BS EN 12952-4:2011

BSI Standards Publication

Water-tube boilers and auxiliary installations

Part 4: In-service boiler life expectancy calculations

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National foreword

This British Standard is the UK implementation of EN 12952-4:2011. It supersedes BS EN 12952-4:2000 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee PVE/2, Water Tube And Shell Boilers.

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

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This European Standard was approved by CEN on 18 June 2011.

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Foreword

This document (EN 12952-4:2011) has been prepared by Technical Committee CEN/TC 269 “Shell and water-tube boilers”, the secretariat of which is held by DIN.

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of an identical text or by endorsement, at the latest by January 2012, and conflicting national standards shall be withdrawn at the latest by January 2012.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 12952-4:2000.

Annex C provides details of significant technical changes between this European Standard and the previous edition.

The European Standard EN 12952, concerning *water-tube boilers and auxiliary installations,* consists of the following parts:

— *Part 1: General;*

— *Part 2: Materials for pressure parts of boilers and accessories;*

— *Part 3: Design and calculation for pressure parts;*

— *Part 4: In-service boiler life expectancy calculations;*

— *Part 5: Workmanship and construction of pressure parts of the boiler;*

— *Part 6: Inspection during construction; documentation and marking of pressure parts of the boiler;*

— *Part 7: Requirements for equipment for the boiler;*

— *Part 8: Requirements for firing systems for liquid and gaseous fuels for the boiler;*

— *Part 9: Requirements for firing systems for pulverized solid fuels for the boiler;*

— *Part 10: Requirements for safeguards against excessive pressure;*

— *Part 11: Requirements for limiting devices of the boiler and accessories;*

— *Part 12: Requirements for boiler feedwater and boiler water quality;*

— *Part 13: Requirements for flue gas cleaning systems;*

— *Part 14: Requirements for flue gas DENOX-systems using liquified pressurized ammonia and ammonia water solution;*

— *Part 15: Acceptance tests;*

— *Part 16: Requirements for grate and fluidized-bed firing systems for solid fuels for the boiler;*

— *CR 12952 Part 17: Guideline for the involvement of an inspection body independent of the manufacturer.*

NOTE 1 A Part 18 on operating instructions is currently in preparation.

Although these parts may be obtained separately, it should be recognized that the parts are inter-dependent. As such, the design and manufacture of water-tube boilers requires the application of more than one part in order for the requirements of this European Standard to be satisfactorily fulfilled.

NOTE 2 Part 4 and Part 15 are not applicable during the design, construction and installation stages.

NOTE 3 A "Boiler Helpdesk" has been established in CEN/TC 269 which may be contacted for any questions regarding the application of European Standards series EN 12952 and EN 12953, see the following website: http://www.boiler-helpdesk.din.de

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

1 Scope

This European Standard is applicable to water-tube boilers as defined in EN 12952-1:2001.

This European Standard specifies procedures for calculating the creep and/or the fatigue damage of boiler components during operation. These calculations are not required to be carried out by the manufacturer as part of his responsibilities within this European Standard.

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 12952-1:2001, *Water-tube boilers and auxiliary installations — Part 1: General*

EN 12952-3:2011, *Water-tube boilers and auxiliary installations — Part 3: Design and calculation for pressure parts*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 12952-1:2001 apply.

4 Symbols and abbreviations

For the purposes of this document, the symbols and abbreviations given in EN 12952-1:2001, Table 4-1 apply.

5 General

The calculations may be carried out, using transposed design equations. The measured (actual) wall thickness of the components shall be used in the calculations, i.e. taking into account any wall thickness reduction that may have occurred due to corrosion or erosion during the service life up to the time of the analysis, see EN 12952-3:2011, 5.7.

Operating temperature, pressure and especially the magnitude of load changes often differ from the estimations used for the design. Thus, these calculations may help to prevent unexpected early failure of components. The results may be used as a guideline for the decision to inspect a component for fatigue cracks or to inspect for creep pores by the replica method or any other suitable method.

NOTE In some cases, the influence of both creep and fatigue damage will be significant. It is normally conservative to combine the creep and fatigue damage mechanisms by adding the calculated usage factors. If necessary, more detailed methods of assessment may be used (see [1] PD 7910 Published by British Standardization Institute, London, UK). Thus, the components are not necessarily to be replaced, if the calculated usage factor exceeds the value of 1.

The highest loaded components shall be chosen for monitoring purposes.

6 Calculations

Annex A describes the creep damage calculation. Annex B describes the fatigue damage calculation.

Annex A
(informative)

Calculation of in-service creep damage

A.1 General

This annex describes a procedure for calculating the creep damage of a boiler and its major components during operation. It is based on measured values of pressure and temperature, from which the actual primary stress and the expected lifetime at these conditions may be determined.

Design lifetime is not necessarily identical with the operating lifetime. It is therefore necessary to make projections at various stages throughout the operating lifetime of the boiler to determine its expected lifetime.

A.2 Symbols and abbreviations

In addition to the symbols given in EN 12952-1:2001, Table 4-1, the symbols given in Table A.1 apply.

Table A.1 — Symbols

Symbol	Description	Unit
f_{op}	Membrane stress at operating conditions	N/mm^2
T_{op}	Operated time at operating conditions	h
T_{al}	Time to reach the theoretical rupture by creep	h
D_c	Creep damage	–

A.3 Calculation of in-service lifetime and creep damage

A.3.1 General

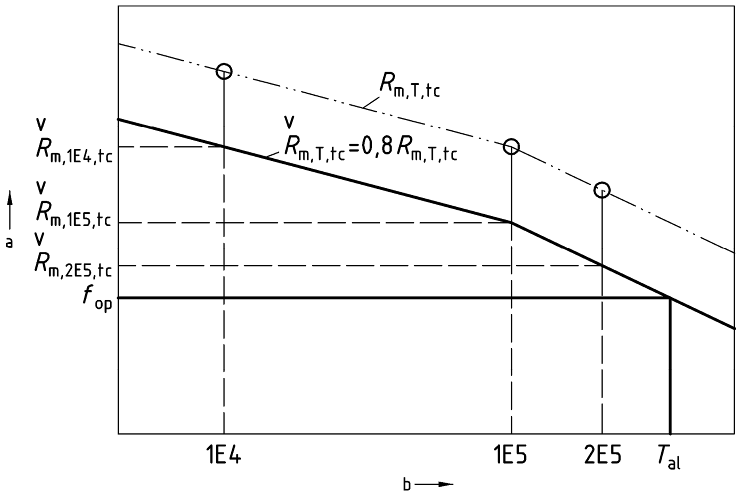
The calculation of the usage factor due to creep is a method that retrospectively takes into consideration the previous modes of operation. It is carried out for highly loaded components on the basis of the measured operating temperatures and gauge pressures.

In order to limit the number of the required calculations and to more clearly present the results, the pressure and temperature range over which the component has been operated, shall be broken down into increments.

The membrane stress f_{op} at the highest loaded point in the component shall be obtained by transposing the design formula using the mean pressure of each pressure increment. If the operating pressure is not measured continuously during operation the separation into increments is not valid and under such circumstances the operating pressure for 100 % load may be used, thus resulting in more conservative predictions. If available, the measured minimum wall thickness may be used. If this was not measured, the guaranteed minimum wall thickness of the material as delivered shall be used.

The theoretical lifetime T_{al} shall be calculated for each rating temperature/pressure. According to Figure A.1, T_{al} is obtained at the intersection of the stress line f_{op} and the lower limit curve of the scatter band of the creep rupture strength (= 0,8 $R_{m\,T\,tc}$) at the mean temperature of each temperature increment.

The respective portion of the creep damage $\Delta D_{ci\,k}$ for each incremental temperature/pressure is obtained by the ratio of the operating time T_{op} for this increment divided by the theoretical lifetime T_{al} for the same increment.



Key

a) lg (R_m)

b) lg (T), h

Figure A.1 — Diagram for the determination of T_{al}

The operating times in the temperature/pressure increment shall be summarized, taking into account the temperature allowances for measuring uncertainties and for temperature asymmetries in due consideration at this classification.

The usage portion for each increment is given by

$$\Delta D_{ci\,k} = \frac{T_{op}}{T_{al}} \tag{A.1}$$

The creep damage D_c during the evaluated period shall be obtained from the linear damage rule by summing up the values $\Delta D_{ci\,k}$ for all temperature increments and, if any, pressure as follows:

$$D_c = \sum_i \sum_k \Delta D_{ci\,k} \tag{A.2}$$

A.3.2 Online computerized data storage

In the case of on-line data storage by means of a data processing system a separation into increments may be waived. For calculation of the theoretical lifetime T_{al} the on-line measured values of pressure and temperature including the above mentioned allowances shall be used instead of the mean values of the increments. The increase of creep damage is obtained in this case from the measured time divided by the theoretical lifetime (see Tables A.2 and A.3).

The computer programme used shall permit the results to be verified by at least a random test.

Table A.2 — Summation of data for the calculation of in-service creep damage

User and boiler plant:	XY	
Power station:	XY	
Boiler:	3	
Works-No.:	12345	
Year built:	2003	
Maximum allowable pressure	HP: 84 bar	Reheater: – bar
Superheated steam temperature:	HP: 525 °C	Reheater: – °C
Steam output:	128 t/h	

1	2	3	4	5	6	7	8	9	10	11	12	13
No.	**Component** **Material; Steel group**	[a]	[b]	d mm	[c]	e_s mm	e_{rs} mm	p_c bar	t_o °C	t_c °C	f_{ap} N/mm^2	T_{al} 10^3 h
1	HP-line 13CrMo44; 5.1	m	A B	292,0	o	24,0	21,0	75,5	525	530	48,7	208
2	Superheater 2 – header 13CrMo44; 5.1	n	A B	419,0	o	39,0	39,0	75,5	510	525	56,3	186
3	Superheater 2 – outlet line 13CrMo44; 5.1	n	A B	241,0	o	17,5	17,5	75,5	510	525	48,2	304
4	Superheater 2 – outlet header 16CrMo44; 5.1	n	A B	250,0	i	20,0	28,0	75,5	510	525	47,1	329
7	Fitting at control 20Mo3; 1.2	m	A B	225,0	i	28,0	20,0	80,4	460	465	86,6	> 500
11	Superheater 1 – outlet line 16Mo3; 1.1	n	A B	241,0	o	14,0	14,0	80,4	460	475	65,2	> 500
12	Superheater 1 – outlet header 20Mo3; 1.2	n	A B	250,0	i	22,0	22,0	80,4	460	475	67,0	> 500

[a] Column 3: Temperature allowances according to EN 12952-3:2011, Table 6.1-1
m unheated = mixed or controlled (+ 5 °C)
n unheated (+ 15 °C)

[b] Column 4: A Nominal or design values
B Operational or actual values

[c] Column 6: i Inside diameter
o Outside diameter

Table A.3 — Summation of data for the calculation of in-service creep damage

User and boiler plant:	XY
Power station:	XY
Boiler:	6
Works-No.:	12345
Component:	Connecting pipes between primary super heater and secondary super heater ∅ 90 × 8
Commissioning:	2003
Material:	Steel group 5.1 (13CrMo44)
Calculation pressure pc:	100 bar
Mean wall temperature tc:	530 °C
Stress at pc:	57,5 N/mm^2
Evaluated period:	from to

1	2			3	4	5	6	7
Evalu-ation range	**At outlet of component**			**Calculation pressure**	**Calculation temperature**	**Related to mean wall temperature**	**Elapsed operating time**	**Creep damage for evaluated period**
	t_o			p_c	t_c	T_{al}	T_{op}	ΔD_c
	From	to	mean					
	°C			bar	°C	10^3 h	h	%
1		< 500	< 500	100	515	430	1 250	0,29
2	500	510	505	100	520	260	820	0,31
3	510	515	512,5	100	527,5	162	6 800	4,20
4	515	520	517,5	100	532,5	106	5 760	5,45
5	520	525	522,5	100	537,5	80	610	0,76
						Sum for evaluated period	15 240	11,01
						Sum prior to evaluated period	20 000	14,00
						Total	35 240	25,01

Annex B
(informative)

Calculation of in-service fatigue damage

B.1 General

This annex describes a procedure for calculating the low cycle fatigue damage of boiler components during operation. It is based on measured values of temperature, temperature difference, pressure, strain, displacement etc. from which the actual stress may be determined.

In order to carry out this analysis it is essential that a computerized data logging system shall be employed.

B.2 Symbols and abbreviations

In addition to the symbols shown in EN 12952-1:2001, Table 4-1 and EN 12952-3:2011, 13.2 and B.3 the following symbols and abbreviations of Table B.1 apply.

Table B.1 — Symbols and abbreviations

Symbol	Description	Unit
ε	Strain	–
σ	Stress	N/mm^2
$\sigma_1, \sigma_2, \ldots$	Successive values of σ	N/mm^2
x	Relative extreme value of the stress (maximum or minimum)	N/mm^2
$x_1, x_2 \ldots$	Successive values of x (shall be alternating maxima or minima)	N/mm^2
Δx_e	Upper limit of stress range that does not cause fatigue damage (elastic stress range ≈ 190 N/mm^2, depends on material and temperature)	N/mm^2
LC	Boolean Value: LC = "true": there is a load cycle LC = "false": there is no load cycle	–

B.3 Calculation of stress due to fatigue

B.3.1 General

Fatigue is a phenomenon of material failure that occurs as a result of repeated variations of the stress. Therefore the actual stress at the highly loaded points of the boiler components, where fatigue is expected to occur, shall be determined continuously in short time steps, (e.g. 1 min intervals), from measured values of pressure p, and temperature differences Δt etc. so that relative maximums and minimums can be determined with sufficient accuracy.

B.3.2 Component of cylindrical or spherical shape

Analogous to EN 12952-3:2011, 13.4, the actual stress at the inside corner of the bore of a cylindrical components is

$$\sigma = \alpha_{\text{m}} \frac{d_{\text{ms}}}{2e_{\text{ms}}} p + \alpha_{\text{t}} \frac{\beta_{\text{Lt}} E_{\text{t}}}{1-\nu} \Delta t \tag{B.1}$$

and for a spherical component

$$\sigma = \alpha_{\text{sp}} \frac{d_{\text{ms}}}{4e_{\text{ms}}} p + \alpha_{\text{t}} \frac{\beta_{\text{Lt}} E_{\text{t}}}{1-\nu} \Delta t \tag{B.2}$$

NOTE The wall-temperature difference Δt is negative, if the temperature is increased. The definition of Δt is given in EN 12952-3:2011, 13.2.

B.3.3 Other geometrical shapes

The calculation of the stress shall be in accordance with EN 12952-3:2011 and its Annex B together with the notch factors given therein.

B.4 Detection of extreme values of stress

B.4.1 General

The low cycle fatigue that is calculated in accordance with this annex is not dependent on the holding time of the stress or on the time between two extreme values of the stress. These effects may be neglected. Thus it is sufficient for these calculations to detect and store the relative extremes of the equivalent stress in their chronological sequence. This is a very effective data reduction method. However, it is necessary to calculate the stress on-line from the measured values, if this data reducing procedure is to be applied. After each measurement and stress calculation it can be determined from the last three values σ_1, σ_2, σ_3 whether the last but one value σ_2 was a relative extreme. If the Boolean formula

$$(\sigma_1 < \sigma_2 \text{ and } \sigma_3 < \sigma_2) \text{ or } (\sigma_1 > \sigma_2 \text{ and } \sigma_3 > \sigma_2) \tag{B.3}$$

is "true", then σ_2 was a relative maximum or a relative minimum of the equivalent stress and may be stored in the sequence of the extreme values x_i.

B.4.2 Storage of extremes

For the subsequent analysis of the sequence of extremes it is also necessary to store the actual measured (of otherwise determined) temperature of the material, so that the reference temperature of the associated load cycle can be calculated. Furthermore, it has been found useful also to store the measured values of the operating pressure and the temperature difference associated with their extreme as well as their date and time. This date may help to explain implausible results. The number of extremes that occur per day or per week is dependent on the mode of operation (basic or peak load). Furthermore, the number of extremes may differ for different components.

NOTE A spray attemperator may be subject to five or more large load cycles per hour. The hot steam header of the same boiler should not even have one load cycle per day. Adequate data storage capacity should therefore be installed.

B.4.3 Elimination of extremes associated with small load cycles

If a boiler is operated at constant load, a large number of relative extremes can occur as a result of small variations and the scatter of the measured values. Such variations do not cause fatigue and the associated extremes may be deleted from the sequence. If the value of the last extreme is between the values of the last but one and the last but two extreme, and if the difference between the last but one and the last but two extreme is smaller than the elastic range Δx_e, then the last extreme and the last but one extreme may be deleted from the sequence. Mathematically expressed:

If the Boolean formula B.4 is "true", then x_1 and x_2 may be deleted from the sequence of extremes.

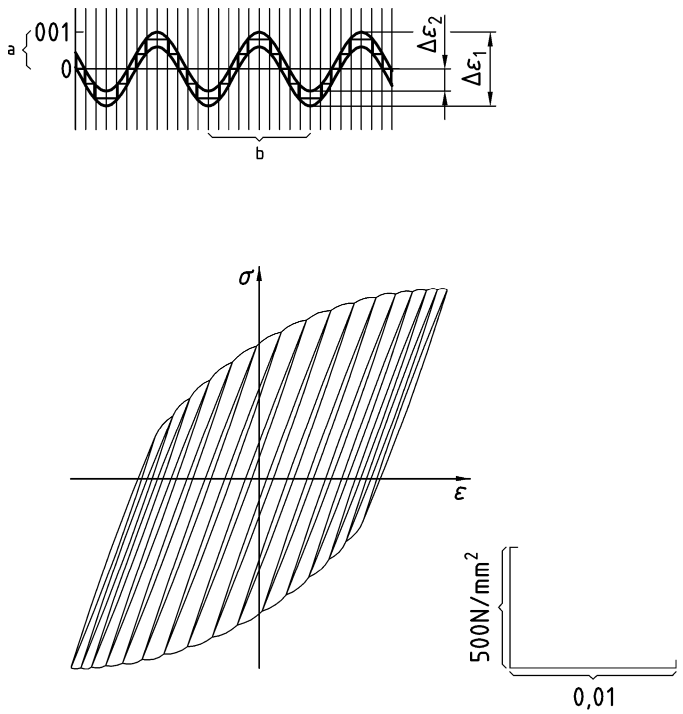
$$\{(x_1 < x_2 \text{ and } x_1 \geq x_3) \text{ or } (x_1 > x_2 \text{ and } x_1 \leq x_3)\} \text{ and } \{|x_2 - x_3| \leq \Delta x_e\} \quad \text{(B.4)}$$

This is also a very effective data reduction method.

B.5 Detection of load cycles

The basis process of load cycle counting shall be the range-pair-method[1)] (see [2], [3]).

According to this method, a load cycle has taken place, when a hysteresis loop in the stress versus strain diagram is closed (see Figure B.1).



Key

a strain

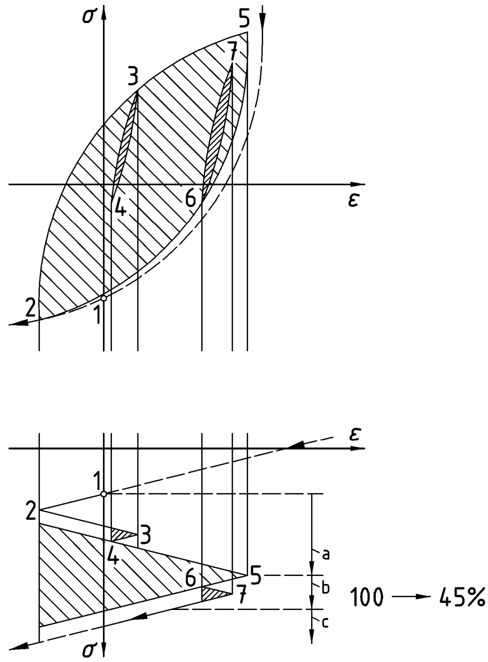
b 1 stack

Figure B.1 — Stress-strain-behaviour according to Dowling [2]

Whether or not a load cycle has taken place can be detected from the sequence of all relative extremes:

If a strain range (as well as a stress range) is interrupted by a smaller range in the opposite direction, this smaller range will cause a closed hysteresis loop in the stress versus strain diagram. The two concerned extremes configure a load cycle (see Figure B.2):

1) The rain-flow-load cycle counting is based on this method and may also be used, see Figure B.5.



Key

a cold start up

b load reduction

c shut down

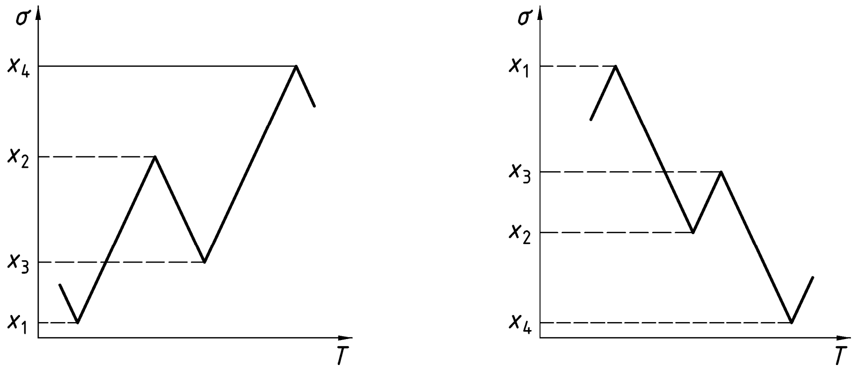
Figure B.2 — Schematic stress-strain behaviour and load cycle counting

The mathematical procedure to detect load cycles from the sequence of all relative extremes is as follows:

All sequences of four succeeding relative extremes x_1, x_2, x_3, x_4 are analysed by the Boolean formula (see Figure B.3)

$$(x_4 > x_3 \text{ and } x_1 \leq x_3 \text{ and } x_2 \leq x_4) \text{ or } (x_4 < x_3 \text{ and } x_1 \geq x_3 \text{ and } x_2 \geq x_4) \quad \text{(B.5)}$$

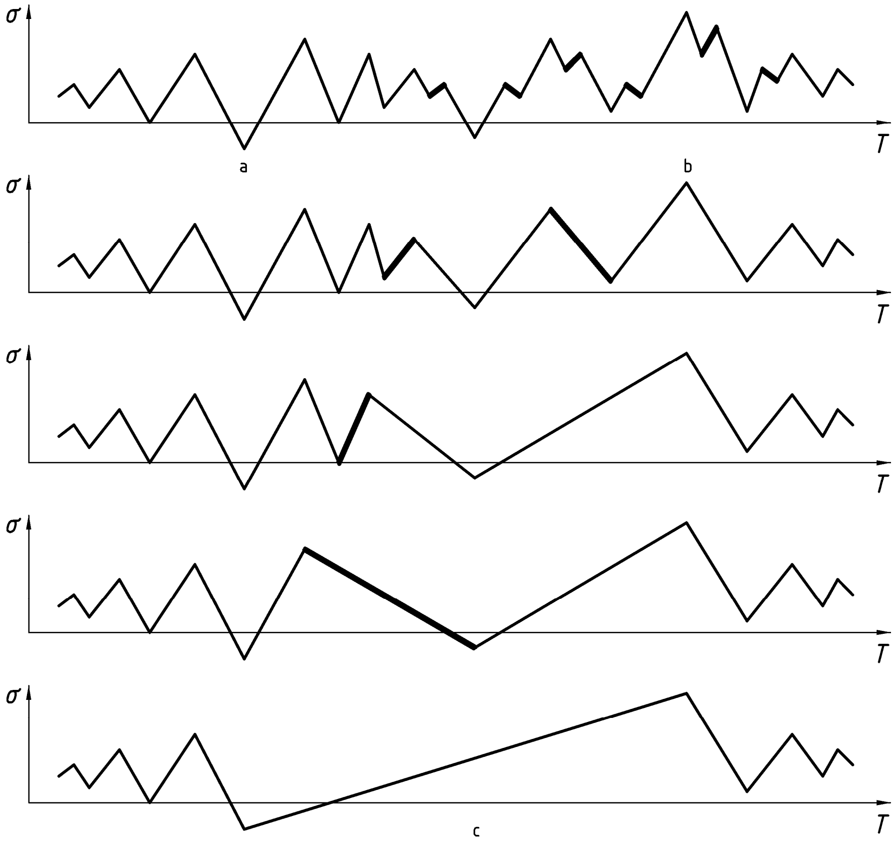
If the formula is "true" then the extremes x_2 and x_3 configure a load cycle that shall be classified according to B.8 and added up in the array of classified load cycles (see Figure B.4). Load cycles with a range smaller than the elastic range $\Delta x_e \approx 190$ N/mm^2 need not be included. The associated extremes x_2 and x_3 of the detected load cycle shall be deleted from the overall sequence of extremes.



LC = ($x_4 > x_3$ and $x_1 \le x_3$ and $x_2 \le x_4$) or ($x_4 < x_3$ and $x_1 \ge x_3$ and $x_2 \ge x_4$)

Figure B.3 — Criterion for a load cycle with a range $\Delta f = |x_2 - x_3|$ at the range-pair- and at the rain-flow-method

The procedure for load cycle detection, classification and deletion of the associated extremes shall be repeated, until there is no further load cycle found in the whole sequence of extremes (see Figure B.4).



Key

a remaining sequence from former extremes

b new extremes

c new remaining sequence of extremes

Figure B.4 — Example for load cycle counting

B.6 Remaining sequence of relative extremes (RSE)

A sequence that does not contain closed load cycles is called "Remaining Sequence of Extremes" (RSE). A RSE is always composed of an oscillation with increasing amplitude[2)] followed by an oscillation with decreasing amplitude. The RSE shall not be deleted but shall be taken into account for further detection of load cycles as shown in Figure B.4. If the load cycle detection is carried out on-line, only the actual RSE need be stored.

The fatigue caused by a RSE cannot be calculated in the same way as the fatigue caused by the detected load cycles. However, it can be estimated:

a) the RSE is neglected during the fatigue calculation. What remains is the pure range-pair-method according to Figures B.3 and B.4;

b) the ranges from extreme to extreme are determined as half load cycles and the range between the highest maximum and the lowest minimum is determined as one complete load cycle. This method is the rain-flow-method (see Figure B.5);

c) the RSE is assumed to be an interrupt of a very large range, that is not determined itself. In this case the RSE can be determined by the range-pair-method. Furthermore, the detection of load cycles may be always simplified according to Figure B.6. The RSE contains just the oscillation with the decreasing amplitude in this case. This is a desirable data reduction and the method is confirmed by the perception, that the part of the RSE with the increasing amplitude cannot influence the further detection of load cycles;

d) starting at the greatest difference in the RSE the preceding and the succeeding pairs of extremes (respective one minimum and one maximum) are determined as a load cycle;

e) the greatest difference is determined as a load cycle. Then the associated extremes are deleted and again the remaining greatest difference is determined as a load cycle and so on. The original RSE shall be stored so that it can be used for further load cycle counting.

All these possibilities are shown in Figure B.5. In all cases the same RSE has been used. The number and size of extremes herein is realistic. For a steel grade with a specified minimum yield strength of 200 N/mm^2, a specified minimum tensile strength of 500 N/mm^2 and for a temperature of 400 °C, the different methods result in the following fatigue from the RSE in Table B.2.

Table B.2 — Fatigue values

Method	Fatigue (percent of lifetime)
a)	0,000
b)	0,268
c)	0,200
d)	0,188
e)	0,212

2) It can be proved that the relative extremes in the first part of the RSE with the increasing amplitude will never be found to associate with a load cycle. Only the extremes in the second part, with the decreasing amplitude inclusive of the highest maximum and lowest minimum in the middle of the RSE, can be a part of further load cycle.

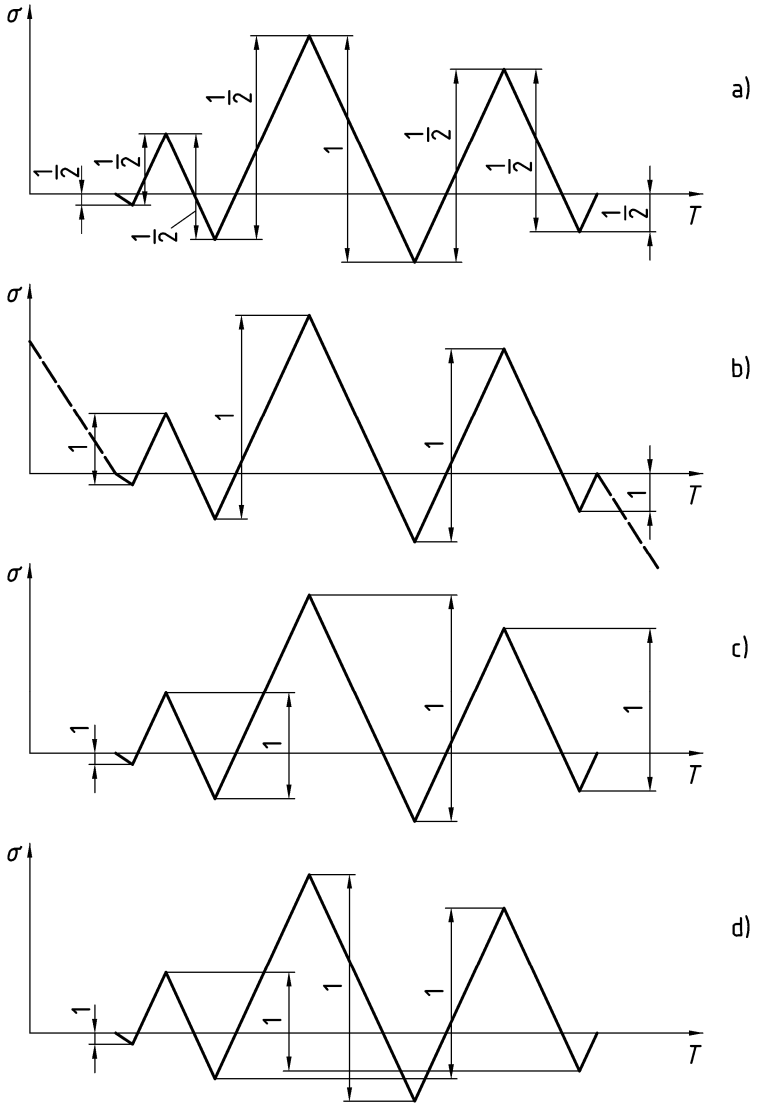
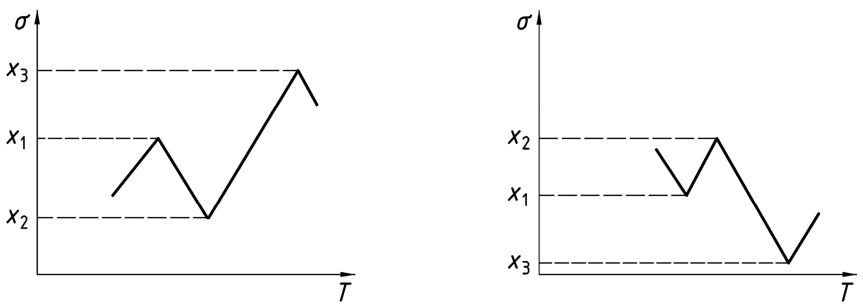


Figure B.5 — Possibilities for estimating the values of the "Remaining Sequence of Extremes" (RSE)



LC = ($x_3 > x_2$ and $x_3 > x_1$) or ($x_3 < x_2$ and $x_3 < x_1$)

Figure B.6 — Criterion for load cycle counting using method c)

B.7 Limitation of the number of the remaining extremes

Using the described load cycle detection, the number of remaining extremes is not limited, because the difference between succeeding maximums and the difference between succeeding minimums may be anyhow small. However, for on-line load cycle detection a limited length of the RSE may be desirable.

One possibility is to limit the length of the RSE e.g. to 20 extremes. If the 21st extreme is detected, the smallest difference between two succeeding maximums or two succeeding minimums in the RSE is located. A maximum and a minimum at this position is counted as a load cycle and the associated two extremes are deleted from the RSE. Thus there is space for two new extremes to be detected and stored. Practical experience shows that the number of extremes is mostly around 10. More than 20 extremes have not been observed, if the load cycle detection follows method c) and Figure B.6, and if extremes that are associated with load cycles, below the elastic range of about 190 N/mm^2, are not stored in the RSE.

B.8 Classification of load cycles

The detected load cycles shall be counted in classes of the stress amplitude $2f_a$ and the reference temperature t^* as shown in Table B.3 (The class limits shown herein are just an example).

The reference stress amplitude $2f_{va}$ (see EN 12952-3:2011, Annex B, Equations (B.2) and (B.5)) is

$$2f_{va} = \left| x_2 - x_3 \right| \tag{B.6}$$

The calculation to determine $2f_a$ from $2f_{va}$ shall be in accordance with EN 12952-3:2011, Annex B.

The reference temperature for a load cycle shall be calculated by

$$t^* = 0{,}75 \max \{t(x_2), t(x_3)\} + 0{,}25 \min \{t(x_2), t(x_3)\} \tag{B.7}$$

Where $t(x_i)$ is the material temperature measured at the same time as the extreme value x_i.

Table B.3 — Fatigue calculation from classified load cycles

User and boiler plant:	XY
Power station:	XY
Boiler:	4
Works-No.:	12345
Component:	reheater header
Material:	Steel group 5.2 (10CrMo9-10)
Operating pressure:	5,35 N/mm^2
Operating temperature:	521 °C
Operating membrane stress:	36,6 N/mm^2
Outside diameter:	660 mm
Wall thickness:	45 mm
Calculation at arithmetic mean of each class	
Date:	31.03.99

$2f_a$ N/mm^2		t^* °C						$\sum_k D_{Fk}$
		≥ 0 < 100	≥ 100 <200	≥ 200 < 300	≥ 300 < 400	≥ 400 < 500	≥ 500	
≥ 190 < 300	n_{1k} N_{1k}	3 1,0 × 10^9	25 3,3 × 10^8	333 8,0 × 10^7	912 2,0 × 10^7	1 803 4,0 × 10^6	617 584 000	
≥ 300 < 390	n_{2k} N_{2k}	5 912 000	12 639 000	91 406 000	435 224 000	410 99 400	51 31 600	
≥ 390 < 460	n_{3k} N_{3k}	2 233 000	4 167 000	51 111 000	270 61 900	295 31 400	25 11 400	
≥ 460 < 510	n_{4k} N_{4k}	0 119 000	1 86 600	12 58 000	150 34 500	245 17 200	24 6 570	
≥ 510 < 540	n_{5k} N_{5k}	0 82 600	0 60 400	10 40 700	96 24 400	215 12 400	48 4 860	
≥ 540 < 560	n_{6k} N_{6k}	0 67 500	0 49 500	4 33 400	66 20 200	150 10 300	61 4 100	
≥ 560 < 580	n_{7k} N_{7k}	0 58 100	0 42 600	1 28 900	35 17 500	123 8 960	80 3 610	
≥ 580	n_{8k} N_{8k}	0 50 400	0 37 000	0 25 100	11 15 300	51 7 660	18 3 200	
$D_{Fk} = \sum_i \frac{n_{ik}}{N_{ik}}$		0,001 4 %	0,005 4 %	0,129 2 %	2,050 5 %	8,031 5 %	6,103 0 %	16,324 %

B.9 Calculation of fatigue damage

The fatigue, that results from each class i, k of load cycles is

$$\Delta D_{F\,ik} = n_{i\,k}/N_{i\,k} \tag{B.8}$$

where

$n_{i\,k}$ is the counted number of load cycles in class i, k;

$N_{i\,k}$ is the allowable number of load cycles in class i, k.

$N_{i\,k}$ shall be calculated according to EN 12952-3:2011, Figure B.9. The used values for $2f_a$ and t^* may be the average between the class limits. The type of averaging (arithmetic, logarithmetic) shall be noted on the calculation sheet.

The total fatigue damage is

$$D_F = D_{F\,RSE} + \sum_{i} \sum_{k} \Delta D_{F\,ik} \tag{B.9}$$

where $D_{F\,RSE}$ is the fatigue damage caused by the RSE.

B.10 Accuracy and plausibility of measured values

The accuracy of the measurement of pressure, through-the wall-temperature difference and other values, that are directly proportional to the stress, shall be within the limit of 3 %. The measurement of temperature difference is especially critical. The measuring equipment itself shall be ordered with a guaranteed accuracy. However, further errors of the measured temperature may occur. Excellent heat transfer contact is required between the material and the tip of the thermocouple. If the measurement of the through-the-wall-temperature difference cannot be improved to a satisfactory accuracy, it should be calculated on-line from the sequence of measured temperatures. The temperature itself has only a slight influence on the result of fatigue calculations. An accuracy of 10 K will be sufficient.

The plausibility of measured values that are determined for a fatigue calculation in automatic computerized plants shall be tested. The simplest method is to establish limits for the value and limits for the transient. A system of comparison with other measured values should also be installed, if possible.

Annex C
(informative)

Significant technical changes between this European Standard and the previous edition

Clause/paragraph/table/figure	Change
General	This European Standard has been completely revised in terms of: — correction of mistakes; — modification of numbering system for tables, drawings and equations.
2 / Normative references	References updated.
NOTE The technical changes referred include the significant technical changes from the EN revised but is not a exhaustive list of all modifications from the previous version.	

Bibliography

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[3] VdTÜV-Merkblatt Dampfkessel 451-87/1, 05/87, Verlag TÜV Rheinland, Köln 1987

[4] EN 12953 (all parts), *Shell boilers*

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