

Metal bellows expansion joints for pressure applications

ICS 23.040.99

National foreword

This British Standard is the UK implementation of EN 14917:2009+A1:2012. It supersedes BS EN 14917:2009, which is withdrawn

BSI, as a member of CEN, is obliged to publish EN 14917:2009 as a British Standard. However, attention is drawn to the fact that during the development of this European Standard, the UK committee voted against its approval as a European Standard.

The reason for this negative vote was that clause 6.1.2.3, and its associated table, either does not specify a factor for the relationship between the minimum tensile strength and the allowable stress in the main and general pressure bearing parts or it specifies a factor of 3:1. It has been customary in the UK (and it is consistent with ISO 15348 and EJMA together with its ANSI and ASME Codes) to use a minimum factor of safety of 4:1.

The start and finish of text introduced or altered by amendment is indicated in the text by tags. Tags indicating changes to CEN text carry the number of the CEN amendment. For example, text altered by CEN amendment A1 is indicated by **A1** **A1**.

The UK participation in its preparation was entrusted to Technical Committee GSE/42, Gas fittings and connections including metal hose and hose assemblies.

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

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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English Version

Metal bellows expansion joints for pressure applications

Compensateurs de dilatation à soufflets métalliques pour
appareils à pression

Kompensatoren mit metallischen Bälgen für
Druckanwendungen

This European Standard was approved by CEN on 6 September 2008 and includes Amendment 1 approved by CEN on 10 January 2012.

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Foreword

This document (EN 14917:2009+A1:2012) has been prepared by Technical Committee CEN/TC 342, "Metal hoses, hose assemblies, bellows and expansion joints", the secretariat of which is held by  SNV .

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of an identical text or by endorsement, at the latest by September 2012, and conflicting national standards shall be withdrawn at the latest by September 2012.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 has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of the EU Directive 97/23/EC.

For relationship with EU Directive 97/23/EC, see informative Annex ZA, which is an integral part of this document.

This document includes Amendment 1, approved by CEN on 2012-01-08.

This document supersedes EN 14917:2009.

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Introduction

Metal bellows expansion joints are used as components in piping or as parts of pressure vessels.

If an expansion joint is designed and manufactured according to this European Standard, the risk analysis is already undertaken, see Annex I.

1 Scope

This European Standard specifies the requirements for design, manufacture and installation of metal bellows expansion joints for pressure applications, i.e. maximum allowable pressure greater than 0,5 bar.

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 287-1, *Qualification test of welders — Fusion welding — Part 1: Steels*

EN 473, *Non destructive testing — Qualification and certification of NDT personnel — General principles*

EN 571-1, *Non destructive testing — Penetrant testing — Part 1: General principles*

EN 764-4, *Pressure equipment — Part 4: Establishment of technical delivery conditions for metallic materials*

EN 764-5:2002, *Pressure equipment — Part 5: Compliance and inspection documentation of materials*

EN 970, *Non-destructive examination of fusion welds — Visual examination*

EN 1092-1, *Flanges and their joints — Circular flanges for pipes, valves, fittings and accessories, PN designated — Part 1: Steel flanges*

EN 1289:1998, *Non-destructive examination of welds — Penetrant testing of welds — Acceptance levels*

EN 1290, *Non-destructive examination of welds — Magnetic particle examination of welds*

EN 1291:1998, *Non-destructive examination of welds — Magnetic particle testing of welds — Acceptance levels*

EN 1418, *Welding personnel — Approval testing of welding operators for fusion welding and resistance weld setters for fully mechanized and automatic welding of metallic materials*

EN 1435:1997, *Non-destructive examination of welds — Radiographic examination of welded joints*

EN 1593, *Non-destructive testing — Leak testing — Bubble emission techniques*

EN 1712:1997, *Non-destructive examination of welds — Ultrasonic examination of welded joints — Acceptance levels*

EN 1713, *Non-destructive examination of welds — Ultrasonic examination — Characterization of indications in welds*

EN 1714:1997, *Non-destructive examination of welds — Ultrasonic examination of welded joints*

EN 1779:1999, *Non-destructive testing — Leak testing — Criteria for method and technique selection*

EN 10002-1, *Metallic materials — Tensile testing — Part 1: Method of test at ambient temperature*

EN 10002-5, *Metallic materials — Tensile testing — Part 5: Method of testing at elevated temperature*

EN 10028-1, *Flat products made of steels for pressure purposes — Part 1: General requirements*

EN 10028-2:2009 ^{A1}, *Flat products made of steels for pressure purposes — Part 2: Non-alloy and alloy steels with specified elevated temperature properties*

EN 10028-3:2009 , *Flat products made of steels for pressure purposes — Part 3: Weldable fine grain steels, normalized*

EN 10028-4, *Flat products made of steels for pressure purposes — Part 4: Nickel alloy steels with specified low temperature properties*

EN 10028-7:2007, *Flat products made of steels for pressure purposes — Part 7: Stainless steels*

EN 10045-1, *Metallic materials — Charpy impact test — Part 1: Test method*

EN 10204:2004, *Metallic products — Types of inspection documents*

EN 10216-1, *Seamless steel tubes for pressure purposes — Technical delivery conditions — Part 1: Non-alloy steel tubes with specified room temperature properties*

EN 10216-2, *Seamless steel tubes for pressure purposes — Technical delivery conditions — Part 2: Non-alloy and alloy steel tubes with specified elevated temperature properties*

EN 10216-3, *Seamless steel tubes for pressure purposes — Technical delivery conditions — Part 3: Alloy fine grain steel tubes*

EN 10216-4, *Seamless steel tubes for pressure purposes — Technical delivery conditions — Part 4: Non-alloy and alloy steel tubes with specified low temperature properties*

EN 10217-1, *Welded steel tubes for pressure purposes — Technical delivery conditions — Part 1: Non-alloy steel tubes with specified room temperature properties*

EN 10217-2, *Welded steel tubes for pressure purposes — Technical delivery conditions — Part 2: Electric welded non-alloy and alloy steel tubes with specified elevated temperature properties*

EN 10217-3, *Welded steel tubes for pressure purposes — Technical delivery conditions — Part 3: Alloy fine grain steel tubes*

EN 10217-4, *Welded steel tubes for pressure purposes — Technical delivery conditions — Part 4: Electric welded non-alloy steel tubes with specified low temperature properties*

EN 10217-5, *Welded steel tubes for pressure purposes — Technical delivery conditions — Part 5: Submerged arc welded non-alloy and alloy steel tubes with specified elevated temperature properties*

EN 10217-6, *Welded steel tubes for pressure purposes — Technical delivery conditions — Part 6: Submerged arc welded non-alloy steel tubes with specified low temperature properties*

EN 10222-2, *Steel forgings for pressure purposes — Part 2: Ferritic and martensitic steels with specified elevated temperature properties*

EN 10222-3, *Steel forgings for pressure purposes — Part 3: Nickel steels with specified low temperature properties*

EN 10222-4, *Steel forgings for pressure purposes — Part 4: Weldable fine grain steels with high proof strength*

EN 10253-2, *Butt-welding pipe fittings — Part 2: Non alloy and ferritic alloy steels with specific inspection requirements*

EN 10269, *Steels and nickel alloys for fasteners with specified elevated and/or low temperature properties*

EN 10272, *Stainless steel bars for pressure purposes*

EN 10273, *Hot rolled weldable steel bars for pressure purposes with specified elevated temperature properties*

EN 12517-1:2006, *Non-destructive testing of welds — Part 1: Evaluation of welded joints in steel, nickel, titanium and their alloys by radiography — Acceptance levels*

EN 13184, *Non-destructive testing — Leak testing — Pressure change method*

EN 13185, *Non-destructive testing — Leak testing — Tracer gas method*

EN 13445-2:2002, *Unfired pressure vessels — Part 2: Materials*

EN 13445-3, *Unfired pressure vessels — Part 3: Design*

EN 13480-2:2002, *Metallic industrial piping — Part 2: Materials*

EN 13480-3, *Metallic industrial piping — Part 3: Design and calculation*

EN 13480-4, *Metallic industrial piping — Part 4: Fabrication and installation*

EN ISO 643, *Steels — Micrographic determination of the apparent grain size (ISO 643:2003)*

EN ISO 3651-2, *Determination of resistance to intergranular corrosion of stainless steels — Part 2: Ferritic, austenitic and ferritic-austenitic (duplex) stainless steels — Corrosion test in media containing sulfuric acid (ISO 3651-2:1998)*

EN ISO 5817, *Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections (ISO 5817:2003, corrected version: 2005, including Technical Corrigendum 1:2006)*

EN ISO 6506-1, *Metallic materials — Brinell hardness test — Part 1: Test method (ISO 6506-1:2005)*

EN ISO 6520-1, *Welding and allied processes — Classification of geometric imperfections in metallic materials — Part 1: Fusion welding (ISO 6520-1:2007)*

EN ISO 9445:2006, *Continuously cold-rolled stainless steel narrow strip, wide strip, plate/sheet and cut lengths — Tolerances on dimensions and form (ISO 9445:2002)*

EN ISO 9606-4, *Approval testing of welders — Fusion welding — Part 4: Nickel and nickel alloys (ISO 9606-4:1999)*

EN ISO 15609-1, *Specification and qualification of welding procedures for metallic materials — Welding procedure specification — Part 1: Arc welding (ISO 15609-1:2004)*

EN ISO 15610, *Specification and qualification of welding procedures for metallic materials — Qualification based on tested welding consumables (ISO 15610:2003)*

EN ISO 15613, *Specification and qualification of welding procedures for metallic materials — Qualification based on pre-production welding test (ISO 15613:2004)*

EN ISO 15614-1, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys (ISO 15614-1:2004)*

ISO 15348:2002, *Pipework — Metal bellows expansion joints — General*

EAM-0526-18 NiMo16Cr15W (2.4819) — Nickel-Molybdenum-chromium alloy — Flat products

EAM-0526-28 NiMo16Cr16Ti (2.4610) — Nickel-Chromium-Molybdenum alloy — Flat products

EAM-0526-40 NiCr22Mo9Nb-gr.1 (2.4856) — Nickel-Chromium-Molybdenum alloy — Flat products

EAM-0526-43-1 NiCr15Fe (2.4816) — Nickel-Chromium-Iron alloy — Hot and cold rolled flat products

EAM-0526-43-2 NiCr15Fe (2.4816) — Nickel-Chromium-Iron alloy — Bars and rods

3 Terms and definitions

For the purposes of this document, the basic terms and definitions given in ISO 15348:2002 and the following apply.

- 3.1**
bellows
flexible element consisting of one or more $\square A_1$ corrugations $\square A_1$ and the end tangents
- 3.2**
corrugation (convolution)
flexible unit of a bellows
- 3.3**
end tangents
straight un-corrugated portions at the ends of a bellows
- 3.4**
reinforcing collar
reinforcing sleeve or ring attached to the end tangent for reinforcement
- 3.5**
assisting collar
ring placed around the end tangents to facilitate welding
- 3.6**
reinforcing and equalizing rings
devices fitting snugly in the roots of the corrugations in order to reinforce the bellows against internal pressure and/or to limit the $\square A_1$ equivalent axial compression $\square A_1$
- 3.7**
classification
classifying expansion joints according to the type of movement they are capable of absorbing and their parts according to their pressure bearing capacity
- 3.7**
classification
classifying expansion joints according to the type of movement they are capable of absorbing and their parts according to their pressure bearing capacity
- 3.8**
maximum allowable pressure, PS
maximum pressure for which the equipment is designed, as specified by the equipment manufacturer
- 3.9**
maximum/minimum allowable temperature, TS
 $\square A_1$ maximum and minimum $\square A_1$ temperature for which the equipment is designed, as specified by the equipment manufacturer
- 3.10**
nominal pressure PN
designation commonly used for reference purposes for piping components and stock parts, and which represents in this European Standard the maximum allowable pressure at 20 °C
- NOTE Normally defined as a dimensionless alphanumeric number.
- 3.11**
pressure thrust, F_p
axial force due to the effect of pressure

3.12

neutral position

bellows length in a “stress-free” state

3.13

squirm

column or in-plane instability of the bellows under the effect of internal pressure

3.14

category

classification of pressure equipment according to ascending level of hazard

NOTE See Annex A.

3.15

equipment manufacturer

person responsible for the values of the parameters PS and TS

NOTE This may be the manufacturer or planner of the piping or the pressure vessel for which the expansion joint is designed or the expansion joint manufacturer if free to set these values.

4 Classification

4.1 Classification of expansion joints

There are four types of expansion joints which are designed according to the type of movements absorbed; common examples are shown in Table 4.1:

4.1.1 Axial

Absorbs mainly axial $\square A_1$ displacement $\square A_1$. When non-pressure balanced, it does not restrain pressure thrust. When pressure balanced, it restrains thrust. It can be internally or externally pressurized.

4.1.2 Angular

$\square A_1$ Absorbs angular rotation. When fitted with hinges, it allows rotation in a single plane. When fitted with gimbal rings, it allows multi-plane rotations. It restrains pressure thrust. $\square A_1$

4.1.3 Lateral

$\square A_1$ Absorbs lateral deflection. An angular rotation is also permissible when the expansion joint is fitted with two spherical tie bars, the deflection being perpendicular to the plane containing the tie bars, or fitted with double hinges or fitted with double gimbals. It restrains pressure thrust. $\square A_1$

4.1.4 Universal

4.1.4.1 Non-pressure balanced

Absorbs several movements. It does not restrain pressure thrust.

4.1.4.2 Pressure balanced

A pressure balanced expansion joint accommodates axial and lateral movements and counteracts the bellows pressure thrust. An additional bellows is incorporated into the unit and is subject to the line pressure to generate a force equal and opposite to that on the main bellows. Tying these bellows together neutralises the pressure load on the unit. These joints are often installed at changes of direction in piping but in-line designs are also available.

Table 4.1 — Types of expansion joints

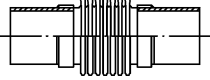
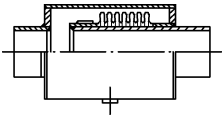
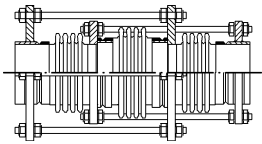
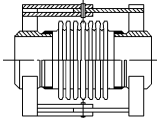
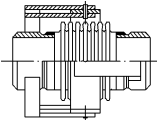
Type	Design		Pressure thrust restraint	Movement				
				Axial	Angular		Lateral	
					Single plane	Multi-plane	Single plane	Multi-plane
Axial	Non-pressure balanced internally pressurized		No	X	(X)	(X)	(X)	(X)
	Non-pressure balanced externally pressurized		No	X	(X)	(X)	(X)	(X)
	In-line pressure balanced		Yes	X				
Angular	Hinge		Yes		X			
	Gimbal		Yes		X	X		

Table 4.1 (continued)

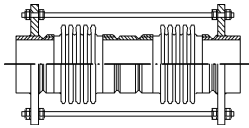
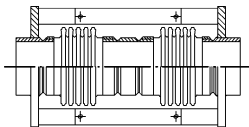
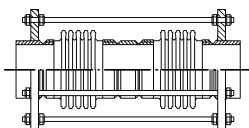
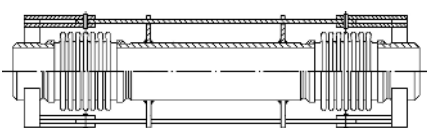
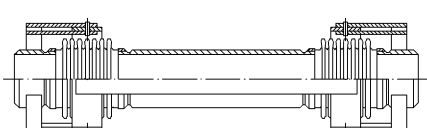
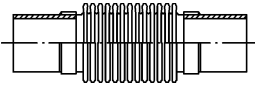
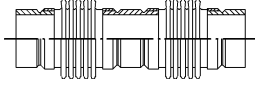
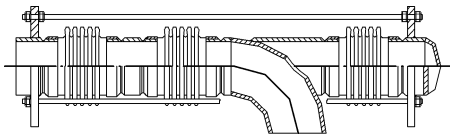
Type	Design		Pressure thrust restraint	Movement				
				Axial	Angular		Lateral	
					Single plane	Multi-plane	Single plane	Multi-plane
Lateral	Two tie-bars spherical		Yes		X		X	X
	Two tie-bars Pinned (plane)		Yes				X	
	Three or more tie-bars		Yes				X	X
	Double hinge		Yes		X		X	
	Double gimbal		Yes		X	X	X	X

Table 4.1 (continued)

Type	Design		Pressure thrust restraint	Movement				
				Axial	Angular		Lateral	
					Single plane	Multi-plane	Single plane	Multi-plane
Universal	Unrestrained One or two bellows		No	X	X	X	X	X
								
	Pressure balanced		Yes	X	X With two tie-bars only		X	X
NOTE 1 X — Applicable NOTE 2 (X) — Limited use								

4.2 Classification of the parts of expansion joints

4.2.1 Main pressure-bearing parts (A)

Parts and assemblies that envelope the medium under pressure and which according to their design and their stress level are essential for the pressure-bearing integrity of the equipment, i.e. its failure can result in a sudden discharge of pressure energy, see Figure 4.2.

4.2.2 Pressure parts other than main pressure-bearing parts (B)

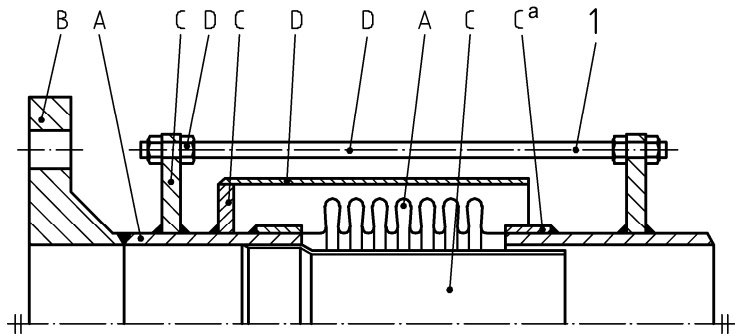
Parts that are charged by the pressure indirectly and have no direct contact to the medium and parts that are in contact with the medium but according to their design are not essential for the pressure-bearing integrity of the equipment, see Figure 4.2.

4.2.3 Attachments to main pressure-bearing parts and to pressure parts (C)

Parts that are directly welded to A or B parts.

4.2.4 Other parts (D)

Parts that are not A, B or C parts.



Key

1 Pretension or shipping bars

Figure 4.2 a — Axial non-pressure balanced internally pressurized

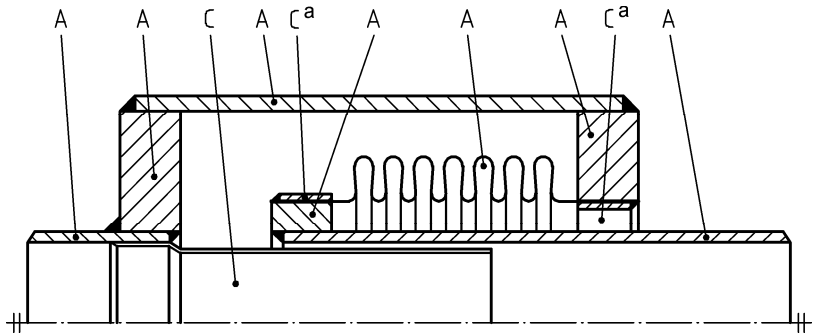


Figure 4.2 b — Axial non-pressure balanced externally pressurized

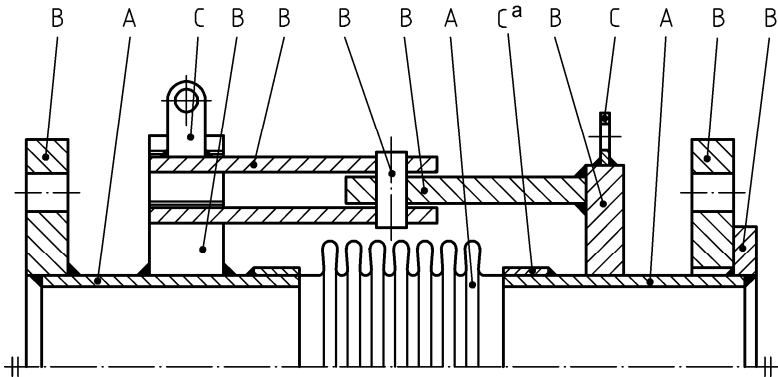


Figure 4.2 c — Angular

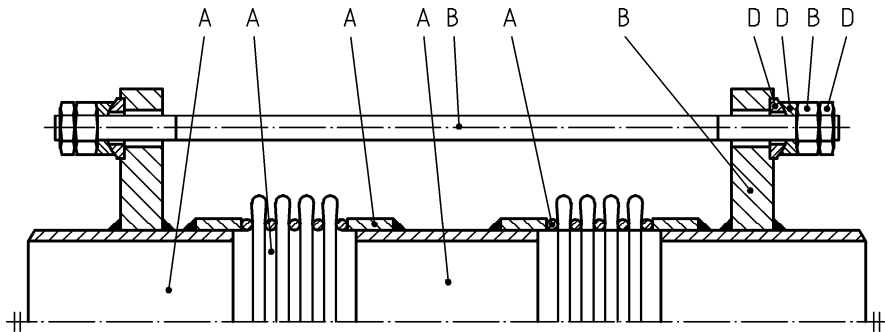


Figure 4.2 d — Lateral

^a Collars, if re-enforcing are A parts (see Table 6.2.2.4.4-1).

NOTE These sketches are diagrammatic only.

Figure 4.2 — Classification of the parts of expansions joint

5 Materials

5.1 General

5.1.1 Materials for pressure-bearing parts

Materials used for pressure-bearing parts as defined in 4.2.1 and 4.2.2 and shown in Figure 4.2 shall be free from surface and internal defects, which impair their suitability. These materials shall be selected to be compatible with anticipated fabrication techniques and to be suitable for the specified conditions. In addition they shall meet the requirements of 5.2.

5.1.2 Materials for parts attached to pressure-bearing parts

For parts that are attached to pressure-bearing parts as defined in 4.2.3 and shown in Figure 4.2, the materials used shall not limit the operating conditions of the pressure-bearing parts to which they are attached, especially when attached by welding.

5.1.3 Materials for non-pressure parts

All materials used for the manufacture of expansion joints shall be suitable for such application during the scheduled lifetime unless replacement is foreseen. 

5.1.4 Documentation

All materials shall be delivered with the documentation as defined in 5.3.

5.2 Pressure-bearing parts

5.2.1 Bellows

5.2.1.1 Allowable materials

Only materials shall be used that fulfil the general requirements of 5.1 and that are suitable for the special forming and welding procedures used for bellows according to the demands of 7.3 and 7.4.

Preferable materials are given in Table 5.1. The table also gives the minimum and maximum operative temperature limits for the various materials.

Appropriate physical properties for these materials are given in EN 10028-7, the respective European Approvals for Materials (EAM) or Annex B respectively.

Annex J (informative) gives an extract of properties documented in the EAMs referred to in Table 5.1 and in addition gives material properties for information; e.g. creep rupture stresses and properties for very low temperatures.

Other materials not listed in Table 5.1 may be used, provided they fulfil the general requirements of 5.1 and are also suitable for the special forming and welding procedures according to 7.3 and 7.4 and provided they conform to a harmonized standard or comply with an European Approval for Material (EAM) or have a Particular Material Appraisal (PMA) as defined in EN 764-4.

5.2.1.2 Corrosion

The material selected for the bellows element shall have adequate resistance to all the corrosive agents likely to be encountered during the lifetime of the system.

Topics of special consideration include pitting corrosion, intergranular corrosion, crevice corrosion and stress corrosion cracking.

NOTE Bellows generally have a wall thickness substantially less than that of the rest of the system with which they are used. Hence the bellows are often manufactured from a material having a higher corrosion resistance than that used in the associated plant.

5.2.2 Other pressure-bearing parts

Allowable materials for other pressure-bearing parts shall be selected from Table 5.1 or from the standards given in Table 5.2 dependent on the application.

The use of low temperatures related to stress levels less than 1,0 given in Table 5.2 is allowed if the following additional demands are fulfilled to achieve similar safety against brittle fracture:

- a) The expansion joint manufacturer shall make sure that:
 - 1) from the design and the manufacture stress peaks are avoided;
 - 2) under working conditions no cracks are expected.
- b) The expansion joint manufacturer shall in addition carry out suitable stress releasing heat treatment after forming or welding.

Heat treatment after forming or welding is not necessary for the stress level 0,75 and for ferritic materials belonging to group 1.1 or 1.2 according to Table J.7 and having a wall thickness not greater than 10 mm.

Other materials may be used provided they fulfil the general requirements of 5.1 and conform to a harmonized standard or comply with a European Approval for Materials (EAM) or have a Particular Material Appraisal (PMA) as defined in EN 764-4.

5.2.3 Ductility

All materials shall be sufficiently ductile in the delivery state.

No material shall be used for main pressure-bearing parts (4.2.1) and other pressure-bearing parts (4.2.2) having an elongation after rupture A less than 14 % and A_{10} an impact energy A_1 less than 27 J, measured on an ISO V test-piece at a temperature not greater than 20 °C and not higher than the lowest scheduled operating temperature.

Bellows materials after forming shall in addition conform to the requirements given in 7.4.

5.2.4 Brittle fracture

Consideration shall be given to the prevention of brittle fracture, especially for expansion joints that are subjected to temperatures below – 10 °C:

- a) Bellows shall be manufactured from the allowable materials according to 5.2.1.1. If bellows are manufactured from materials according to Table 5.1 they shall not be used at temperatures lower than that given in the column "Minimum" in this table, except the nickel alloys 2.4816 and 2.4856.

To enable the use of these nickel alloys at lower temperatures impact energy values shall be specified and verification procedures shall be agreed to between the material manufacturer and the purchaser at the time of ordering.

- b) Other pressure-bearing parts shall be manufactured from the allowable materials according to 5.2.2 and shall not be used at temperatures below that given in Table 5.1 and Table 5.2, except the nickel alloys 2.4816 and 2.4856, see a).

Materials with more than 5 mm thickness for ferritic steel (Group 1) or more than 20 mm thickness for austenitic stainless steel (Group 8) and for nickel alloys shall pass a Charpy V-notch test according to EN 10045-1 if the A_1 impact energy A_1 is not already covered by the related material standard.

Its A_1 impact energy A_1 shall be measured by the impact test at a temperature not greater than 20 °C and not higher than the lowest scheduled operating temperature or at a test temperature of – 196 °C when the operating temperature is less.

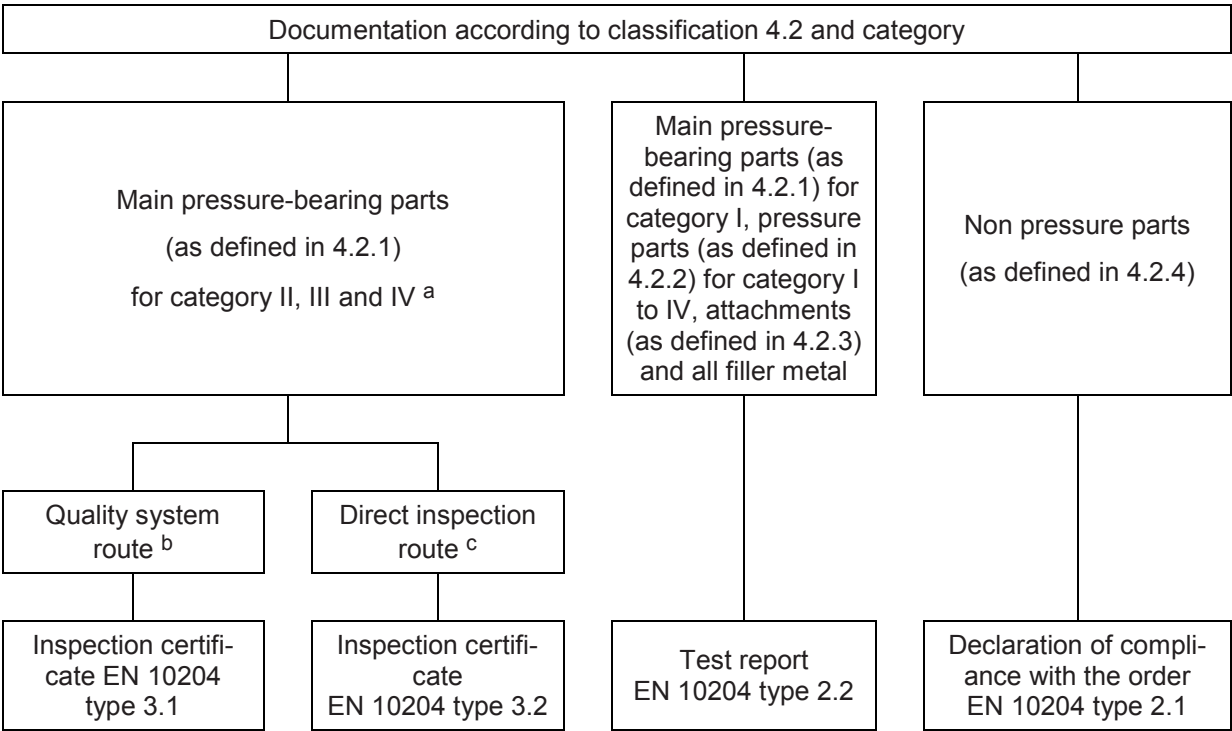
The measured impact energy shall be:

- for ferritic steels (Group 1) in minimum 27 Joules;
- for austenitic stainless steel (Group 8) and for nickel alloys in minimum 40 Joules or that given in the relating standard what ever is greater.

5.3 Material documentation

Materials used for expansion joints shall be delivered with documentation as defined in EN 764-5.

A simplified diagram of the routes for inspection, documentation and compliance with the material specification is given in Figure 5.3.



- ^a The categories are described in Annex A.
- ^b The quality system route (production under QM system coverage according to EN 764-5 / Clause 4) shall be used when using a listed material.
- ^c The direct inspection route (according to EN 764-5 / Clause 5) shall be used when using a material not listed.

Figure 5.3 — Required material documentation

Table 5.1 — Materials for bellows elements and other pressure bearing parts and their temperature limits (see also Table 5.2)
(Additional information see Annex J)

Material			Temperature °C		Document
Type	Number	Steel name	Minimum	Maximum	
stainless austenitic steels	1.4301	X5CrNi18-10	– 196 ^a	550	EN 10028-7:2007
	1.4306	X2CrNi19-11	– 270 ^a	550	
	1.4401	X5CrNiMo17-12-2	– 196 ^a	550	
	1.4404	X2CrNiMo17-12-2	– 270 ^b	550	
	1.4435	X2CrNiMo18-14-3	– 270 ^a	550	
	1.4539	X1CrNiMoCuN25-20-5	– 196 ^a	550	
	1.4541	X6CrNiTi18-10	– 270 ^c	550	
	1.4550	X6CrNiNb18-10	– 196 ^a	550	
	1.4571	X6CrNiMoTi17-12-2	– 270 ^c	550	
heat resistant austenitic steels	1.4828	X15CrNiSi20-12	–196	900 ^d	Annex B, Position 1
	1.4876	X10NiCrAlTi32-21 X10NiCrAlTi32-21 (H)	– 196	600 900 ^d	Annex B, Position 2.1 Annex B, Position 2.2
Nickel alloys	2.4610	NiMo16Cr16Ti	– 196	400	EAM-0526-28
	2.4816	NiCr15Fe	– 10 (– 270)	450 (900) ^d	EAM-0526-43-1, EAM-0526-43-2 ([9], [10])
	2.4819	NiMo16Cr15W	– 196	400	EAM-0526-18
	2.4856	NiCr22Mo9Nb	– 196 (– 270)	450 (900) ^d	EAM-0526-40 ([11], [12])
	2.4360	NiCu30Fe	– 196	425	Annex B, Position 3
	2.4858	NiCr21Mo	– 270	540	Annex B, Position 4
ferritic steels	1.0345	P235GH	– 20	400	EN 10028-2:2009
	1.0425	P265GH	– 20	400	
	1.5415	16Mo3	– 20 ^e	500	
	1.7335	13CrMo4-5	– 20 ^e	500	
	1.0565	P355NH	– 20	400	EN 10028-3:2009
	1.8935	P460NH	– 20	400	
^a Minimum temperature according to EN 13445-2/Annex B or EN 13480-2/Annex B.					
^b Minimum temperature according to CERN [7].					
^c Minimum temperature for cold-rolled strip up to 6 mm and hot-rolled sheet up to 12 mm thickness [2].					
^d Special care should be exercised due to the risk of embrittlement when using the materials at elevated temperatures above 550 °C.					
^e Minimum temperature is possible when the specified minimum impact energy (normally 27 J) can be proved.					

A1

Table 5.2 — Material standards for other pressure-bearing parts

Running no	Description	European Standard	Lowest allowable working temperature in °C		
			Stress level		
			1,0	0,75 ^a	0,25 ^a
1	Non-alloy steel tubes with specified room temperature properties: — seamless pipes — welded pipes	EN 10216-1 EN 10217-1	– 10	– 60 ^b	– 85 ^b
2	Non-alloy and alloy steels with specified properties at elevated temperatures: — flat products — seamless pipes — welded pipes (E-welded) — welded pipes (SA-welded) — steel forgings — bars — fasteners	EN 10028-2 ^c EN 10216-2 EN 10217-2 EN 10217-5 EN 10222-2 EN 10272, EN 10273 EN 10269	– 10	– 60	– 85
3	Weldable fine grain mild steels, normalized: — flat products — seamless pipes — welded pipes — steel forgings	EN 10028-3 (P...NH) EN 10216-3 EN 10217-3 EN 10222-4	– 20	– 70	– 100
4	Flat and long products from weldable fine grain mild steels, normalized / normalized rolled with specified low temperature properties	EN 10028-3 (P...NL1, NL2)	$T_{\min}^d$	$T_{\min} - 50$	$T_{\min} - 80$
5	Flat products for pressure purpose from Nickel alloy steels with specified low temperature properties	EN 10028-4	$T_{\min}^d$	$T_{\min} - 50$	$T_{\min} - 80$
6	Pipes for pressure purpose, from non-alloy steels with specified low temperature properties: — seamless pipes — welded pipes (E-welded) — welded pipes (SA-welded)	EN 10216-4 EN 10217-4 EN 10217-6	$T_{\min}^d$	$T_{\min} - 50$	$T_{\min} - 80$
7	Forgings for pressure purpose, Nickel steels with specified low temperature properties	EN 10222-3	$T_{\min}^d$	$T_{\min} - 50$	$T_{\min} - 80$
8	Fittings for welding, with specified low temperature properties	EN 10253-2	$T_{\min}^d$	$T_{\min} - 50$	$T_{\min} - 80$
9	Austenitic stainless steels according to Table 5.1 with minimum allowable temperature – 196°C	EN 10028-7	– 196	– 255	– 270
^a Additional requirements for stress levels smaller than 1,0, see 5.2.2. ^b Killed steels only. ^c For materials suitable for use at – 20 °C, see temperatures according to running number 3. ^d Lowest temperature of the regarded material according to the mentioned standards.					

6 Design

6.1 General

6.1.1 Symbols and general factors

6.1.1.1 Symbols

The following symbols listed in Table 6.1.1.1 apply.

Table 6.1.1.1 — Symbols

Symbol	Description	Unit
A	elongation at rupture according to EN 10002-1	%
A_c	cross sectional metal area of one corrugation; see Equation (6.1.1.2.1-1)	mm ²
A_e	bellows effective area; see Equation (6.1.1.2.1-2)	mm ²
A_f	cross sectional metal area of one reinforcement fastener (see Figure 6.2.4.1-1)	mm ²
A_r	cross sectional metal area of one bellows reinforcing member (see Figure 6.2.4.1-1)	mm ²
a	factor for calculation of the effective spring rate (see Table 6.2.9.2)	—
[A1] deleted text [A1]		
b	factor for calculation of the effective spring rate (see Table 6.2.9.2)	—
b_n	nominal width of material (strip, sheet, plate); see Table 7.5.2.1.1-1	
C_1, C_2	[A1] factors used to determine the coefficients C_p, C_f, C_d ; see Equations (6.1.1.2.1-3) and (6.1.1.2.1-4) [A1]	—
C_p, C_f, C_d	coefficients for U-shaped corrugations (see Figures 6.1.1.2.2-1, -2 and -3)	—
$\hat{c}$	increasing factor for angular rotated bellows under pressure (see 6.2.8.4)	—
c_σ	stress correction factor; see Equation (6.2.8.4.4-1)	—
[A1] c_w	stress correction factor for bellows with circumferential welds; see Equation (6.2.3.7.5-2)	— [A1]
D	external diameter of tubular shape section [A1] deleted text [A1]	mm
D_c	mean diameter of end tangent reinforcing collar; see Equation (6.1.1.2.1-5)	mm
D_i	inside diameter of bellows corrugation and end tangents (see e.g. Figure 6.2.3.1-1)	mm
D_m	mean diameter of bellows corrugation; see Equation (6.1.1.2.1-6)	mm
d	internal diameter of tubular shape section [A1] deleted text [A1]	mm
d_p	pin diameter (see [A1] Table 6.3.2.2 [A1])	mm
d_H	bearing diameter of the hinges, pin or sphere (see 6.2.9.3.2)	mm
E_B	modulus of elasticity of bellows material at design temperature	N/mm ² (MPa)
E_c	modulus of elasticity of collar material at design temperature	N/mm ² (MPa)
E_f	modulus of elasticity of fastener material at design temperature	N/mm ² (MPa)
E_r	modulus of elasticity of reinforcing ring material at design temperature	N/mm ² (MPa)
E_0	modulus of elasticity of bellows material at room temperature	N/mm ² (MPa)
e	bellows nominal thickness; see Equation (6.1.1.2.1-7)	mm
e_c	end tangent reinforcing collar thickness (see Figures 6.2.3.1-1, 6.2.4.1-1 and 6.2.5.1-1)	mm
e_p	nominal thickness of one ply	mm
e^*	equivalent bellows wall thickness, corrected for thinning during forming; see Equation (6.1.1.2.1-8)	mm
e_p^*	equivalent thickness of one ply, corrected for thinning during forming; see Equation (6.1.1.2.1-9)	mm
F_{alw}	allowable force in tension for lug in the bored cross section (see [A1] Table 6.3.4.3-1 [A1])	N
F_p	force due to pressure effect (pressure thrust); see Equation (6.1.1.2.1-10)	N
F_w	working force of bellows (see 6.2.9.3)	N
f	allowable general membrane stress at design temperature (see Table 6.1.2.3)	N/mm ² (MPa)
[A1] f_{20}	allowable general membrane stress at ambient temperature	N/mm ² (MPa) [A1]
f_T	allowable general membrane stress at test conditions (see Table 6.1.2.3)	N/mm ² (MPa)
[A1] f_y	height of arch related to lateral deflection; see Equation (D.3-3)	mm [A1]
[A1] deleted text [A1]		

Table 6.1.1.1 (continued)

Symbol	Description	Unit
H	width of lug in the bored cross section (see [A1] Table 6.3.2.2 [A1])	mm
K_B	axial spring rate of one bellows; see Equations (6.2.3.8-1), (6.2.4.6-1) and (6.2.5.7-1)	N/mm
K_d	cold-work factor; see Equation (6.2.3.3-1)	—
K_F	friction factor to calculate the forces or moments due to the friction in the restraining parts (see 6.2.9.3)	mm ² or mm ³
$\tilde{K}$	effective spring rate of a bellows (see 6.2.9.3)	N/mm
K_P	[A1] pressure factor giving additional forces or moments of angular rotated or lateral deflected bellows due to the influence of pressure (see 6.2.9.3.2 and 6.2.9.3.3) [A1]	mm or mm ² or mm ³ /radian
K_w	working spring rate of a bellows (see 6.2.9.3)	N/mm
K_β	factor for the effect of the side wall angle on forces or moments (see 6.2.9.3)	N/mm ² or Nmm/radian ²
K_μ	factor for the effect of friction between the plies on forces or moments (see 6.2.9.3)	mm ² or mm ³
$K_{m,b}$, $K_{\theta,l}$	in-plane instability factors; see Equations (6.2.3.3-2) and (6.2.3.3-3)	—
k	correction factor considering stiffening effect of attachment weld and end corrugation on the pressure capacity of the end tangent; see Equation (6.2.3.3-4)	—
$k_{p,t}$	de-rating factor for the pressure at the temperature t (see 6.1.2.2)	—
k_s	stabilising factor for definition of column instability; see Equation (6.2.3.4.2.1-3)	—
k_1	factor for occasional load (see 6.3.2.2)	—
k_2	bored cross section correction factor for lug (see [A1] Table 6.3.4.3-1 [A1])	—
[A1] deleted text [A1]		
$k_{\Delta,t}$	de-rating factor for the movement Δ at the temperature t (6.1.2.2)	—
L	distance of the pin centre line to the end of the head of the lug (see [A1] Table 6.3.2.2 [A1])	mm
L_c	bellows collar length (see Figures 6.2.3.1-1, 6.2.4.1-1 and 6.2.5.1-1)	mm
L_t	end tangent length (see Figures 6.2.3.1-1, 6.2.4.1-1 and 6.2.5.1-1)	mm
l_B	initial corrugated length of a bellows (see Figure 6.2.7.1-1)	mm
$\bar{l}_B$	equalised corrugated length of a bellows; see Equation (6.2.3.4.2.1-2)	mm
l^*	middle distance of the bellows of a double bellows type; see Figure 6.2.7.3-2	mm
M_w	working moment of bellows (see 6.2.9.3)	Nmm
M_y	moment due to lateral deflection (see 6.2.7)	Nmm
M_θ	moment due to angular rotation (see 6.2.7)	Nmm
N	number of corrugations of one bellows	—
N_{alw}	allowable number of fatigue cycles	—
N_{spe}	specified number of fatigue cycles	—
n	exponent for calculation of the effective spring rate (see Table 6.2.9.2)	—
n_p	number of plies	—
n_B	[A1] number of bellows (for universal expansion joints, usually $n_B = 2$) [A1]	—
p^a	calculation pressure	N/mm ² (MPa)
P_m	primary membrane stress (see [A1] Table 6.3.2.2 [A1])	N/mm ² (MPa)
P_L	primary local membrane stress (see [A1] Table 6.3.2.2 [A1])	N/mm ² (MPa)
P_b	primary bending stress (see [A1] Table 6.3.2.2 [A1])	N/mm ² (MPa)
PS^a	maximum allowable pressure	N/mm ² (MPa)
P_{sc}	limiting internal design pressure based on column instability	N/mm ² (MPa)
P_{si}	limiting design pressure based on in-plane instability and local plasticity	N/mm ² (MPa)
PT	test pressure	bar
$P_{t,max}^a$	maximum allowable pressure at temperature t	bar

Table 6.1.1.1 (continued)

Symbol	Description	Unit
q	corrugation length (see Figures 6.2.3.1-1, 6.2.4.1-1 and 6.2.5.1-1)	mm
R_e^*	effective proof strength at design temperature (unless otherwise specified) of bellows material in the as-formed, or annealed condition; see Equations (6.2.3.3-5a) and (6.2.3.3-5b)	N/mm ² (MPa)
$R_{eH,t}$	minimum specified value of upper yield strength at design temperature	N/mm ² (MPa)
$R_{m,t}$	minimum specified value of tensile strength at design temperature	N/mm ² (MPa)
$R_{m,20}$	minimum specified value of tensile strength at room temperature	N/mm ² (MPa)
$R_{p0,t}$	maximum elastic strength at design temperature (see Table 6.2.9.2)	N/mm ² (MPa)
$R_{p0,2,t}$	minimum specified value of 0,2 % proof strength at design temperature	N/mm ² (MPa)
$R_{p1,0,t}$	minimum specified value of 1 % proof strength at design temperature	N/mm ² (MPa)
r_i	internal radius of crest and root torus of U-shaped corrugations ; see Equation (6.1.1.2.1-11) and Figures 6.2.3.1-1 and 6.2.4.1-1	mm
r_m	mean radius of torus at the crest and the root of U-shaped corrugations, see Equation (6.1.1.2.1-12)	mm
S	shear modulus; see Equation (6.2.10-3)	N/mm ² (MPa)
S_L	thickness of the lug in the bored cross section (see A1 Table 6.3.2.2 A1)	mm
s_θ	circumferential true strain caused by deformation; see Equations (6.2.2.5-2), (6.2.2.5-3), (6.2.5.2-2) and (6.2.5.2-4)	—
s_b	bending component of true strain caused by deformation; see Equations (6.2.2.5-4), (6.2.2.5-5), (6.2.5.2-3) and (6.2.5.2-5)	—
s_d	strain caused by deformation; see Equation (6.2.2.5-1)	—
s_r	true strain of rupture; see Equation (7.4.1.2-1)	—
t	design temperature of the hardware parts (see 6.3.3.1)	°C
A1 deleted text A1		
t_n	nominal thickness of the material (strip, sheet, plate) ; see Table 7.5.2.1.1-1	mm
w	corrugation height, see e.g. Figures 6.2.3.1-1 and 6.2.4.1-1	mm
x	applied axial displacement from the neutral position (see 6.2.7)	mm
x^*	normalised axial displacement; see Equation (6.2.9.3.1-2)	—
x_{el}	maximum axial displacement in the elastic range; see Equation (6.2.9.3.1-2)	mm
$\bar{x}$	mean axial displacement; see Equation (6.2.9.3.1-2)	mm
y	applied lateral deflection (see 6.2.7)	mm
y^*	normalised lateral deflection (see 6.2.9.3.2.2-2)	—
y_{el}	maximum lateral deflection in the elastic range; see Equation (6.2.9.3.2.2-2)	mm
$\bar{y}$	mean lateral deflexion; see Equation (6.2.9.3.2.2-2)	mm
z	joint coefficient (see A1 Table 6.3.2.2 A1 , 6.3.4.7 and 8.4.4)	—
α	in-plane instability stress interaction factor, see Equation (6.2.3.3-6)	—
β	side wall angle of the corrugation; subscripts denote initial "0" and extended position "e" (see Figure 6.2.3.2-1, respectively Equations (6.2.3.2-3), (6.2.4.2-3) and (6.2.8.2-4c)	degree
δ	in-plane instability stress ratio, see Equation (6.2.3.3-7)	—
η	factor for the influence of the forming process; see Equation (6.2.2.5-8)	—
κ	calculation factor; see Equation (6.1.1.2.1-13)	1/mm
μ	friction coefficients (see 6.2.9.3)	—
ν_B	Poisson's ratio of bellows material (for stainless steel $\nu = 0,3$)	—
θ	applied angular rotation per individual bellows (see 6.2.7)	radians
θ^*	normalised angular rotation; see Equation (6.2.9.3.3-2)	—
θ_{el}	maximum angular rotation in the elastic range; see Equation (6.2.9.3.3-2)	radians
$\bar{\theta}$	mean angular rotation; see Equation (6.2.9.3.3-2)	radians
Δq	equivalent axial displacement per corrugation (see 6.2.7)	mm
Δ_t	maximum allowable movement (axial, lateral or angular) at the temperature t	mm or degree
Δ_N	maximum allowable movement (axial, lateral or angular) at ambient temperature (20 °C)	mm or degree

Table 6.1.1.1 (continued)

Symbol	Description	Unit
$\sigma(P)$	stress depending on P	N/mm ² (MPa)
$\sigma(\Delta q)$	stress depending on Δq	N/mm ² (MPa)
σ_{eq}	$\langle A_1 \rangle$ total equivalent stress range due to cyclic displacement $\langle A_1 \rangle$	N/mm ² (MPa)
Subscripts: 0 initial B bellows H hinge P pin T test conditions b bending c collar, corrugation $\langle A_1 \rangle$, compression $\langle A_1 \rangle$ d deformation $\langle A_1 \rangle$ e extension $\langle A_1 \rangle$ el elastic f fastener h hardware i inside m membrane or meridional or mean o outside p plies r reinforced bellows t end tangents or torsion or toroidal or temperature Δ difference Θ circumferential Σ sum μ friction		
a All pressures for calculation purposes are in N/mm ² (MPa) and $p_{t, max}$ is in bar.		

6.1.1.2 $\langle A_1 \rangle$ General factors and coefficients $\langle A_1 \rangle$

6.1.1.2.1 General intermediate factors

The following general factors apply in the calculations of this subclause.

$$A_c = 2 \cdot e \cdot \left[w + r_m \cdot (\pi - 2) \right] \quad (6.1.1.2.1-1)$$

$$A_e = \frac{\pi}{4} \cdot D_m^2 \quad (6.1.1.2.1-2)$$

$$C_1 = \frac{2 \cdot r_m}{w} \quad (6.1.1.2.1-3)$$

$$C_2 = \frac{2r_m}{1,1 \sqrt{D_m \cdot e_p^*}} \quad (6.1.1.2.1-4)$$

$$D_c = D_i + 2 \cdot e + e_c \quad (6.1.1.2.1-5)$$

$$D_m = D_i + e + w \quad (6.1.1.2.1-6)$$

$$e = n_p \cdot e_p \quad (6.1.1.2.1-7)$$

$$e^* = n_p \cdot e_p^* \quad (6.1.1.2.1-8)$$

$$e_p^* = e_p \cdot \left[(1 - \eta) \cdot \left(1 + \frac{(1 - \eta) \cdot w}{D_i} \right)^{-\frac{1}{2}} + \eta \cdot \left(1 + \frac{\eta \cdot w}{D_i} \right)^{-\frac{2}{3}} \right] \quad (6.1.1.2.1-9)$$

$$F_p = P \cdot A_e \quad (6.1.1.2.1-10)$$

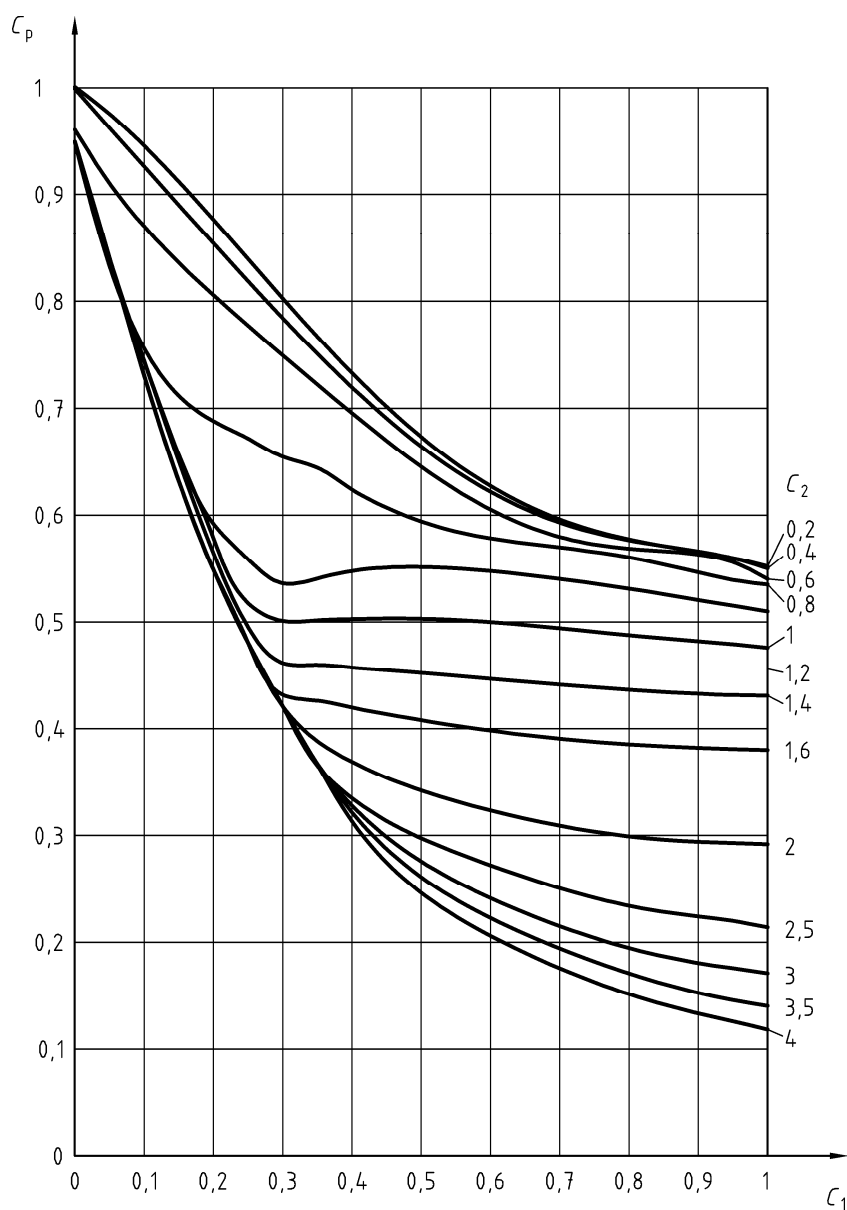
$$r_i = (r_{ic} + r_{ir})/2 \quad (6.1.1.2.1-11)$$

$$r_m = r_i + e/2 \quad (6.1.1.2.1-12)$$

$$\kappa = \sqrt{2 \cdot \pi \cdot \frac{P}{K_B \cdot l_B}} \quad (6.1.1.2.1-13)$$

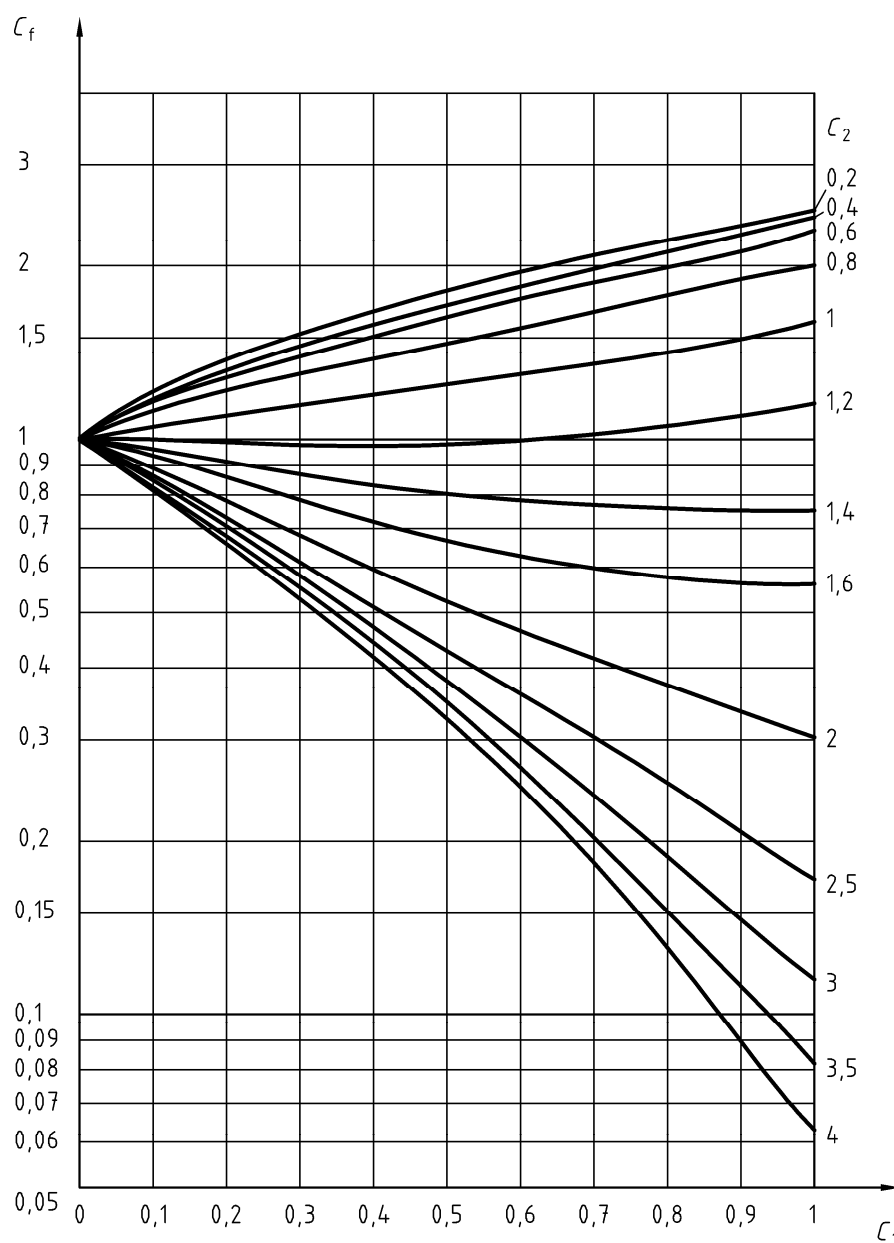
6.1.1.2.2 Coefficients C_p , C_f , C_d

A1



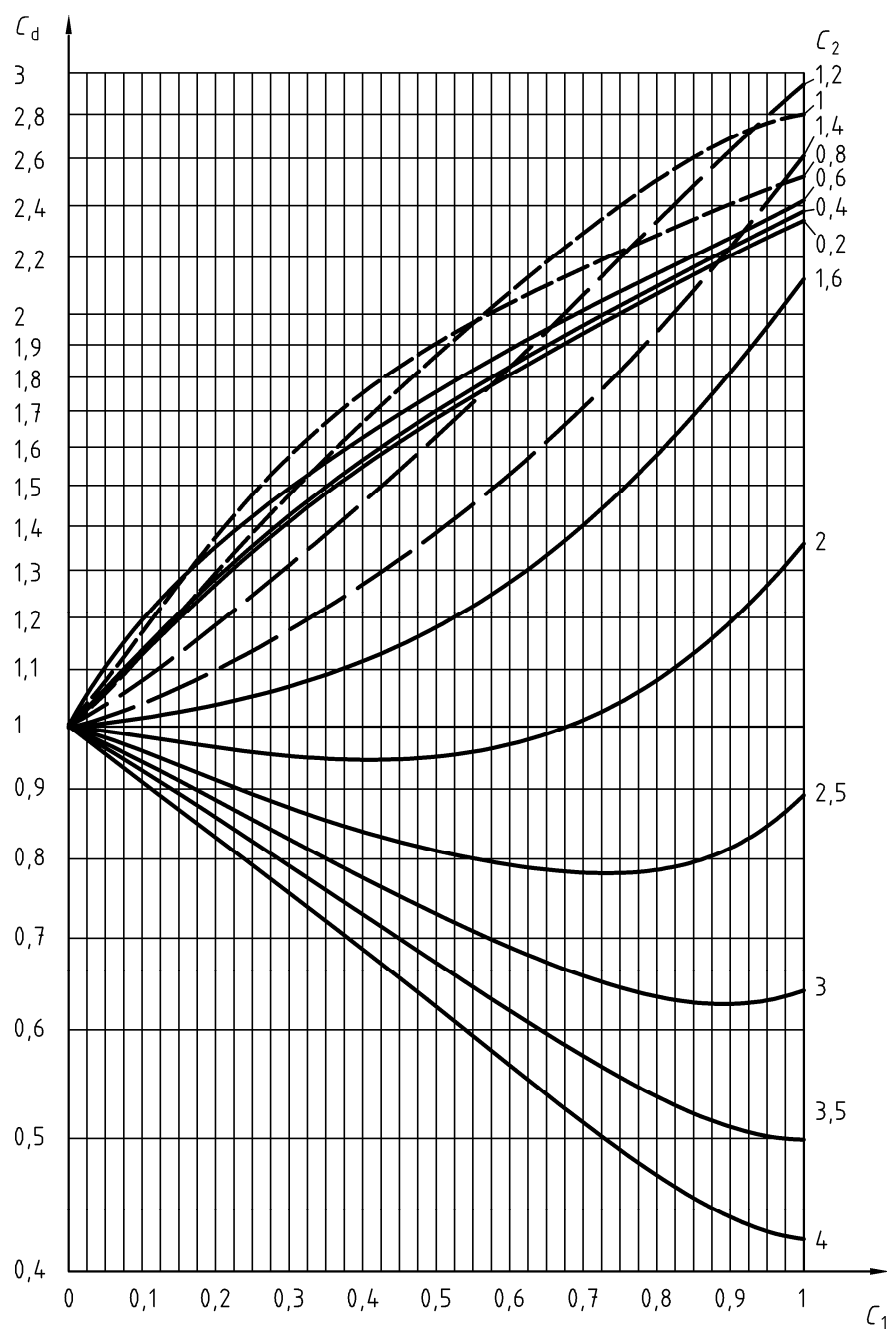
NOTE Annex G gives polynomial approximations for these curves.

Figure 6.1.1.2.2-1 — Coefficient C_p



NOTE Annex G gives polynomial approximations for these curves.

Figure 6.1.1.2.2-2 — Coefficient C_f



NOTE Annex G gives polynomial approximations for these curves.

Figure 6.1.1.2.2-3 — Coefficient C_d $\left[\frac{A_1}{A_2} \right]$

6.1.2 Basic design criteria

6.1.2.1 General design

6.1.2.1.1 General

Expansion joints shall be designed to withstand the specified pressure PS at the specified temperature TS. This combination of pressure and temperature shall as a minimum represent the most onerous foreseeable working conditions.

The specified additional loads according to 6.1.3 shall be taken into account as well.

NOTE The Annex H gives the main design conditions and information and may be used as a guideline.

6.1.2.1.2 Bellows

Shall be designed according to 6.2.

6.1.2.1.3 Flanges

Shall be according to EN 1092-1.

6.1.2.1.4 Pipe sections

Shall be designed according to the appropriate standard EN 13445-3 or EN 13480-3.

6.1.2.1.5 Internal sleeves

Shall be designed according to 6.4.

6.1.2.1.6 Hardware

Shall be designed according to 6.3.

6.1.2.2 Design on PN basis

Expansion joints designed on PN basis may be designated for temperatures higher than 20 °C. In these cases the manufacturers de-rating factors for pressure $k_{p,t}$ and movement $k_{\Delta,t}$, which shall be based on the respective material standards, shall be applied according to the following equations:

$$p_{t,max} = PN \cdot k_{p,t} \quad (6.1.2.2-1)$$

$$\Delta_{t,max} = \Delta_N \cdot k_{\Delta,t} \quad (6.1.2.2-2)$$

6.1.2.3 Allowable stresses

For main pressure-bearing parts and pressure parts other than bolts the maximum allowable stresses (general membrane stress for predominantly static loads) shall be determined as in Table 6.1.2.3.

Table 6.1.2.3 — Allowable stresses

Material	Design conditions ^a	Test conditions ^a
Austenitic steel and Ni alloys — general — alternatively ^b if $A > 35\%$	$f = \left(\frac{R_{p1,0,t}}{1,5} \right)$ $f = \min \left(\frac{R_{p1,0,t}}{1,2}; \frac{R_{m,t}}{3} \right)$	$f_T = \left(\frac{R_{p1,0,tT}}{1,05} \right)$ $f_T = \max \left(\frac{R_{p1,0,tT}}{1,05}; \frac{R_{m,tT}}{2} \right)$
Ferritic steel ^c including normalised (normalised rolled) steel	$f = \min \left(\frac{R_{p0,2,t}}{1,5}; \frac{R_{m,20}}{2,4} \right)$	$f_T = \left(\frac{R_{p0,2,tT}}{1,05} \right)$
^a Proof stress $R_{p0,2}$ may be replaced by yield strength R_{eH} . ^b Shall not be used for the design of bellows. ^c Fine-grained steel and specially heat-treated steel non-alloy or low-alloy cast steel are excluded.		

6.1.3 Additional loadings

Additional loadings (normal or occasional) shall be stated by the equipment manufacturer.

Additional loadings that may influence the design of expansion joints, but are not the loads normally regarded for the design of bellows (see 6.2.2.2), shall also be taken into account.

Loadings present within the expansion joint:

- dead weight of expansion joint components (i.e. intermediate pipe, inner sleeve, restraint hardware, refractory linings etc.);
- dead weight of flow medium within expansion joint;
- dynamic loading due to flow of medium.

External loadings due to adjacent piping or equipment:

- unsupported weight of adjacent piping/equipment;
- pipe pre-stressing;
- thermal movement;
- environmental (i.e. snow, wind etc.);
- vibration from adjacent equipment (i.e. pumps, compressors, machines, etc.);
- shock loading (i.e. earth quake, explosion loading, etc.);
- dynamic loading due to flow of medium.

This list is not exhaustive.

External loadings (normal or occasional) shall be stated by the piping or pressure vessel manufacturer.

6.2 Bellows

6.2.1 Purpose

This subclause provides rules for design and calculation of bellows subject to internal and external pressure and cyclic displacement.

The rules are applicable to the following types of bellows (single or multiple corrugations):

- a) unreinforced U-shaped bellows as shown in Figure 6.2.3.1-1;
- b) reinforced U-shaped bellows as shown in Figure 6.2.4.1-1;
- c) toroidal bellows as shown in Figure 6.2.5.1-1.

They are part of expansion joints as defined in Clause 4.

NOTE Attention is drawn to the fact that the design of bellows is complex because strength and flexibility requirements are generally conflicting. Annex E gives detailed information on this issue.

6.2.2 Conditions of applicability

6.2.2.1 Geometry

- a) A bellows comprises one or more identical corrugations. Each corrugation is axisymmetric.
- b) Each corrugation may have one or more plies of the same thickness and same material.

A1 *deleted text* A1

- c) The number of plies shall be such that:

$$n_p \leq 5$$

6.2.2.2 Loadings

Loadings mainly regarded for the design of bellows dealt with in 6.2 are static or variable internal pressure, and cyclic axial, lateral or angular displacements.

Specific rules are given to cover external pressure (see 6.2.3.5) and bellows torsion (see 6.2.10).

Additional loadings according to 6.1.3 shall be given special consideration.

6.2.2.3 Temperature

These requirements are only valid at temperatures below the creep range, as stated in 5.2.1.1 or in the relevant European material standards.

6.2.2.4 Welding seams

6.2.2.4.1 General

Typical welding joints are shown in Figures  8.4.3.1-1a  and  8.4.3.1-1b .

6.2.2.4.2 Longitudinal butt welds W1 and W2

Bellows may include one or several longitudinal butt welds.

- a) bellows with circumferential welds (see 6.2.3.7): the concept of weld joint coefficient z shall be applied to longitudinal butt welds W1;
- b) bellows without circumferential welds: the concept of weld joint coefficient z does not apply to longitudinal butt welds W2.

6.2.2.4.3 Circumferential butt welds W3

For bellows with circumferential welds (see 6.2.3.7) and for butt weld bellows attachment as shown in Table 6.2.2.4.4-1 No 3.0, the concept of weld joint coefficient z shall be applied to such butt welds W3.

6.2.2.4.4 Bellows attachment welds

The circumferential attachment welds of single and multi-ply bellows shall be designed according to the sketches given in Table 6.2.2.4.4-1. For butt weld bellows attachment as shown in Table 6.2.2.4.4-1, No 3.0, the provision of 6.2.2.4.3 shall be applied.

Table 6.2.2.4.4-1 — Bellows attachment welds

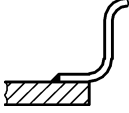
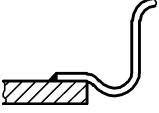
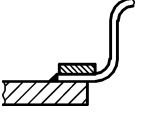
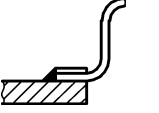
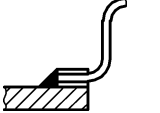
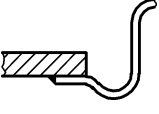
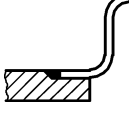
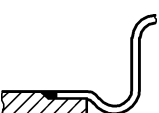
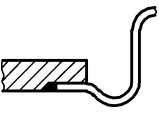
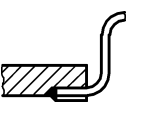
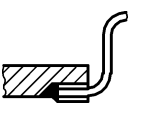
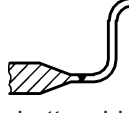
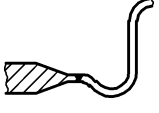
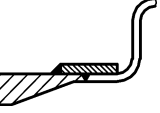
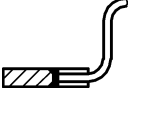
Weld type		Variants (Combinations of A to D are permitted)			
No	General design	A increased neck	B reinforcing collar	C Assisting collar single	D double
1.1	 outside lap joint/filled weld				
1.2	 inside lap joints/fillet weld				
2.1	 outs. lap joint/groove weld				
2.2	 inside lap joint/groove weld				
3.0	 butt weld				
4.1	 radial edge weld (inside or outside)				

Table 6.2.2.4.4-1 (continued)

Weld type		Variants (Combinations of A to D are permitted)			
No	General design	A increased neck	B reinforcing collar	C assisting collar single	D double
4.2	 axial edge weld (inside or outside)				
General: Fittings and reinforcing collars opposite to the pressure bearing side of the bellows shall have a radius or a bevel at the edge in contact with the bellows and tangent. a In the case of fillet welds, the weld thickness "a" shall fulfil following equation: $a \geq 0,7 \cdot e$. b A reinforcing collar is advisable, if the cylindrical end tangent of bellows L_t exceeds: $L_t \geq 0,5 \cdot \sqrt{D_i \cdot e_p}$ c The reinforcing collar shall be fixed axially by welding or mechanical devices. d In the case of butt welds, special tools are necessary for welding of multi-ply bellows. e The diameter of the weld shall not exceed the mean diameter of bellows D_m by more than 20 % of the corrugations height w.					

6.2.2.5 Strain caused by deformation

The maximum equivalent true strain caused by deformation is given for bellows by:

$$\boxed{A_1} s_d = \max \left\{ \begin{array}{l} 1,04 \cdot \sqrt{s_{\Theta,o}^2 + 0,31 \cdot s_{\Theta,o} \cdot s_{b,o} + 0,41 \cdot s_{b,o}^2} \\ 2,0 \cdot \left| s_{\Theta,i} - \frac{1}{3} s_{b,i} \right| \end{array} \right\} \boxed{A_1}, \quad (6.2.2.5-1)$$

at the crest (outside) respectively at the root (inside) of a corrugation after the forming process, where the components of the true strains — also depending on their position — are:

— for the circumferential direction:

$$s_{\Theta,o} = \ln \left[(D_i + 2 \cdot w) / (D_i + 2 \cdot \eta \cdot w) \right] \quad (6.2.2.5-2)$$

$$s_{\Theta,i} = \ln \left[D_i / (D_i + 2 \cdot \eta \cdot w) \right] \quad (6.2.2.5-3)$$

— for the bending components:

$$s_{b,o} = \frac{1}{2} \ln \left(1 + \frac{e_{p,o}}{r_{i,c}} \right) \quad (6.2.2.5-4)$$

$$s_{b,i} = \frac{1}{2} \ln \left(1 + \frac{e_{p,i}}{r_{i,r}} \right), \quad (6.2.2.5-5)$$

— where the minimum wall thickness is given by:

$$e_{p,o} = e_p \cdot \left(\frac{D_i + 2 \cdot w}{D_i + 2 \cdot \eta \cdot w} \right)^{-0,75} \quad (6.2.2.5-6)$$

$$e_{p,i} = e_p \cdot \left(\frac{D_i}{D_i + 2 \cdot \eta \cdot w} \right) \quad (6.2.2.5-7)$$

The forming factor η is defined as:

$$\eta = \left(\frac{D_0 - D_i}{2w} \right) \quad (6.2.2.5-8)$$

with the neutral diameter D_0 as the original inner diameter of the cylinder or of the ring plate before forming starts. It is depending on the forming process, see Table 6.2.2.5-1 below for information.

For bellows made of half-corrugations, see Figure 6.2.3.7.1-1. D_0 can be calculated from the ready formed S-shape of the half-corrugation as follows:

$$D_0 = D_i + e_p - \left(\frac{\pi}{2} - 1 \right) \cdot (2r_i + e_p) \quad (6.2.2.5-9)$$

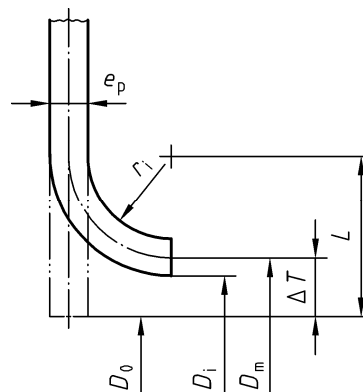


Figure 6.2.2.5-1 — Root of a half-corrugation

NOTE Half-corrugations are manufactured from ring plates with a centre hole bending their outer and inner edges to a S-shaped profile by rolling or other methods, with the maximum strain occurring at the inner root formed to the outside.

Table 6.2.2.5-1 — Typical values of forming factor η (informative)

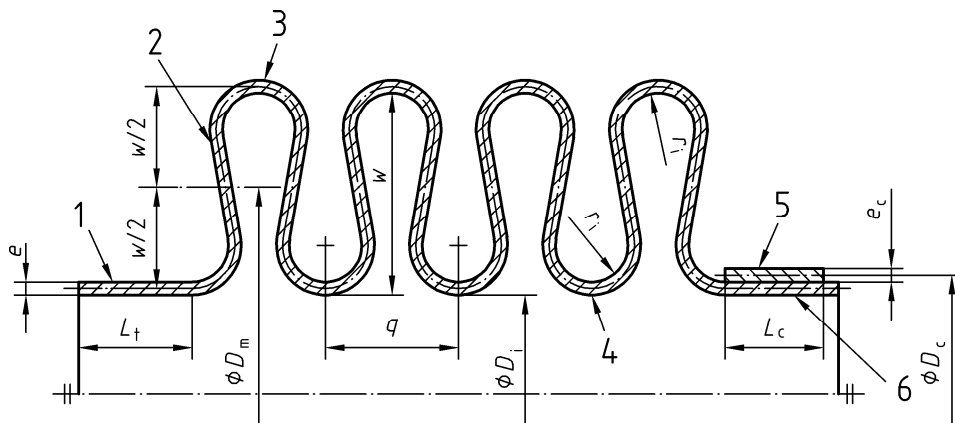
Forming process for corrugations		Forming factor η	Remarks
1	from inside to outside with restraining tools starting from the inner diameter D_i by: — hydraulic forming (including elastomer cushion) — expansion (punching) — roll-forming	0	Outside restraining tools holding back the roots of the corrugations
2	partly to outside and to inside with restraining tool starting from a neutral diameter D_0 by: — roll-forming — combined process (hydraulic, elastomer or expansion and roll-forming)	0,4 to 0,6	Restraining tools holding back the neutral diameter D_0
3	partly to outside and to inside without restraining tools (free forming) by: — roll-forming	0,5 to 0,6	Crest and root diameter result from equilibrium of strains
4	from outside to inside without restraining tools (free forming) by: — roll-forming	0,6 to 0,8	Usually not applied to diameters greater than DN 100

6.2.3 U-shaped unreinforced bellows

6.2.3.1 General

This subclause applies to two types of unreinforced bellows having nominally U-shaped corrugations according to the allowable limitations given in this subclause.

- Those shown in Figure 6.2.3.1-1 are generally manufactured by a forming process (e.g. hydraulic forming, roll forming) without any circumferential welding in the corrugations. This type of bellows is covered by 6.2.3.2 to 6.2.3.6 and those of 6.2.3.8.
- Those shown in Figure 6.2.3.7.1-1 are of single ply construction where the corrugations, have circumferential welds at their roots and crests. This type of bellows is covered by requirements of 6.2.3.2 to 6.2.3.8.



Key

- | | | | |
|---|--|---|-------------------------------------|
| 1 | end tangent without reinforcing collar | 4 | corrugation root |
| 2 | corrugation | 5 | reinforcing collar |
| 3 | corrugation crest | 6 | end tangent with reinforcing collar |

Figure 6.2.3.1-1 — U-shaped unreinforced bellows

6.2.3.2 Limitations

The following conditions shall apply in addition to those listed in 6.2.2:

- a) The internal radius of the torus r_i at the crest and the root of the corrugations shall be nominally the same.

A variation of $\pm 10\%$ between the real radii at the crest r_{ic} or the root r_{ir} in relation to the mean value r_i is permitted (see Figure 6.2.3.2-1 for definitions of r_{ic} and r_{ir}).

- b) The torus radius shall be such that:

$$r_i \geq 2 \cdot e_p \quad (6.2.3.2-1)$$

- c) The corrugation height shall be such that:

$$\frac{D_i}{3} \geq w \geq 2 \cdot r_m \quad (6.2.3.2-2)$$

- d) The off-set angle β_0 of the sidewalls in the neutral position (see Figure 6.2.3.2-1) shall be such that:

$$-15^\circ \leq \beta_0 \leq +15^\circ$$

where

$$\beta_0 = \arcsin \left\{ \sqrt{\frac{q}{2 \cdot r_m} - 2 + \left(\frac{w}{2 \cdot r_m} - 1 \right)^2} - \left(\frac{w}{2 \cdot r_m} - 1 \right) \right\} \cdot \frac{180}{\pi} \quad (6.2.3.2-3)$$

In addition it shall be checked if the initial side wall angle β_0 is limited by the intended movement which may lead to blocking in the case of compression or to buckling when extending movement is foreseen (see 6.2.8.2).

- e) The corrugation length shall be such that:

$$q > \max \left\{ \begin{array}{l} 2(r_{ic} + e) \\ 2(r_{ir} + e) \end{array} \right\}.$$

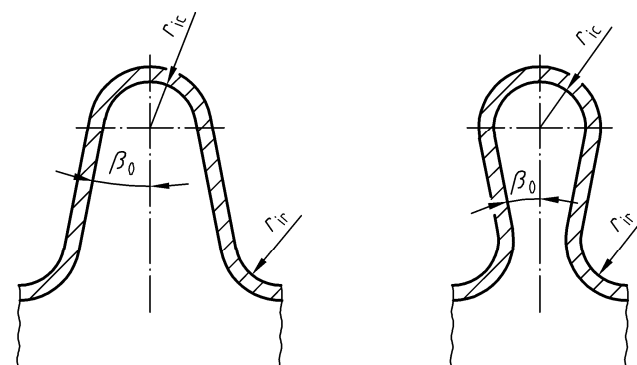


Figure 6.2.3.2-1 — Possible configuration shapes in the neutral position

6.2.3.3 Determination of additional intermediate factors

The following factors apply in addition to that of 6.1.1.2.1.

$$K_d = \begin{cases} 1 + 5 \cdot s_d & \text{if } s_d \leq 0,2 \\ 2,0 & \text{if } s_d > 0,2 \end{cases} \quad (6.2.3.3-1)$$

NOTE Equation (6.2.3.3-1) for K_d is only valid for austenitic steel and other similar materials. Higher values of K_d may be used if justified by representative tests.

$$K_{m,b} = \frac{1}{2 \cdot n_p} \cdot \left(\frac{w}{e_p^*} \right)^2 \cdot C_p \quad (6.2.3.3-2)$$

$$K_{\theta,l} = \frac{q \cdot D_m}{2 \cdot A_c} \quad (6.2.3.3-3)$$

$$k = \min \left[\left(\frac{L_t}{1,5 \cdot \sqrt{D_i \cdot e_p}} \right); (1,0) \right] \quad (6.2.3.3-4)$$

$$R_e^* = K_d \cdot R_{p1,0,t} \quad \text{for as-formed bellows (with cold work)} \quad (6.2.3.3-5a)$$

$$R_e^* = 0,75 \cdot R_{p1,0,t} \quad \text{for annealed bellows (without cold work)} \quad (6.2.3.3-5b)$$

The values for R_e^* shall be used for austenitic steel and other similar materials only.

For nickel alloys $R_{p1,0,t}$ shall be replaced by the 0,2 % proof strength $R_{p0,2,t}$ if $R_{p1,0,t}$ is not available.

For ferritic materials R_e^* is equal to R_e .

$$\alpha = 1 + 2\delta^2 + \sqrt{1 - 2\delta^2 + 4\delta^4} \quad (6.2.3.3-6)$$

$$\delta = \frac{K_{m,b}}{3K_{\theta,l}} \quad (6.2.3.3-7)$$

6.2.3.4 Internal pressure capability

6.2.3.4.1 Limitation due to stresses

a) End tangent

A1 The cylindrical end tangent of a pressurised bellows (see Figure 6.2.3.1-1) will partly be supported by the fitting to which it is welded.

Where the length of the bellows tangent without any collar but, including a possible cylindrical part of same thickness of a weld end $\bar{L}_t$ (see Table 6.2.2.4.4-1, No 3.0, General design) fulfils the following condition no stress calculation is required for the tangent:

$$\bar{L}_t \leq 0,5 \cdot \sqrt{D_i \cdot e_p}.$$

Otherwise the circumferential membrane stress due to pressure is calculated by:

$$\sigma_{\theta,t}(P) = \frac{(D_i + e)^2 L_t \cdot E_B \cdot k}{2 \cdot [e \cdot (D_i + e) \cdot L_t \cdot E_B + e_c \cdot D_c \cdot L_c \cdot E_c \cdot k]} \cdot P. \quad (6.2.3.4.1-1)$$

It shall comply with:

$$\sigma_{\theta,t}(P) \leq f \cdot \text{A1}$$

b) Reinforcing collar

The circumferential membrane stress due to pressure:

A1

$$\sigma_{\theta,c}(P) = \frac{D_c^2 \cdot L_t \cdot E_c \cdot k}{2 \cdot [e \cdot (D_i + e) \cdot L_t \cdot E_B + e_c \cdot D_c \cdot L_c \cdot E_c \cdot k]} \cdot P \quad (6.2.3.4.1-2) \text{ A1}$$

shall comply with:

$$\sigma_{\theta,c}(P) \leq f_c$$

c) Bellows corrugations

— End corrugations

— The circumferential membrane stress due to pressure:

$$\sigma_{\theta,E}(P) = \frac{1}{2} \cdot \frac{q \cdot D_m + L_t \cdot (D_i + e)}{A_c + e \cdot L_t} \cdot P \quad (6.2.3.4.1-3)$$

shall comply with:

$$\sigma_{\theta,E}(P) \leq f$$

[A1] NOTE An equivalent calculation considering the additional reinforcing areas may replace the Equation (6.2.3.4.1-3) which does not consider any support of the bellows attachment. **[A1]**

— Intermediate corrugations

The circumferential membrane stress due to pressure:

$$\sigma_{\Theta, I} (P) = \frac{1}{2} \cdot \frac{q \cdot D_m}{A_c} \cdot P \quad (6.2.3.4.1-4)$$

shall comply with:

$$\sigma_{\Theta, I} (P) \leq f .$$

[A1] *deleted text* **[A1]**

The meridional membrane stress due to pressure is given by:

$$\sigma_{m, m} (P) = \frac{w}{2 \cdot e^*} \cdot P \quad (6.2.3.4.1-5)$$

The meridional bending stress due to pressure is given by:

$$\sigma_{m, b} (P) = \frac{1}{2 \cdot n_p} \cdot \left(\frac{w}{e_p^*} \right)^2 \cdot C_p \cdot P \quad (6.2.3.4.1-6)$$

The meridional membrane and bending stresses shall conform to:

$$\sigma_{m, m} (P) + \sigma_{m, b} (P) \leq K_f \cdot f \quad (6.2.3.4.1-7)$$

where

$K_f = 3,0$ for as-formed bellows (with cold work);

$K_f = 1,5$ for annealed bellows (without cold work).

6.2.3.4.2 Limitation due to instability

6.2.3.4.2.1 Column instability

[A1] To avoid column instability the different types of expansion joints have to be regarded under different conditions.

a) Axial expansion joints with one or more bellows

1) Working conditions – internal pressure and design temperature TS

The limiting internal pressure is given by:

$$\bar{P}_{sc, t} = \frac{2\pi}{1,5} \cdot \frac{1}{\bar{l}_B \cdot n_B^2} \cdot K_{B, t} \cdot c_{dyn, x} , \text{ with} \quad (6.2.3.4.2.1-1)$$

i) the equalised length of one bellows after some cycles

$$\bar{l}_B = l_B + 0,5 \cdot (x_1 + x_2) \cdot \frac{1}{n_B}, \quad (6.2.3.4.2.1-2)$$

where x_1 and x_2 are understood as the initial maximum values of axial displacement at the extreme positions of a cycle with positive sign for extension and negative sign for compression related to l_B of each single bellows (see Figure 6.2.3.4.2-1);

ii) the elastic spring rate $K_{B,t}$ at design temperature for one bellows according to Equation (6.2.3.8-1),

iii) the dynamic factor

$$c_{\text{dyn},x} = \begin{cases} 1 & \text{for } x^* \leq 1 + n_t \\ \frac{a_t \cdot (x^*)^{n_t-1} - b_t \cdot (x^*)^{-3}}{2 - (a_t \cdot (x^*)^{n_t-1} - b_t \cdot (x^*)^{-3})} & \text{for } x^* > 1 + n_t \end{cases} \quad (6.2.3.4.2.1-3)$$

The maximum allowable pressure PS shall not exceed the limiting pressure $\tilde{P}_{sc,t}$:

$$PS \leq \tilde{P}_{sc,t}$$

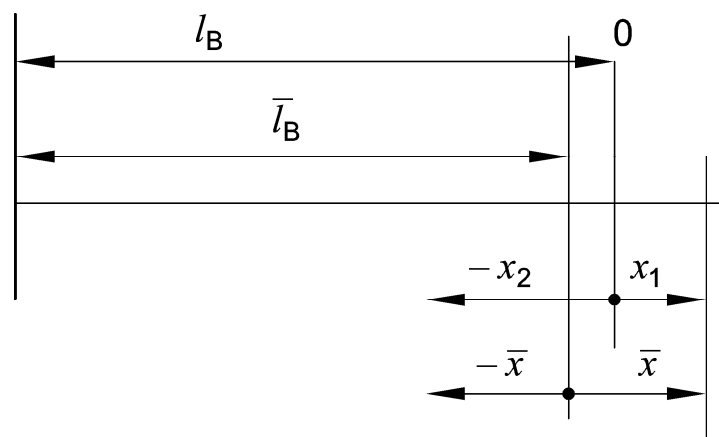


Figure 6.2.3.4.2-1 — Bellows corrugated length and axial displacements shown for $n_B = 1$

2) Test conditions – internal pressure and test temperature

The limiting internal pressure is given by:

i) in the work shop, neutral position ($x = 0$)

$$P_{sc,T} = \frac{2\pi}{1,5} \cdot \frac{k_s}{l_B \cdot n_B^2} \cdot K_{B,T}, \text{ with:} \quad (6.2.3.4.2.1-4)$$

— a stabilising factor

$k_s = 0,5$ for non-stabilised bellows (as formed);

$k_s = 1,0$ for stabilised bellows, e.g. by pre-compressing to block or stress releasing heat treatment;

- the elastic spring rate for one bellows at test temperature $K_{B,T}$ according to Equation (6.2.3.8-1);
- ii) on site, after some cycles and cooling down with the expansion joint extended (+) or compressed (-) depending on the installation situation in the compensation system

$$P_{sc,T} = \frac{1}{1,5} \cdot \frac{2\pi \cdot K_{B,T}}{\left(\bar{l}_B \pm \frac{\bar{x}}{n_B}\right) \cdot n_B^2} + \frac{4}{\pi \cdot D_m^2} \cdot \frac{K_{wx,T}}{n_B} \cdot (\pm \bar{x}), \text{ with} \quad (6.2.3.4.2.1-5)$$

- the mean axial displacement of the expansion joint (see Figure 6.2.3.4.2-1)

$$\bar{x} = 0,5 \cdot |x_1 - x_2| \quad (6.2.3.4.2.1-6)$$

- the elastic spring rate for one bellows at test temperature $K_{B,T}$ according to Equation (6.2.3.8-1);
- the working spring rate for one bellows at test temperature $K_{wx,T}$ according to Equation (6.2.9.3.1-6).

The test pressure PT shall not exceed the limiting pressure $P_{sc,T}$:

$$PT \leq P_{sc,T}.$$

3) Working conditions – external pressure and design temperature TS

The axial force induced by axial compression of the bellows may cause column instability without internal pressure acting on the bellows.

The allowable axial compressing force increased by external pressure acting on the bellows at the same time is given by:

$$F_{sc,t} = \frac{1}{1,5} \cdot \frac{2 \cdot \pi^2}{\bar{l}_B \cdot n_B^2} \cdot \frac{D_m^2}{4} \cdot K_{B,t} \cdot c_{dyn,x} + \pi \cdot \frac{D_m^2}{4} \cdot | -PS |. \quad (6.2.3.4.2.1-7)$$

The maximum force from axial displacement may not exceed the allowable force:

$$K_{wx,t} \cdot \left| -\frac{\bar{x}}{n_B} \right| \leq F_{sc,t}$$

4) Test conditions – external pressure and test temperature

The limiting axial compressing force for the test situation on site is given by:

$$F_{sc,T} = \frac{1}{1,5} \cdot \frac{2 \cdot \pi^2}{\left(\bar{l}_B - \frac{\bar{x}}{n_B}\right) \cdot n_B^2} \cdot \frac{D_m^2}{4} \cdot K_{B,T} + \pi \cdot \frac{D_m^2}{4} \cdot | -PT |. \quad (6.2.3.4.2.1-8)$$

The maximum force from axial displacement shall not exceed the limiting force:

$$K_{wX,T} \cdot \left| -\frac{\bar{x}}{n_B} \right| \leq F_{sc,T} \quad .$$

b) Angular and lateral expansion joints with one or more bellows

1) Working conditions – internal pressure and design temperature TS

The limiting internal pressure is given by:

$$P_{sc,t} = \frac{1}{1,5} \cdot \frac{2 \cdot \pi}{l_B \cdot n_B^2} \cdot K_{B,t} \cdot c_{dyn,\Delta} \cdot (1 - \nu^2), \text{ with} \quad (6.2.3.4.2.1-9)$$

i) the elastic spring rate for one bellows at design temperature $K_{B,t}$

ii) the dynamic factor at design temperature

$$c_{dyn,\Delta} = \begin{cases} c_{dyn,y} & \text{for lateral deflected bellows} \\ c_{dyn,\Theta} & \text{for angular rotated bellows} \end{cases} ,$$

where

$$c_{dyn,y} = \begin{cases} 1 & \text{for } y^* \leq 1 + n_t \\ \frac{a_t \cdot (y^*)^{n_t-1} - b_t \cdot (x^*)^{-3}}{2 - (a_t \cdot (y^*)^{n_t-1} - b_t \cdot (y^*)^{-3})} & \text{for } y^* > 1 + n_t \end{cases} \quad (6.2.3.4.2.1-10a)$$

and

$$c_{dyn,\Theta} = \begin{cases} 1 & \text{for } \Theta^* \leq 1 + n_t \\ \frac{a_t \cdot (\Theta^*)^{n_t-1} - b_t \cdot (\Theta^*)^{-3}}{2 - (a_t \cdot (\Theta^*)^{n_t-1} - b_t \cdot (\Theta^*)^{-3})} & \text{for } \Theta^* > 1 + n_t \end{cases} \quad (6.2.3.4.2.1-10b)$$

The maximum allowable pressure PS shall not exceed the limiting pressure $P_{sc,t}$:

$$PS \leq P_{sc,t} .$$

2) Test conditions – internal pressure and test temperature

The limiting internal pressure is given by:

i) in the work shop or on site in a straight position

$$P_{sc,T} = \frac{2\pi}{1,5} \cdot \frac{k_s}{l_B \cdot n_B^2} \cdot K_{B,T} , \text{ with:} \quad (6.2.3.4.2.1-11)$$

— the above defined stabilising factor k_s ;

— the elastic spring rate at test temperature $K_{B,T}$ for one bellows according to Equation (6.2.3.8-1).

- ii) on site, after some cycles and cooling down with the bellows angular rotated or lateral deflected according to the installation situation in the compensation system

$$P_{sc,T} = \frac{2\pi}{1,5} \cdot \frac{k_s}{l_B \cdot n_B^2} \cdot K_{B,T} \cdot (1 - \nu^2) \quad (6.2.3.4.2.1-12)$$

The test pressure PT shall not exceed the limiting pressure $P_{sc,T}$:

$$PT \leq P_{sc,T} \cdot \sqrt{A_1}$$

6.2.3.4.2.2 Inplane instability

The allowable internal design pressure to avoid in-plane instability is given by:

$$P_{si} = \frac{0,57 \cdot R_c^*}{K_{\Theta,l} \cdot \sqrt{\alpha}} \quad (6.2.3.4.2.2-1)$$

The internal pressure shall not exceed P_{si} :

$$P \leq P_{si}$$

The allowable test pressure to avoid in-plane instability is given by:

$$P_{si,T} = 1,35 \cdot P_{si,20} \quad (6.2.3.4.2.2-2)$$

The test pressure PT shall not exceed $P_{si,T}$:

$$PT \leq P_{si,T}$$

6.2.3.5 External pressure capability including vacuum

6.2.3.5.1 General

[A1] The limitations according to 6.2.3.4 shall be applied accordingly taking P with a positive sign as the maximum difference between external and internal pressure. **[A1]**

When a bellows within its working conditions is also submitted to vacuum, the design for this condition shall be performed assuming that only the internal ply resists the pressure. Thus the pressure stress equations of 6.2.3.4 shall be applied with $n_p = 1$.

NOTE The calculation methods can accordingly be applied to bellows which are subjected to vacuum only, though they are not within the scope of this European Standard.

6.2.3.5.2 Instability due to external pressure

This design shall be performed according to external pressure design rules by replacing the bellows with an equivalent cylinder.

The dimensions of the equivalent cylinder shall be defined as follows:

— the equivalent thickness e_{eq} is given by:

$$e_{eq} = \sqrt[3]{12 \cdot (1 - \nu^2) \cdot \frac{I_{xx}}{q}}, \quad (6.2.3.5.2-1)$$

where the moment of inertia for one corrugation cross section is given by:

$$I_{xx} = e^* \cdot \left[\frac{(2 \cdot w - q)^3}{48} + 0,4 \cdot q \cdot (w - 0,2 \cdot q)^2 \right] \quad (6.2.3.5.2-2)$$

— the equivalent mean diameter is given by:

$$D_{eq} = D_i + w + 2 \cdot e_{eq}. \quad (6.2.3.5.2-3)$$

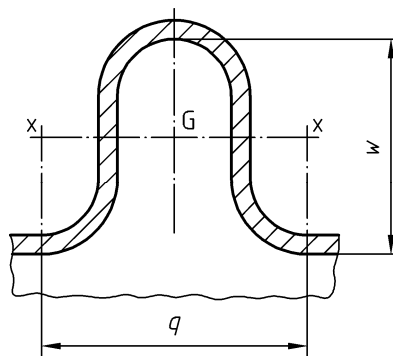


Figure 6.2.3.5-1 – Cross section for moment of inertia I_{xx}

The allowable external pressure P_{cir} is given by:

$$P_{cir} = \frac{2 \cdot E_B}{S_{cir}} \cdot \left(\frac{e_{eq}}{D_{eq}} \right)^3 \quad (6.2.3.5.2-4)$$

The external working pressure shall not exceed P_{cir} :

$$P \leq P_{cir}, \text{ where } S_{cir} = 3.$$

The test pressure P_T shall not exceed $P_{cir, T}$:

$$P_T \leq P_{cir, T}, \text{ where } S_{cir} = 2,25.$$

NOTE 1 The moment of inertia I_{xx} is understood as that of one corrugation cross section relative to the axis passing through the centre of gravity and parallel to the axis of the bellows (see Figure 6.2.3.5-1).

NOTE 2 The allowable external design pressure to avoid circumferential instability is based on the behaviour of an infinitely long cylinder.

NOTE 3 Consideration of the influence of the attached piping may be included if subject to detailed analysis.

6.2.3.6 Fatigue

6.2.3.6.1 General

The specified number of cycles N_{spe} shall be the anticipated number of cycles expected to occur during the operating life of the bellows. The allowable number of cycles N_{alw} , as calculated in this subclause, shall always exceed the specified number of cycles N_{spe} .

[A1] If the bellows is submitted to different cycles of pressure or displacement, such as those produced by start-up or shutdown, the cumulative effect of these cycles can be accounted for by linear summation of the fatigue damage indices for the cycles from the design stress range spectrum (see 6.2.3.6.4). **[A1]**

Use of specific fatigue curves set-up by a manufacturer is allowed, provided that requirements of 6.2.6 are applied.

NOTE The allowable number of cycles given by the following equations include a reasonable safety factor (3 on cycles and 1,25 on stresses) and represents the estimated number of operating cycles, see also Annex E.

6.2.3.6.2 Stresses due to equivalent axial displacement

The following stresses which are the basic stresses for the calculation of fatigue cycles are calculated from the total equivalent axial displacement range Δq of each corrugation according to 6.2.7.

[A1] Meridional membrane stress range: **[A1]**

$$\sigma_{m,m}(\Delta q) = \frac{E_B \cdot (e_p^*)^2}{2 \cdot w^3 \cdot C_f} \cdot \Delta q \quad (6.2.3.6.2-1)$$

[A1] Meridional bending stress range: **[A1]**

$$\sigma_{m,b}(\Delta q) = \frac{3}{2 \cdot (1 - \nu^2)} \cdot \frac{E_B \cdot e_p^*}{w^2 \cdot C_d} \cdot \Delta q \quad (6.2.3.6.2-2) \text{ [A1]}$$

[A1] Total equivalent stress range: **[A1]**

$$\sigma_{eq} = 0,7 \cdot [\sigma_{m,m}(P) + \sigma_{m,b}(P)] + [\sigma_{m,m}(\Delta q) + \sigma_{m,b}(\Delta q)] \quad (6.2.3.6.2-3)$$

6.2.3.6.3 **[A1]** Cycles due to equivalent stress range **[A1]**

6.2.3.6.3.1 Austenitic steel and other similar materials

This subclause applies to austenitic steel and nickel-chromium-iron alloys, nickel-iron-chromium alloys. It applies to as-formed bellows (with cold work) and to annealed bellows (without cold work).

The allowable number of cycles is given by (see Figure 6.2.3.6-1):

$$N_{alw} = \left(\frac{8\,900}{E_0/E_B \cdot \sigma_{eq} - 280} \right)^{3,6}, \text{ where } 370 \leq N_{alw} \leq 10^6 \quad (6.2.3.6.3-1)$$

$$N_{alw} = 10^6 \text{ if } \frac{E_0}{E_B} \sigma_{eq} \leq 471 \text{ N/mm}^2 \quad (6.2.3.6.3-2)$$