCF) testing of metallic materials governed by EN Aerospace standards. It defines the mechanical properties that may need to be determined, the equipment, test pieces, methodology of test and presentation of results.

It applies to uniaxially loaded tests carried out on plain or notched test pieces at ambient and elevated temperatures. It is not intended to cover the testing of more complex test pieces, full scale components or structures, although the methodology could well be adopted to provide for such tests.

The purpose of this document is to ensure the compatibility and reproducibility of test results. It does not cover the evaluation or interpretation of results.

2 Normative references

The following referenced documents are indispensable for the application 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.

EN 10002-2:1991, *Metallic materials — Tensile testing — Part 2: Verification of the force measuring system of the tensile testing machine.*

ASTM E 1012, *Standard practice for Verification of test frame and specimen alignment under tensile and compressive axial force application.* [1)]

3 Principle

The uniaxially loaded force-controlled high cycle fatigue test consists of maintaining a test piece at a uniform temperature and subjecting it to a constant force-amplitude waveform. The magnitude of the applied cyclic force affects the development of microscopic plastic strain within the test section, thus determining the fatigue life. A series of such tests allows the relationship between the applied force and the number of cycles to failure to be established.

The fatigue lives generated are typically in the range 10^4 - 10^8 cycles to failure and the test regime is said to be that of high cycle fatigue (HCF).

4 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

4.1
force-control
used to describe tests in which the force acting on a known test section is controlled

4.2
test section
defined as the region of the test piece between the blending fillets into the gripping section, and may be a continuous radius or a parallel sided section

1) Published by: American Society for Testing and Materials (ASTM), 1916 Race Street- Philadelphia PA 19103 USA.

4.3
cycle
defined as the smallest section of the force-time function which is repeated periodically. This is shown for a sinusoidal waveform in Figure 1, together with appropriate nomenclature which further defines the force cycle

4.4
failure
defined as complete separation of the test piece within the test section

5 Symbols and abbreviations

See Table 1.

Table 1 — Definitions and symbols relating to force-controlled fatigue testing

Symbol	Units	Term	Definition
F	kN	Force	The force applied to the test section. Tensive forces are considered to be positive and compressive forces negative.
$F_{max.}$	kN	Maximum force	The highest algebraic value of force applied.
$F_{min.}$	kN	Minimum force	The lowest algebraic value of force applied.
ΔF	kN	Force range	The algebraic difference between the maximum and minimum forces. $(F_{max.} - F_{min.})$
Fa	kN	Force amplitude	Half the algebraic difference between the maximum and minimum forces. $(F_{max.} - F_{min.})/2$
Fm	kN	Mean force	Half the algebraic sum of the maximum and minimum forces. $(F_{max.} + F_{min.})/2$
R		Force Ratio	The algebraic ratio of the minimum force to the maximum force. See Figure 2 for examples of different force ratios. (F min./F max.)
σ	MPa	Stress	The force applied divided by the nominal cross-sectional area. The nominal cross-sectional area is that calculated from measurements taken at ambient temperature, and no account is taken for the change in section as a result of elevated temperatures. The above nomenclature for force also applies to stress, with F replaced by σ.
N		Number of force cycles	The number of cycles applied.
f	Hz	Frequency of cycles	The number of cycles applied per second.
N_f		Endurance or fatigue life	The number of cycles to failure.
K_t		Theoretical stress concentration factor	The ratio of the notch tip stress to net section stress, calculated in accordance with defined elastic theory, to the nominal section stress. NOTE Different methods used in determining K_t may lead to variations in reported values.
σ_N	MPa	Fatigue strength at N cycles	The value of the stress amplitude at a stated stress ratio under which the test piece would have a life of at least N cycles with a stated probability.

6 Test equipment

6.1 Test machine

6.1.1 General

The tests shall be carried out on a tension-compression machine designed for a smooth start-up with no backlash when passing through zero. In order to minimise the risk of buckling of the test piece, the machine should have great lateral rigidity and accurate alignment between the components used to grip the test piece ends.

The machine loading system shall be a controlled system in which the loading of the test piece is servo-controlled. It may be hydraulic or electromechanical.

During elevated temperature tests, the machine load cell should be suitably shielded and/or cooled such that it remains within its temperature operation range.

6.1.2 Test machine calibration

The force measurement system shall be verified at intervals not exceeding one year. The method to be used is that of EN 10002-2 with the following amendment related to the application of test forces, to cover calibration in tension and compression going through zero (clause 5.4.5 of EN 10002-2:1991).

Three series of measurements shall be carried out. Each series shall comprise at least 20 force steps as follows:

— 5 increasing force steps in tension at regular intervals from 20 % to 100 % of the full scale,

— 10 decreasing force steps at regular intervals from 100 % of the full scale in tension down to the full scale in compression,

— 5 increasing force steps at regular intervals from 100 % of the full scale in compression up to zero.

The relative errors of accuracy, repeatability, reversibility and zero shall be within the limits stated for class 1 of EN 10002-2:1991.

During the calibration process, an initial calibration shall be performed prior to adjustment of the test machine, such that the effect of any errors outside of the grade 1.0 requirement can be understood.

NOTE Modern test machines should readily meet this requirement, however if initial errors are present then the calibration period would need to be reviewed accordingly.

6.2 Cycle counting

The number of cycles applied to the test piece shall be recorded such that the resolution is better than 0,1 % of the indicated life.

NOTE A calibrated timer is a desirable adjunct to the cycle counter. When used to indicate total elapsed time to failure, it provides an excellent check against the cycle counter frequency for a fixed waveform frequency.

6.3 Waveform generation and control

The force cycle waveform shall be constant and is to be applied at a fixed frequency throughout the duration of a test programme. The waveform generator in use shall have repeatability such that the variation in force levels between successive cycles is within the calibration tolerance of the test machine as stated in 6.1.2, for the duration of the test with the total variation in the force level within 1 % of the requested value.

Terms have been identified relative to a sinusoidal waveform in Figure 1. Other waveform shapes may require further parameter definition although nomenclature should be retained where possible.

NOTE The waveform frequency will generally be between 10 Hz and 200 Hz. Although higher or lower frequencies may be used, the effect of frequency and waveform shape on fatigue life can be significant.

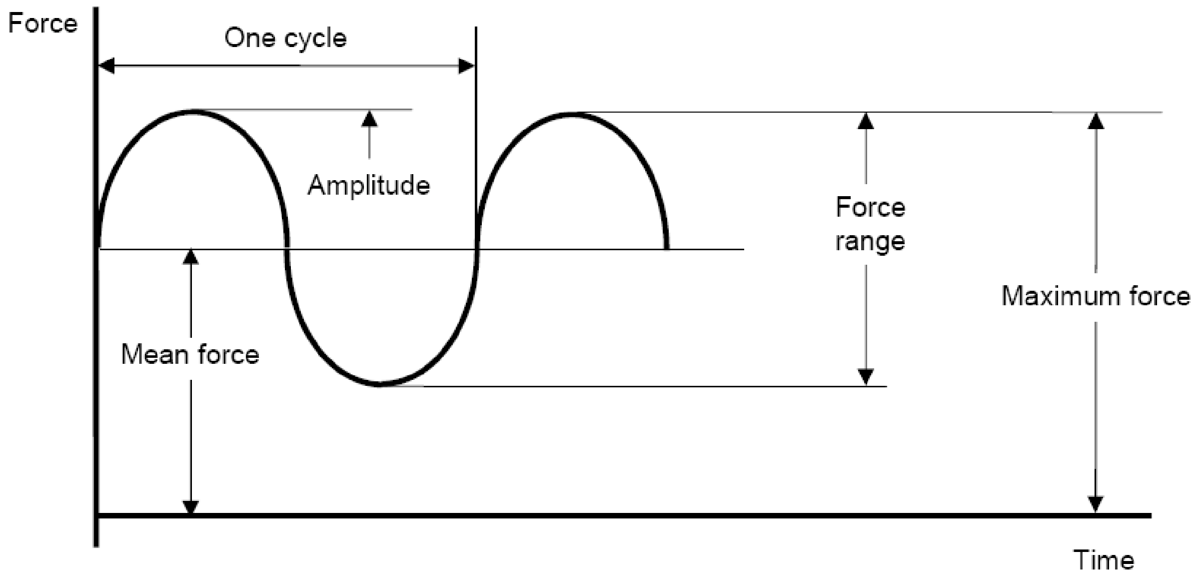

Figure 1 — Fatigue force cycle

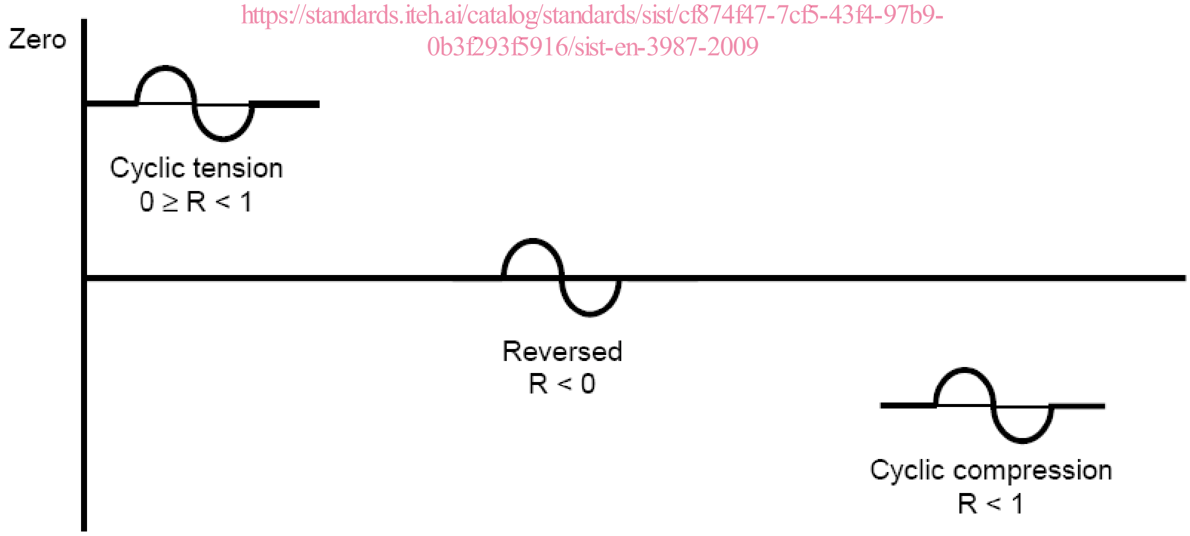

Figure 2 — Varying force ratio

6.4 Test fixtures

6.4.1 General

An important consideration for test piece grips and fixtures is that they can be brought into good alignment consistently from test to test. Good alignment is achieved from very careful attention to design details, i.e. specifying the concentricity and parallelism of critical machined parts.

In order to minimise bending strains the gripping system should be capable of alignment such that the major axis of the test piece coincides closely with the force axis throughout each stress cycle and in the case of tension-compression tests ($R \leq 0$) the gripping system must also be free from backlash effects.

The occurrence of misalignment either due to twist (rotation of the grips) or to a displacement on their axes of symmetry, must be controlled within known limits.

NOTE A parallelism error of less than 0,2 mm/m, and an axial error of less than 0,03 mm for a test space of less than 300 mm, and of less than 0,1 mm for a test space of more than 300 mm, should allow the alignment requirements described in 6.4.2 to be achieved. A further benefit can be realised by minimising the number of mechanical interfaces in the load train and the distance between the machine actuator and crosshead.

6.4.2 Alignment verification

Alignment of the load train assembly shall be checked at intervals not exceeding one year or 100 tests, whichever occurs sooner. In addition, it must be checked following disassembly of the test fixtures, movement of the machine crosshead or following a compressive failure that has caused the two test piece halves to overlap.

It is recommended that the alignment is checked by means of a strain-gauged test piece of geometry identical to that to be tested and that has been manufactured to the same tolerances.

The maximum bending strain determined in accordance with Method 1 of ASTM E 1012 (Standard Practice for the Verification of Alignment Under Tensile Loading) must not exceed 5 % of the mean axial strain induced at the lowest maximum tensile force and the maximum compressive force to be encountered in the test programme. This criterion should be met at each of 4 positions as the test piece is rotated through 90°.

The use of 2 sets of strain gauges in groups of 4, fixed at 90° intervals around the test section is recommended. The gauges should be equally distant from the test piece centre line, 3 of the parallel gauge length apart. Any strains induced into the gauge length due to the gripping mechanism should be minimised to less than 100 με.

The National Physical Laboratories "Code of Practice for the Measurement of Bending in Uniaxial Low Cycle Fatigue Testing" - NPL MMS 001:1995 is recommended as a good detailed best working practice document.

The use of dial gauge indicators in checking alignment should be avoided. When they are used, the tolerances adopted should ensure an equivalent alignment error to that obtained using strain gauges. However, bending induced by an aligned, but off-centred load train will not be detected by this technique.

6.5 Heating device

6.5.1 General

Testing will generally be conducted in air at ambient or elevated temperatures, although there may be a requirement to test in vacuum or in a controlled atmosphere.

Where additional apparatus is used such as furnaces, chambers etc., it is essential that the full force indicated by the force indicator is being applied to the test piece and is not being diverted through the auxiliary apparatus (e.g. by friction).

For elevated temperature tests the heating device employed shall be such that the test piece can be uniformly heated to the specified temperature, and an indicated temperature gradient along the test section of less than or equal to 4 °C maintained for the duration of the test.

NOTE A resistance furnace with three control zones is recommended. If a direct induction heating system is used, it is advisable to select a generator of medium frequency (f ≤ 100 kHz) to achieve minimal radial thermal gradient in the test piece.

6.5.2 Verification of temperature uniformity

The uniformity of temperature along the test section shall be verified before every series of tests that introduces a new test piece geometry or test temperature, or in which the cooling, fixturing or heating device mounting arrangement are adjusted.

This verification may be made by means of a dummy test piece of identical geometry to that to be tested, equipped with several thermocouples fixed along and around its test section. The thermocouples should be suitably screened from direct radiant heat from the heating device.

The variation in indicated temperature anywhere on the test section must not exceed 4 °C.

Where temperature uniformity cannot be assured by this technique, for example where it is not possible to correctly position the heating device repeatedly, then an adequate number of temperature sensors must be employed during each test to ensure that the variation in indicated temperature anywhere on the test section does not exceed 4 °C.

6.6 Temperature measurement

The temperature measuring system comprising sensors and readout equipment shall be capable of operating continuously for the duration of the test and have a resolution of at least 1 °C and an accuracy of ± 2 °C. It must be verified over the working temperature range, traceable to National Standards by a documented method.

The use of thermocouples is recommended. Annex A describes their method of use.

The permitted deviations due to instability between the specified test temperature, and the indicated temperature measured at the surface of the test section, are as indicated in Table 2.

Table 2 — Permitted deviations between indicated temperature and specified test temperature

Test temperature	Tolerance
θ ≤ 600 °C	± 2 °C
600 °C < θ ≤ 800 °C	± 3 °C
800 °C < θ ≤ 1 200 °C	± 5 °C

NOTE 1 For ambient temperature tests (10 °C to 35 °C) it is not necessary to measure the test piece temperature.

NOTE 2 The effect of compounding errors could result in the real tolerance in temperature from the specified level to be 3 °C greater.

NOTE 3 The temperature rise due to plastic deformation shall be minimised (see 8.3.1) and shall be compensated for within the Table 2 tolerances.