BS ISO 12110-1:2013

BSI Standards Publication

Metallic materials — Fatigue testing — Variable amplitude fatigue testing

Part 1: General principles, test method and reporting requirements

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National foreword

This British Standard is the UK implementation of ISO 12110-1:2013.

The UK participation in its preparation was entrusted to Technical Committee ISE/101/6, Fatigue testing of metals and metal matrix composites.

A list of organizations represented on this committee can be obtained on request to its secretary.

ISBN 978 0 580 69935 1

ICS 77.040.10

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 July 2013.

Amendments issued since publication

Date	Text affected

INTERNATIONAL STANDARD

ISO 12110-1

First edition
2013-07-01

Metallic materials — Fatigue testing — Variable amplitude fatigue testing —

Part 1:
General principles, test method and reporting requirements

Matériaux métalliques — Essais de fatigue — Essais sous amplitude variable —

Partie 1: Principes généraux, méthode d'essai et exigences sur le rapport d'essai

Reference number
ISO 12110-1:2013(E)

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Web www.iso.org

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. www.iso.org/directives

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The committee responsible for this document is ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 5, *Fatigue testing*.

ISO 12110 consists of the following parts, under the general title *Metallic materials — Fatigue testing — Variable amplitude fatigue testing*:

- *Part 1: General principles, test method and reporting requirements*
- *Part 2: Cycle counting and related data reduction methods*

Metallic materials — Fatigue testing — Variable amplitude fatigue testing —

Part 1:
General principles, test method and reporting requirements

1 Scope

This part of ISO 12110 establishes general principles for fatigue testing of laboratory specimens under a sequence of cycles the amplitude of which varies from cycle to cycle.

This sequence of cycles is called loading time history (see 3.7) and is usually derived from loading measurements performed on components or structures submitted to true service loadings.

Detailed description of service loads recording is relevant to each laboratory or industrial sector and is therefore outside the scope of this part of ISO 12110.

The aim of the two parts of ISO 12110 is to set requirements and give some guidance on how to perform a variable amplitude fatigue test in order to produce consistent results for comparison purposes taking into account the typical scatter of fatigue data. Achieving this should help designers to correlate models and experimental data obtained from various sources.

Since this part of ISO 12110 involves mainly loading time histories and control signal generation, one expects it might be applied to strain or fatigue crack growth rate controlled loading conditions as well as to force-controlled loading conditions. This is theoretically true but precautions may be taken when applying this part of ISO 12110 to loading modes other than force-controlled loading mode.

This part of ISO 12110 relates to variable amplitude loading under force control mode which corresponds to most of the variable amplitude fatigue tests performed worldwide at the date of publication of this part of ISO 12110.

This part of ISO 12110 applies to the single actuator loading mode which corresponds to uniaxial loading in many cases.

The variable amplitude loading time histories referred in this part of ISO 12110 are deterministic; that is why this part of ISO 12110 deals with variable amplitude loading instead of random loading.

The following issues are not within the scope of this part of ISO 12110 and therefore will not be addressed.

— constant amplitude tests with isolated overloads or underloads;

— tests on large components or structures;

— environmental effects like corrosion, creep linked to temperature/time interactions leading to frequency and waveform effects;

— multiaxial loading.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 1099, *Metallic materials — Fatigue testing — Axial force-controlled method*

ISO 12106, *Metallic materials — Fatigue testing — Axial-strain-controlled method*

ISO 12107, *Metallic materials — Fatigue testing — Statistical planning and analysis of data*

ISO 12108, *Metallic materials — Fatigue testing — Fatigue crack growth method*

ISO 23788, *Metallic materials — Verification of the alignment of fatigue testing machines*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 1099, ISO 12106, ISO 12107, and ISO 12108 and the following apply.

3.1
cumulative frequency diagram
histogram showing the cumulative occurrence of each cycle since the beginning of the test

Note 1 to entry: The cumulative frequency diagram is also called cumulative spectrum or cumulative distribution.

3.2
cycle
smallest segment of the force-time, stress-time, or strain-time, or another signal that is applied to the specimen, which is repeated periodically under constant amplitude fatigue loading

Note 1 to entry: In variable amplitude loading, the definition of cycle varies with the counting method used.

3.3
cycle counting method
method to count the number of cycles of a loading time history of a given length

3.4
loading
generic term designating varying force, strain, or any other controlling variable applied to a specimen

Note 1 to entry: The present standard refers mostly to controlled force loading mode.

3.5
loading distribution
simple or cumulative distribution of load cycle ranges

Note 1 to entry: The loading distribution is the result of a statistical treatment of a record of true service loading or is a typical distribution specific to an industrial sector (e.g. automotive, aerospace). Loading distribution applies for load/stress control mode as well as strain control mode and other loading modes.

Note 2 to entry: The loading distribution is often called “loading spectrum”. Nevertheless, the word spectrum shall be avoided since it means a loading description in the frequency domain.

3.6
loading histogram
simple or cumulative histogram of load cycle ranges

Note 1 to entry: The loading histogram is the result of a statistical treatment of a record of true service loading or is a typical distribution specific to an industrial sector (e.g. automotive, aerospace). Loading histogram applies for load/stress control mode as well as strain control mode and other loading modes.

Note 2 to entry: The loading histogram is often called “loading spectrum”. Nevertheless, the word spectrum shall be avoided since it means a loading description in the frequency domain.

3.7
loading time history
sequence of load cycles the amplitude of which varies from one cycle to the next

Note 1 to entry: The loading time history is a record of true service loading or is a typical sequence specific to an industrial sector (e.g. automotive, aerospace). Loading time history applies for load/stress control mode as well as strain control mode and other loading modes.

Note 2 to entry: In force-controlled loading mode, the term "force history" should have been used but this is not common within the variable amplitude fatigue community. "Loading time history" is always used whatever the controlling variable including force.

3.8
loading power spectrum
energy density spectrum
description of a random loading time history in the frequency domain

Note 1 to entry: The power spectrum is a Fourier integral of the time signal correlation function.

3.9
omission
eliminating of non-damaging cycles or cycles with amplitude less than the omission level

3.10
omission level
cutoff level for eliminating non-damaging cycles

3.11
peak
point at which the first derivative of the load-time history changes from a positive to a negative sign

Note 1 to entry: For a constant amplitude loading, the peak corresponds to the maximum loading. For variable amplitude loading, the peak corresponds to a local maximum load in the load-time history.

3.12
random draw
sequence of half cycles with different ranges and mean values

3.13
valley
part at which the first derivative of the load-time history changes from a negative to a positive sign

Note 1 to entry: The valley is a relative minimum or "trough".

Note 2 to entry: The valley is the point of minimum load in constant amplitude loading.

3.14
variable amplitude loading
loading mode in which all the peak or valley loads are not equal or both

Note 1 to entry: It is also called "irregular loading".

Note 2 to entry: The term "spectrum loading" is incorrectly employed instead of variable amplitude loading. It should be avoided since a spectrum is a loading description in the frequency domain, not a load versus time function.

4 Principle of test

4.1 Control signal generation

In most cases, the original loading time history cannot be directly applied to the specimen without any simplification since it is too difficult to derive any cycle number or cycles to failure from it and to control the fatigue testing machine effectively directly from it.

In addition, real loading time history records applied to the specimen whatever their number will never be representative of the true loading which can be only derived from a thorough statistical evaluation of the loading signal. Those statistical characteristics are determined from a very large number of true loading measurements.

Thus, the original loading time history needs to be simplified. This is usually done by signal analysis loading to two kinds of modelled loading control signals. These two kinds of modelled control signals are obtained by programmed blocks or signal reconstruction from random draw in a transition matrix.

Original loading time history without any simplification can be applied to the specimen if the testing machine and related electronics can do so.

In these cases, the analysis of the original signal is performed using a method called cycle counting.

The data obtained from cycle counting is then used to build a cumulative frequency diagram for block programming or a transition matrix for random draw.

NOTE 1 The main advantage of programmed blocks is that the control signal consists of a series of blocks of constant amplitude, which varies from one block to another. Hence, sophisticated digital control signal generation by computer is not needed.

NOTE 2 Whatever the complexity of the control signal reconstructed by random draw from a transition matrix, it remains much more representative of the real loading than programmed blocks derived from the same real loading. In addition, control signal generation through random draw has been made easier and easier over the last decades due to the spectacular improvement of digital electronics and computers.

Sometimes, filtering of signals is necessary for the following reasons.

a) The original signal obtained from direct measurement on components loaded in service is often polluted by electronic noise or other undesirable vibrations which are not caused by the fatigue process. Those disturbing vibrations have to be eliminated before applying the cycle counting procedure to the original signal.

b) An omission may be carried out to eliminate the non-damaging cycles (smallest cycles) from the control signal obtained from block programming or random draw to significantly reduce the test duration when results are needed quickly since those non-damaging cycles are generally the most numerous ones (see 8.3).

However, filtering shall be performed with great caution by choosing the most relevant filtering parameters. Inadequate filtering may lead to neglecting significantly damaging fatigue cycles.

Care shall be taken as well when considering mean stresses, residual stress effects, isolated very high amplitude overloads, etc.

NOTE 3 When the loading time history presents high isolated stress amplitudes, these high isolated stress amplitudes can actually increase fatigue life due to the beneficial residual stresses they cause.

4.2 Overview of test procedure

The variable amplitude fatigue test consists in loading the specimen using the control signal obtained from a cumulative frequency diagram (programmed blocks) or random draw.

The specimen's response is monitored through measurements given by load cell or force transducer or extensometry. These output data are used for closed loop control.

NOTE Variable amplitude fatigue testing usually uses servo-hydraulic test facilities, but the usage of other actuators is possible in the case of a closed loop controlled test.

When the specimen fails either by breaking in two parts or by reaching another failure criterion, the test results are reported. The test results may include the number of cycles or sequences to failure, crack propagation measurements, or any another specimen damage process data.

The test principle is summarized in the flow chart presented in Figure 1. Details about the main steps of the test are reported in the following sections of the present standard.

5 Original loading time history

5.1 General

The original component or structure loading time history comes from two sources.

a) The first source is direct measurement of in-service component or structure loading. To make these direct measurements, components and structures are instrumented with strain gauges or other sensing devices and digital data acquisition systems perform the recording and storage of the measurements.

   NOTE Car wheels, suspension systems, railway bogies, turbine blades, aircraft wing spars are typical components which experience fatigue loads.

b) The second source is standardized loading time history typical of an industrial sector. Its significance is generally acknowledged by most of those involved in the relevant industrial sector.

The original loading time history often consists in repeating a loading sequence of a given length (time or number of cycles) which remains the same. Only very slight changes may be observed from a sequence to the next.

In the case of original loading time history determined from direct measurement of in-service component loading, filtering may be necessary to eliminate electronic or mechanical noise. However, filtering parameters shall be set with caution to avoid elimination of significant damaging fatigue cycles.

The mean stress modulated filtering method may be used (see 8.3).

5.2 Data filtering

5.2.1 General

Efficient data filtering may reduce drastically the amount of data to be used to produce a variable amplitude fatigue control signal.

However, filtering generally involves a critical or threshold value of the load or load amplitude which has to be set.

The critical or threshold value shall be chosen taking into account the available knowledge and experience of the fatigue process under study and especially avoiding neglecting true damaging cycles which play a major role in the fatigue damaging process of the specimen or component involved.

5.2.2 Noise filtering

It consists in neglecting generally high frequency and low amplitude peaks superimposed to the fatigue loading signal which do not contribute to the fatigue process, e.g. electronic noise produced by the data recording systems (strain gages). If noise filtering is performed according to an ISO or a national standard, the standard shall be mentioned in the test report for each individual specimen.

6 Loading time history description

6.1 General

Loading time histories time can be described in one of three ways:

- time history sequences;
- cycle counts;
- power or energy density spectrum.

6.2 Time history sequences description

Variable amplitude loading can be grouped into discontinuous or partially continuous random processes. The knowledge of these random processes can be determined by service measurements or time step computation.

Short-term loading time history can be represented by a continuous force versus time signal, but long-term histories require a representation by a series of short-term sequences (see Figure 2), each of them being generally continuous. The long-term history is obtained by joining the short-term sequences in the correct order.

6.3 Cycle counting description

The loading time history can be represented by a series of number of cycle ranges. In such case, the order of appearance of the cycles is lost.

The original loading time history is processed through a cycle counting procedure which is intended to summarize the original signal by defining cycles and number of cycles at any time of the fatigue life. This procedure allows for the definition of a number of cycles to failure of the component in the same way as for constant amplitude loading conditions.

There are different cycle counting methods. All methods are based on the partition of the whole load range (between the lowest minimum and the highest maximum) into levels or classes. 32 load levels are mostly sufficient (see Figure 2).

NOTE 1 General industrial practices adopt 64 load levels.

NOTE 2 Some of the most common cycle counting methods are:

- level crossing counting;
- peak counting;
- simple range counting;
- range pair counting;
- “rainflow” counting.

The counting methods and how to use them are the subject of ISO 12110-2.

When the original loading time history is fully processed through the relevant counting method, one of the following routes in two steps is followed:

a) determination of the cumulative frequency diagram and building programmed blocks;

b) determination of the transition matrix and reconstruction of the loading time history by random draw.

Since the fatigue life under a programmed block sequence is sometimes much different from that under a random service load sequence, the use of block programming is decreasing and should be avoided whenever possible.

7 Programmed blocks

Programmed blocks are derived from the cumulative frequency diagram.

The cumulative frequency diagram corresponds to the cumulative probability of load expressed in terms of load exceedances versus the number of cycles. This is a smooth continuous curve (see Figure 3).

The cumulative frequency diagram is then simplified into a diagram of discrete bins. The load division should be done in a damage-equivalent way. The load level of the first bin is defined as being equal to the maximum load of the loading time history. For the other bins, load levels are defined as being equal to the mean value.

Such bins of constant amplitude loading are also called blocks (see Figure 4).

Generally, 8 to 10 blocks in a sequence are sufficient to give a good description of the cumulative frequency diagram not exceeding 10^6 cycles. The blocks are taken from the cumulative frequency diagram to build loading sequences such as that shown in Figure 5.

The load division should be done in a damage-equivalent way. That means the areas A and B should be equal, see Figure 4. All loads within a bin are defined as being equal to the mean value.

The order of appearance of blocks may have a great influence on the fatigue life in fatigue tests carried out with few blocks.

For instance, for a fatigue test consisting in two blocks only, the fatigue life is lower if the greater amplitude block is applied first than if the lower amplitude one is applied first. It is highly recommended to repeat the sequence at least 20 times to reduce the block order appearance on the fatigue life

The process of setting-up the blocks to design a loading sequence is generally called block programming. Such programmed blocks are easy to generate by a testing machine controller since each block consists in constant amplitude loading. No sophisticated real-time computer-control systems are needed to run programmed blocks.

Cumulative frequency diagrams are typical of the true loading pattern of the real component or structure. Some examples are shown in Figure 6. Load distribution “a” represents constant amplitude loading at maximum load. Load distribution “d” represents Gaussian normal distribution of loads (zero load at expected maximum of load exceedances, e.g. 10^6).

Load distributions shown in Figure 6 are examples of non-Gaussian loading distributions in which high relative frequencies correspond to high loads. This is typical of highly loaded structures such as cranes, lifting rolling bridges, etc.

8 Transition matrix and generation of control signal from the matrix

8.1 Establishment of the matrix

The alternative way of conducting variable amplitude fatigue tests is by the means of a reconstructed control signal from random draw in a transition matrix.

The transition matrix is established from the load levels or classes that were already defined in the cycle counting process. The number of transitions from one relative extreme value to the following one is reported in the matrix.

For instance, the number of transitions a_{ij} from level i to level j is reported in the matrix at the intersection of line i and column j.

If the transition is from a relative maximum value in class i to a relative minimum in class j ($i > j$) (peak to valley), the transition a_{ij} is reported below the matrix diagonal (see Figure 7). The values a_{ij} in the diagonal should be zero or very close to zero since transitions from level i to within the same level i occur very seldomly. If such a transition in the same class occurs more frequently, the original signal shall be re-divided into a greater number of narrower classes. This will increase the precision of signal modelling.

The counting of transitions i to j is performed over a large number of cycles, typically 10^8 cycles. Since the definition of classes or levels and the counting of occurrences depend on the counting method which has been used previously, the content of the transition matrix depends on the cycle counting method. For instance, if the rainflow counting method had been used, a rainflow transition matrix is established.

In fact, if the original loading time history is digitally analysed using computer techniques, cycle counting and transition matrix construction are performed simultaneously.

When the transition matrix is completely filled with the number of transitions, the construction is completed. Then, the control signal that will be used for loading the specimen is reconstructed by random draw of transitions in the matrix.

8.2 Reconstruction of the loading signal

8.2.1 From the transition matrix

The following procedure is used to reconstruct the loading signal by random draw of the transitions in the matrix. In fact, only some draws are truly random but not all because discontinuities shall be avoided in the reconstructed signal and every upward transition shall be followed by a downward one and vice-versa (upward and downward transitions shall alternate).

The value of i is drawn by random, for instance $i = \alpha$. Then j shall be within $\alpha < j \leq n$. By random draw within this interval [j, β], the first transition is then $a_{\alpha\beta}$. To avoid discontinuities and to generate a downward transition following the first upward one, the next transition shall be $a_{\beta j}$ and j shall be within $1 \leq j < \beta$.

By random draw within this interval, $j = \lambda$, and the second transition is $a_{\beta\lambda}$ which is downward ($\beta > \lambda$).

For the same reasons, the third transition shall be $a_{\lambda j}$ with $\lambda < j \leq n$. By random draw within this interval [j, δ], the third transition $a_{j\delta}$ is upward ($\lambda < \delta$).

An example of a random draw is given in Annex B.

NOTE In particular cases, a constraint can be fixed on the acceptable maximum difference between two following transitions (1/2 cycles) to prevent non-representative cycles.

8.2.2 From energy density spectrum

From an energy density spectrum, various procedures can be applied to reconstruct the loading signal. For each, the important point is to verify that the generated time signal energy is equal to the spectrum energy. As an example, the following procedure can be applied.

Noting that S is the total area (total energy) of the energy density spectrum $E(\omega)$, a series of equally distributed ω_i is selected covering the full range of the spectrum ω. Their number is N. The interval between two successive ω_i is $\Delta\omega$.

The loading signal can be written:

$$F(t)=\alpha\sum_{1}^{N}A_i\sin\left(i\,\Delta\omega\,t+\psi_i\right) \tag{1}$$

where

A_i is the component amplitude equal to $[\Delta\omega\,E(\omega_i)]^{1/2}$;

Ψ_i is the random phase obtained by a random draw from an uniform distribution;

α is the total energy adjusting factor so that:

$$\alpha^2\sum_{1}^{N}\frac{1}{2}A_i{}^2=S \tag{2}$$

8.3 Control signal simplification

8.3.1 General

Although the reconstructed control signal is a simplified modelling of the average true loading experienced by the component, it remains usually a complex signal.

In many cases, the lowest amplitude cycles may be neglected provided a cutoff load level is defined. Then any cycles whose amplitude is less than the load level cutoff can be eliminated. This operation consists in filtering either the original signal or the reconstructed one or both.

It has been observed that those variable amplitude cycles, whose amplitudes are less than the load level cutoff, can produce damage in some materials. Therefore, test results shall clearly document when and how low amplitude cycles have been eliminated from the loading signal.

Since the so-called non-damaging smaller cycles are the most numerous ones (low amplitude vibrations), this kind of filtering leads to an even simpler control signal and, hence, to an easier fatigue testing procedure.

However, filtering may be dangerous if performed incorrectly: the higher the cutoff level, the simpler is the resulting control signal but higher is the risk of neglecting actually damaging cycles leading to an overestimation of the fatigue life of the component under investigation.

8.3.2 Neglecting small amplitude cycles

Small amplitude cycles, the amplitude of which is under a fixed threshold, are considered as non-damaging and, hence, do not contribute to the fatigue process and can be neglected.

A mean stress-modulated filtering method may be selected as a convenient way of eliminating small amplitude cycles.

9 Conducting fatigue testing under variable amplitude conditions

The specimen is submitted to a control signal which is either a sequence of programmed blocks (see Clause 7) or a sequence of transitions taken from pseudo-random draw out of the transition matrix (see Clause 8) or loading time history sequence.

A force-controlled variable amplitude test should be conducted in accordance with the present Part 1 and Part 2 on cycle counting techniques (ISO 12110-2) if necessary and in accordance with ISO 1099.

Load train alignment, load cell features, controlling and monitoring systems, closed loop control accuracy, and the whole test configuration shall comply with the requirements reported in ISO 23788 unless otherwise agreed.

For a given variable amplitude signal with its own frequency or frequency range, it shall be ensured that the test configuration is suitable for this signal. If not, the specimen, grips, load cell, and/or any component used for the test shall be modified to accommodate the frequency, amplitude, and all other characteristics of the signal.

All test conditions deviating from ISO 1099 shall be mentioned in the test report.

If another loading mode is envisaged, the relevant ISO or national standard shall be referred to.

If a computer is used for test control and data acquisition, its presence shall not prevent the whole testing setup from being in accordance with the appropriate requirements of ISO 1099 or the relevant testing standard if another loading mode is envisaged.

The failure criterion, i.e. critical crack with a depth of $a = x$ mm and surface length of $l = y$ mm, or total fracture of the specimens in two parts, or stiffness loss of z %, should be defined.

10 Test report for each individual specimen

10.1 General

In addition to the data required by the relevant ISO or national standard, the test report of a variable amplitude fatigue test shall include the following items:

a) original loading description (as set out in 10.2);

b) testing conditions (as set out in 10.3);

c) failure data;

d) any changes in the test setup to accommodate the signal characteristics (see 10.4);

e) the standard used to perform noise filtering, if this is performed (see 5.2.2).

10.2 Original loading description

The description of the original loading shall include:

a) a full description of the original loading time history;

b) the exact name and references of the standard loading time history if a standardized loading time history is chosen (see Annex A);

c) a thorough description of the measurement procedure used as well as the related conditions in the case of an in-line service loading of a real component. All exceptional events (e.g. high overloads or low underloads) shall be reported.

10.3 Testing conditions

10.3.1 General

Any material or component characterization may be modelled from a variable amplitude fatigue test plan. Statistical aspects should be considered when assessing material or component behaviour.

The testing conditions listed in 10.3.2 to 10.3.4 shall be covered in the test report.

10.3.2 Sampling

The sampling procedure shall include:

a) material sampling procedure;

b) specimen geometry and associated instrumentation according to the relevant ISO or national standards.

10.3.3 Signal generation

The procedure on how to generate the signal shall be described according to the following relevant items:

a) if the signal analysis is performed on a filtered original signal, the filtering conditions and parameters shall be reported;

b) the maximum and minimum loads, the number and height of classes or levels;

c) the mean loads associated to the defined data in b) above;

d) the cycle counting method used and the reasons explaining the choice;

e) the route followed: programmed blocks or transition matrix and the reasons explaining the choice;

f) a description of the cumulative loading diagram (Gaussian);

g) the number, width, and level of the blocks and the method used to set them (when programmed blocks are used);

h) the establishment of the sequence of programmed blocks (when programmed blocks are used);

i) the transition matrix (when transition matrix is used);

j) the random draw process (when transition matrix is used);

k) the reconstructed control signal from random draw in the transition matrix (when transition matrix is used);

l) the random draw process (when energy density spectrum is used);

m) the filtering criteria to eliminate non-damaging cycles (omission level).

10.3.4 Test operation

The procedure on how to operate the test shall include the following:

a) alignment and calibration check data according to ISO 1099 or the relevant ISO or national standard if a loading mode other than force control mode is used;

b) fatigue testing conditions according to ISO 1099 or the relevant ISO or national standard if a loading mode other than force control mode is used;

c) all relevant information about the software used for load control of the testing machine;

d) measurement of the quality of the control closed loop:

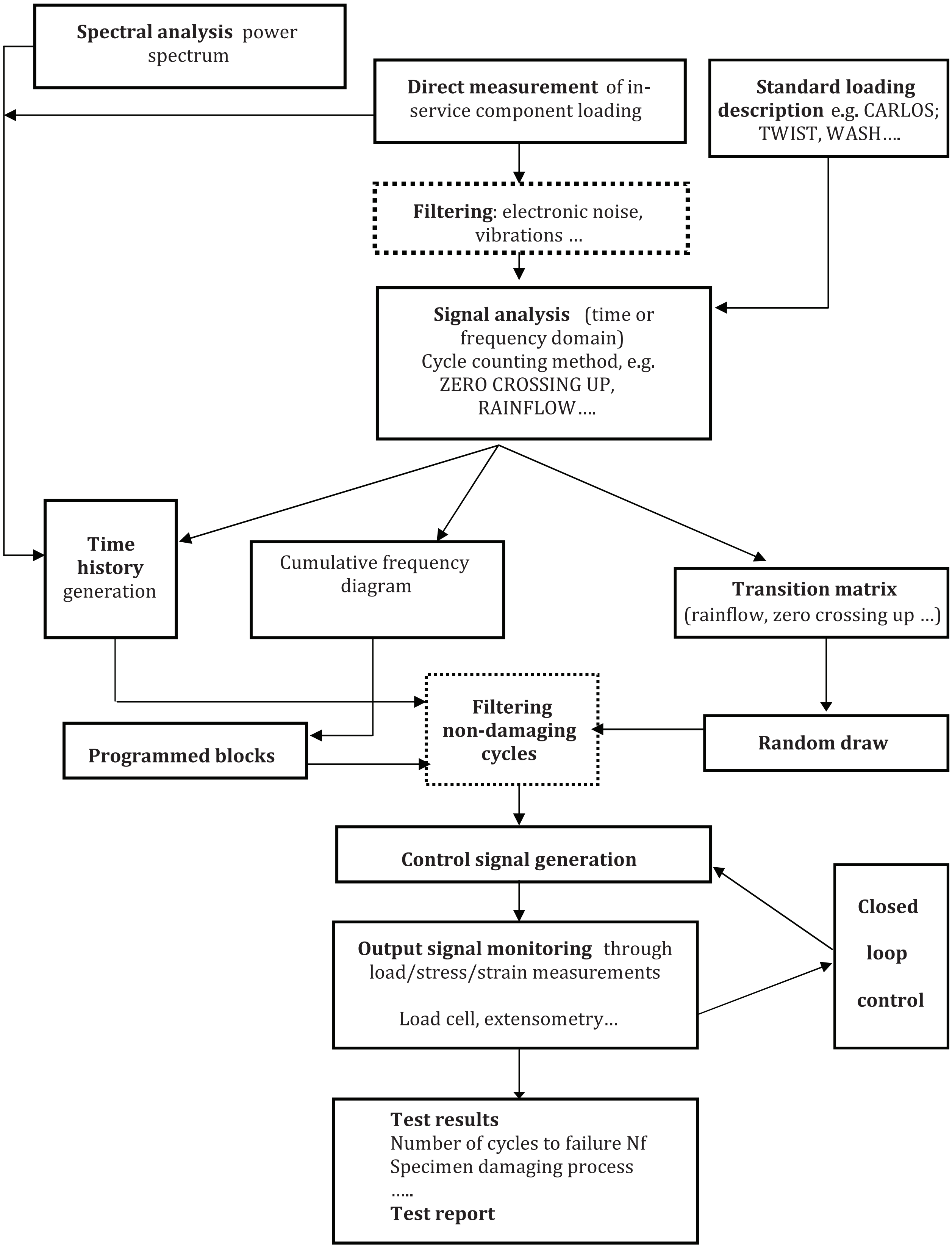
  - error (expressed in %) between command and measured signals at the maximum load of the sequence;
  - comparison of cumulative loading diagrams, and transition matrices of command and measured signals;
  - calculation of a damage sum, D, for the input command and the measured output signals employing an S-log N curve of the material at R = -1 constant amplitude conditions and compare the subsequent difference;

e) any deviation from ISO 1099.

10.4 Preliminary analysis of test data for each specimen and for a series of specimens

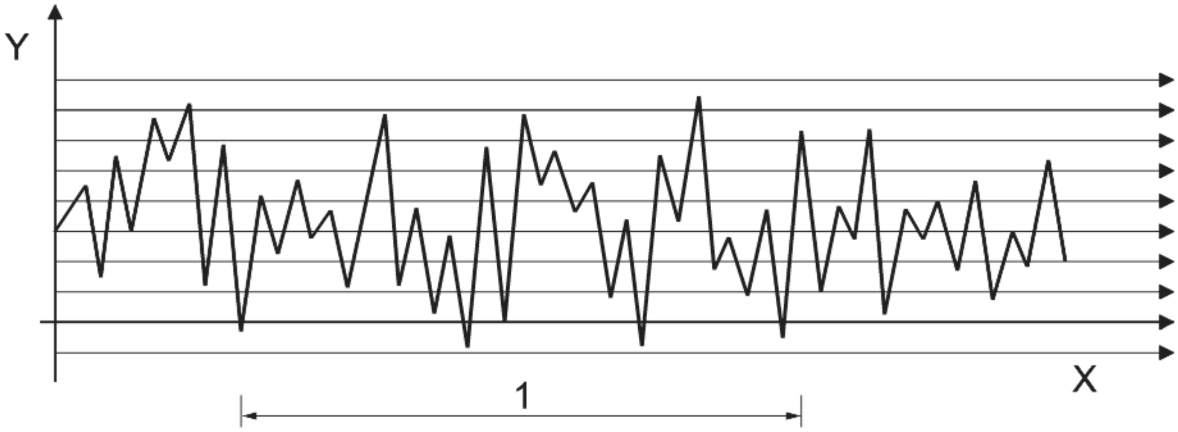
See Annex C.

All changes of the test setup (including specimen) to accommodate the signal characteristics (including frequency) shall be mentioned in the test report.



Dashed boxes: optional steps

Figure 1 — Flow chart for collecting variable amplitude loading data and conversion of it into input data to conduct a laboratory variable amplitude fatigue test



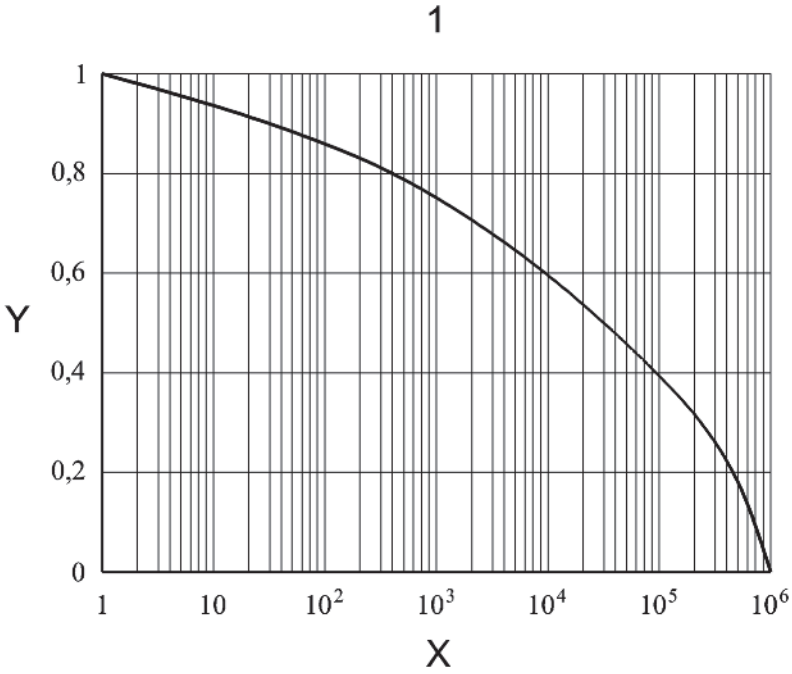
Key

X time

Y load

1 loading sequence

Figure 2 — Load versus time history



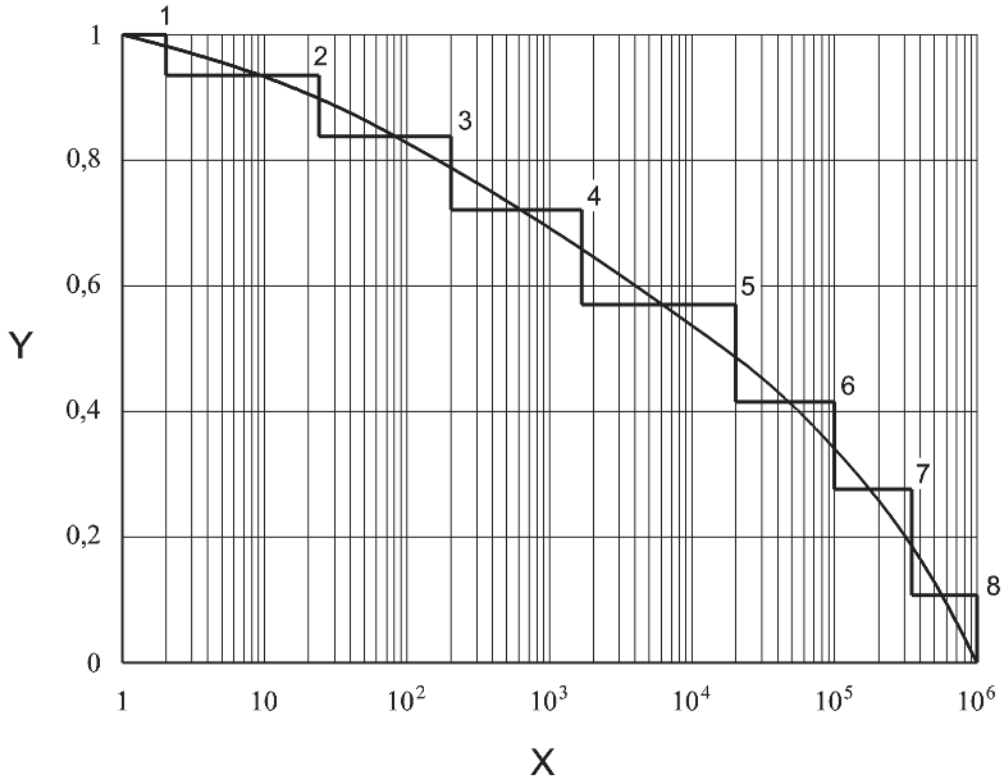
Key

1 Gaussian normal distribution

X cycles

Y unified stress range

Figure 3 — Example of a cumulative loading diagram

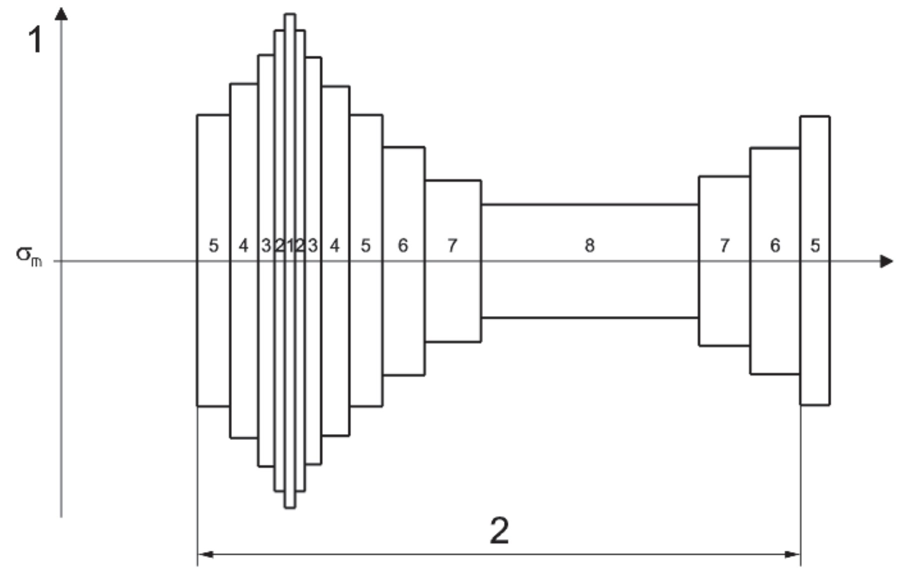


Key

X	cumulated cycles
Y	unified stress range

NOTE Such blocking permits Palmgren-Miner summation.

Figure 4 — Block modelling of the cumulative loading diagram

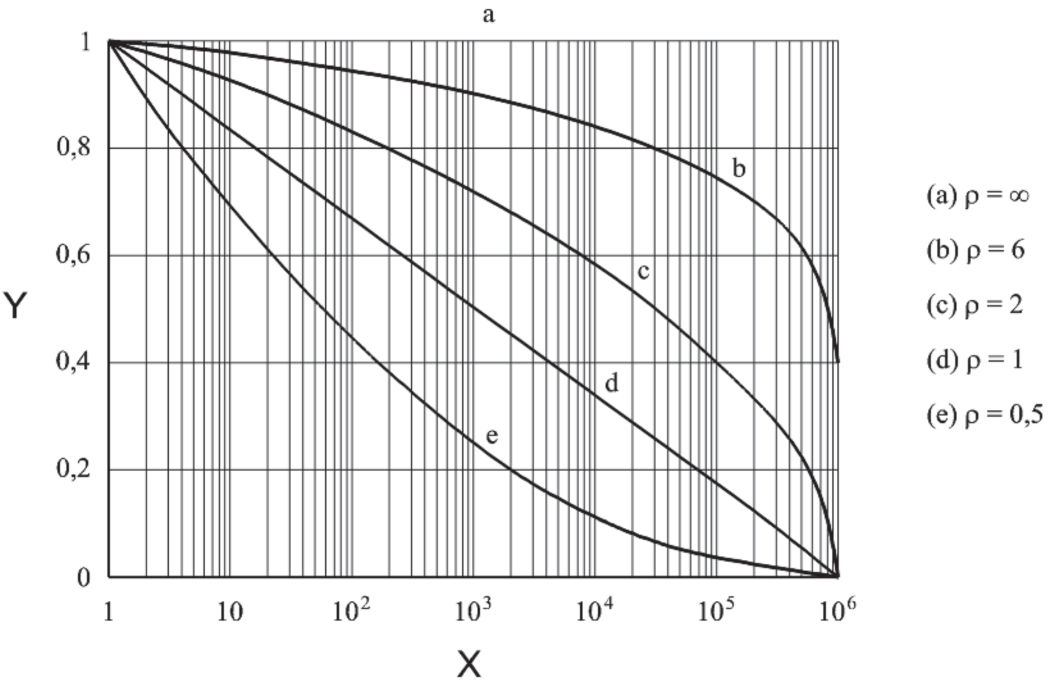


Key

1 stress

2 one sequence

Figure 5 — Gassner's eight-step blocked programme sequence with 500 000 cycles



Key

X cumulated cycles, N_c

Y unified stress range

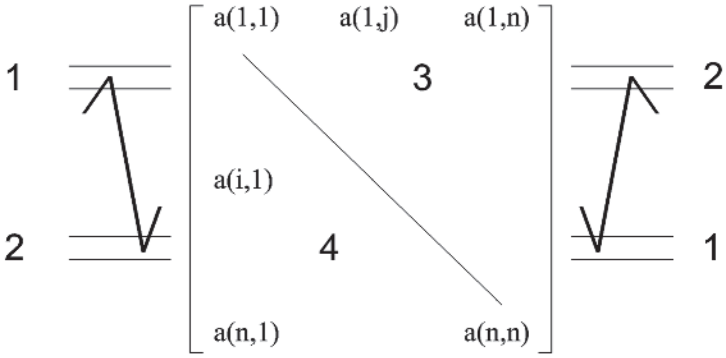
Figure 6 — Examples of different load distribution functions

$$X = \left(N_{\text{tot}}\right)^{1-Y^{\rho}} \tag{3}$$

X = cumulative cycles

N_{tot} = total cumulative cycles

Y = unified load amplitude (maximum load corresponds to 1)



Key

1 stress level, *i*

2 stress level, *j*

3 transition from min to max, *i* < *j*

4 transition from max to min, *i* > *j*

Figure 7 — Transition matrix

Annex A
(informative)

Standard loading time histories

Standard loading time histories used in some industrial sectors are reported in Table A.1.

NOTE It should be reminded that the most applied loading time history is the one with Gaussian distribution function.

Table A.1 — Examples of typical standard loading time histories

Sequence name (loading time history)	Application
TWIST	Transport air craft wing root (lower wing skin)
FALSTAFF	Fighter aircraft wing root (lower wing skin)
Cold/Hot TURBISTAN	Cold/Hot section disks in fighter aircraft engine
HELIX, FELIX	Hinged/Fixed helicopter rotors
CARLOS	Car suspension components
Sequences defined by UIC (International Federation of Railways)	Railway components, e.g. boogies
WASH	Offshore rigs in the North Sea
IACS long-term distribution (International Association of Classification Societies)	Ships: North Atlantic and worldwide navigation cases

Annex B
(informative)

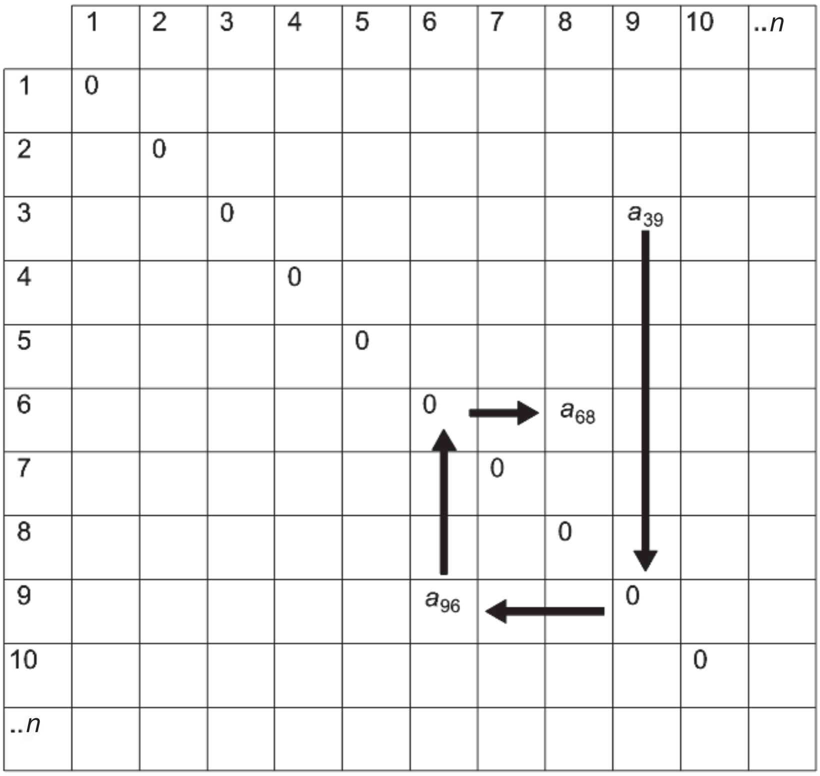
Example of loading signal reconstruction by random draw in the transition matrix

The following procedure is used to avoid discontinuities in the reconstructed signal.

NOTE In Table B.1 and Figure B.1, arbitrary numbers are chosen for clarity.

The first transition should be an increasing one ($i < j$) for practical reasons, and increasing and decreasing transitions shall alternate.

Table B.1 — Example of a transition matrix



	1	2	3	4	5	6	7	8	9	10	..n
1	0										
2		0									
3			0						a_{39}		
4				0							
5					0						
6						0		a_{68}			
7							0				
8								0			
9						a_{96}			0		
10										0	
..n											

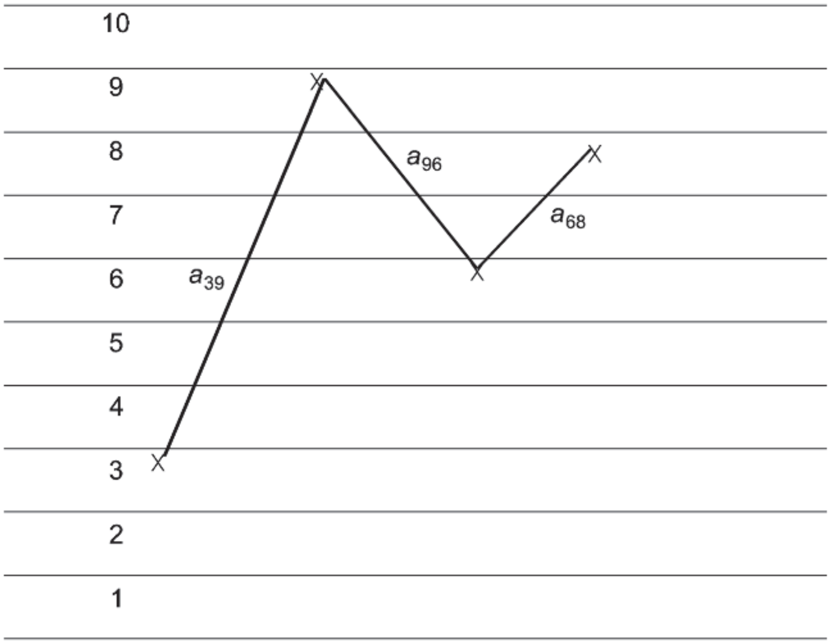


Figure B.1 — Random draw procedure from the transition matrix

The random draw procedure is described as follows (see also Figure B.1).

a) Take a random draw of $i = 3$ for instance.

b) With a pseudo-random draw of $j > 9$, we get a_{39}.

c) To avoid discontinuities of the loading signals and to produce a decreasing transition, the next transition shall be from level 9 to another one a_{9j}. So, here j shall be drawn to have a $j < 9$ pseudo-random draw, for instance $j = 6$, we get a_{96}.

d) Still to avoid discontinuities and to produce an increasing transition, i shall be $i = 6$ and $j > 6$ (from 7 to n) pseudo-random draw, for instance $j = 8$, we get a_{68} and so on. Provided that increasing transitions are always followed by decreasing ones and vice-versa.

If any transition from i to j has been counted m times, $a_{ij} = m$. When reconstructing the control signal, as soon as the first transition i to j is added to the signal, $a_{ij} = m-1$ and so on.

The reconstructed control signal is completed when all values a_{ij} of the matrix are equal to zero. This means that the reconstructed signal will include $a_{ij} = m$ transitions from level i to level j.

Only a part of the “random” draw is really performed at random.

Annex C
(informative)

Preliminary analysis of test data on a single specimen

C.1 General

For variable amplitude, the load or stress range to be associated to the number of cycles at failure of a sample is not directly defined. Various possibilities exist to provide the variable amplitude test results: Palmgren-Miner sum or equivalent load or stress range. In each case, an *S*-*N* or Wöhler curve of the tested material or component under constant amplitude has to be known.

Miner sum and equivalent stress range analyses are based upon linear cumulative damage. In addition, the equivalent stress range analysis is based upon the possibility of modelling the *S*-*N* curve by a straight line, the slope of which is *m* in a log-log plot.

Both the Miner sum and equivalent stress range analyses should be used with great care.

C.2 Palmgren-Miner sum

The Palmgren-Miner sum is calculated from the cumulative frequency diagram (stress range Δσ versus number of cycles *N*) and an *S*-*N* or Wöhler curve (stress range Δσ versus number of cycles *N* at failure). The Palmgren-Miner sum is given by the following formula:

$$D=\frac{N_\mathrm{t}}{C}\int_0^\infty \Delta s^m f(\Delta s)\, d\Delta s \qquad \text{(C.1)}$$

where

N_t is the total number of cycles of the cumulative frequency diagram;

C is the constant of the *S*-*N* or Wöhler curve expressed by $(\Delta s)^\mathrm{m}\, N = C$;

$f(\Delta s)$ is the probability density function of Δσ, derived cumulative frequency diagram function.

When the cumulative frequency diagram is given as a stair curve (number of cycles, n_i, versus stress range, Δs_i), the Palmgren-Miner sum is given by the following formula (see Figures 4 and C.1):

$$D=\sum_i \frac{n_i}{N_i} \qquad \text{(C.2)}$$

C.3 Equivalent stress range

From a cumulative frequency stair diagram (see Figure 4), the equivalent stress is defined either as an equivalent stress amplitude or as an equivalent stress range.

The equivalent stress amplitude is derived from the following equation:

$$\left(\frac{\Delta S}{2}\right)_{\mathrm{eq}} = \left[\frac{\sum_i n_i \left(\frac{\Delta s_i}{2}\right)^m}{N_{\mathrm{ref}}}\right]^{1/m} \tag{C.3}$$

The equivalent stress range is derived from the following equation:

$$\Delta S_{\mathrm{eq}} = \left[\frac{\sum_i n_i \left(\Delta s_i\right)^m}{N_{\mathrm{ref}}}\right]^{1/m} \tag{C.4}$$

where in both equations:

m is the power parameter of the S-N or Wöhler curve expressed by $(\Delta s)^{\mathrm{m}} N = C$;

N_{ref} is the reference number of cycles to determine the stress range level at failure on the S-N or Wöhler curve.

Often, the N_{ref} is taken equal to the total number of cycles N_{t} of the cumulative frequency stair diagram.

C.4 Test report for a series of specimens

A series of specimens may be tested by applying to each a loading time history which is proportional to a given reference loading time history. The results of this test series may be reported on a Gassner diagram.

A point of the Gassner curve represents the number of cycles associated to the maximum stress range level of a given cumulative frequency diagram obtained by repetition of this diagram until failure (see Figure C.2).

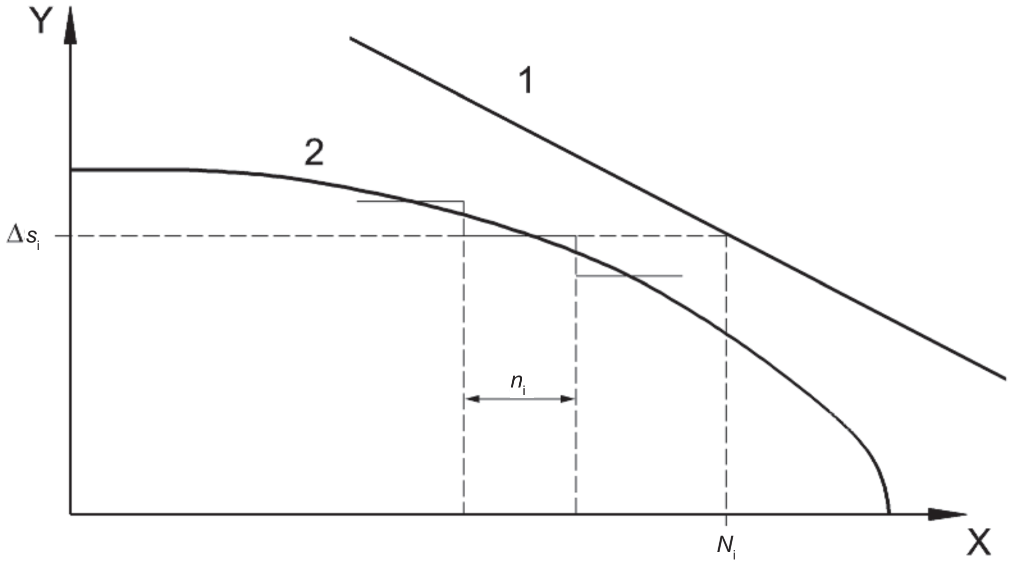
C.5 Fatigue behaviour data

The series of the numerical values of the couples (number of cycles at failure/equivalent load or stress range) has to be provided plus:

a) the equivalent stress range and the associated parameters m and N_{ref};

and/or

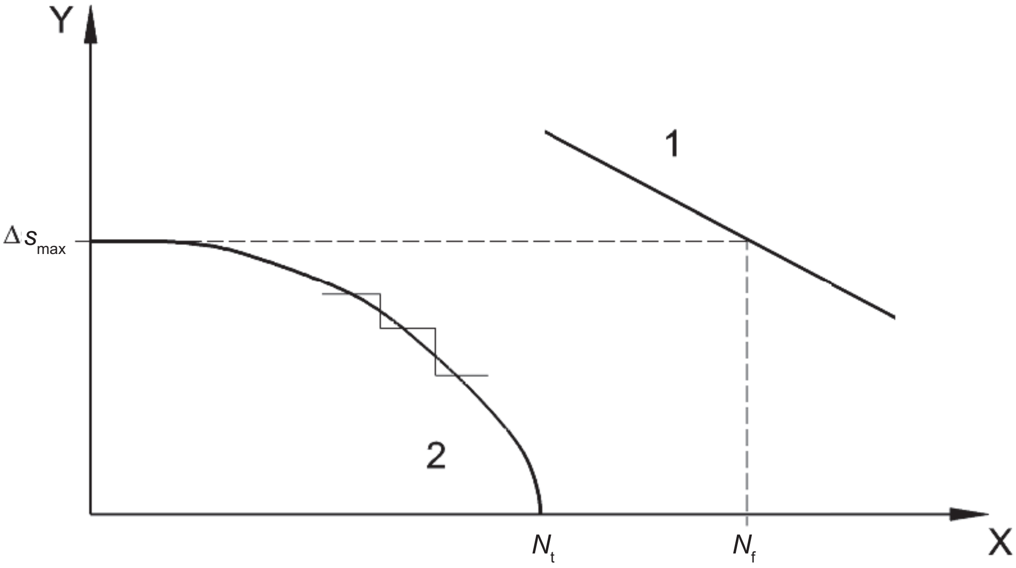
b) the Gassner curve point and the number of repetitions of the cumulative frequency diagram associated to each point.



Key

1	*S*-*N* or Wöhler curve
2	cumulative frequency diagram
X	number of cycles
Y	stress range

Figure C.1 — Principle for Palmgren-Miner summation



Key

1	Gassner curve
2	cumulative frequency diagram
X	number of cycles
Y	stress range

Figure C.2 — Gassner curve definition

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