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Foreword

This translation has been made based on the original Japanese Industrial Standard revised by the Minister of Health, Labour and Welfare and the Minister of Economy, Trade and Industry through deliberations at the Japanese Industrial Standards Committee, as the results of proposal for revision of Japanese Industrial Standard submitted by The High Pressure Gas Safety Institute of Japan (KHK)/Japanese Standards Association (JSA) with the draft being attached, based on the provision of Article 12 Clause 1 of the Industrial Standardization Law applicable to the case of revision by the provision of Article 14.

Consequently **JIS B 8277**: 2003 is replaced with this Standard.

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Expansion joint for pressure vessels

1 Scope

This Japanese Industrial Standard specifies the design, manufacturing and inspection methods of the expansion joint intended to be used to absorb the expansion and contraction generated on the heat exchanger, the container with jacket and the like by the temperature change, etc. When the application of the design method specified in Annex 10 of **JIS B 8265** to the pressure vessel is allowed, it is applicable.

NOTE : Some figures are block diagrams to show the function only.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this Standard. The most recent editions of the standards (including amendments) indicated below shall be applied.

JIS B 0190 *Glossary of terms used in construction of pressure vessels*

JIS B 8265 *Construction of pressure vessel—General principles*

JIS B 8266 *Alternative standard for construction of pressure vessels*

JIS B 8267 *Construction of pressure vessel*

JIS B 8274 *Flat tubesheet for pressure vessels*

JIS G 4902 *Corrosion-resisting and heat-resisting superalloy plates and sheets*

JIS H 4551 *Nickel and nickel alloy plate, sheet and strip*

3 Terms and definitions

For the purposes of this Standard, the terms and definitions given in **JIS B 0190** shall apply.

4 Types of expansion joint and common items

- a) The types of expansion joint shall be as shown in figure 1, and classified into the bellows type [figure 1 a), figure 1 b) and figure 1 d)] and the moulded shell type [figure 1 c)].
- b) The bellows type expansion joint consists of the bellows and the shell, and the bellows shall be strengthened with a reinforcing ring or a collar, if necessary. An application example of the stopper for the reinforcing ring is shown in figure 2. For the bellows type expansion joint, the multilayered construction may be applied to the bellows part.
- c) The shape of corrugation part of the bellows shall be basically the U-shaped as shown in figure 5 a) and figure 5 b); however, the toroidal shape as shown in figure 5 c) is applicable.
- d) The moulded shell type expansion joint consists of the moulded shell having the flexibility in the axial direction, and the shell. In the moulded shell part, the weld line in the peripheral direction and the nozzle may be installed. The construction of joint part of this case is shown in figure 3.

- e) The expansion joint shall consist of single or multiple identically formed convolutions. They may be as cold formed or heat treated after forming.
- f) The design rules of the expansion joint according to this Standard shall conform to the following conditions (see **6.3** for the meaning of symbols).
 - 1) Dimension of bellows type expansion joint: $Nq \leq 3D_b$
 - 2) Nominal thickness of bellows type expansion joint: $nt \leq 5.0 \text{ mm}$
 - 3) Number of plies of multilayered bellows type expansion joint: $n \leq 5$
 - 4) The expansion and contraction from the neutral position shall be basically axial; however, it is applicable for the case when the bellows type expansion joint is installed with initial displacement from the neutral position or when it is installed with the lateral displacement to the axis or with bending. In this case, the amount of displacement shall be clarified and considered in the design.
 - 5) The design temperature of the expansion joint shall not be in the range where the time-dependent property governs the allowable stress (creep temperature range). For the austenitic stainless steels and the high nickel alloy, the design temperature shall not exceed 425 °C.

The high nickel alloy herein shall be the material corresponding to UNS N066XX and UNS N04400 (see **ASME Section II Part D**), which are the corrosion-resisting and heat-resisting superalloy plates and sheets (NCF-P) of **JIS G 4902** and the nickel and nickel alloy plates and sheets (NCuP) of **JIS H 4551**.

5 Construction of joint part

The construction to attach the expansion joint to the cylindrical shell by welding shall be in accordance with figure 4. In this case, the construction shall conform to the conditions shown in the figures, respectively. When calculating σ_t according to the formula of this Standard, the maximum length of the tangent part of expansion joint L_t or $(L_t - L')$ may exceed the limitation shown in figure 4.

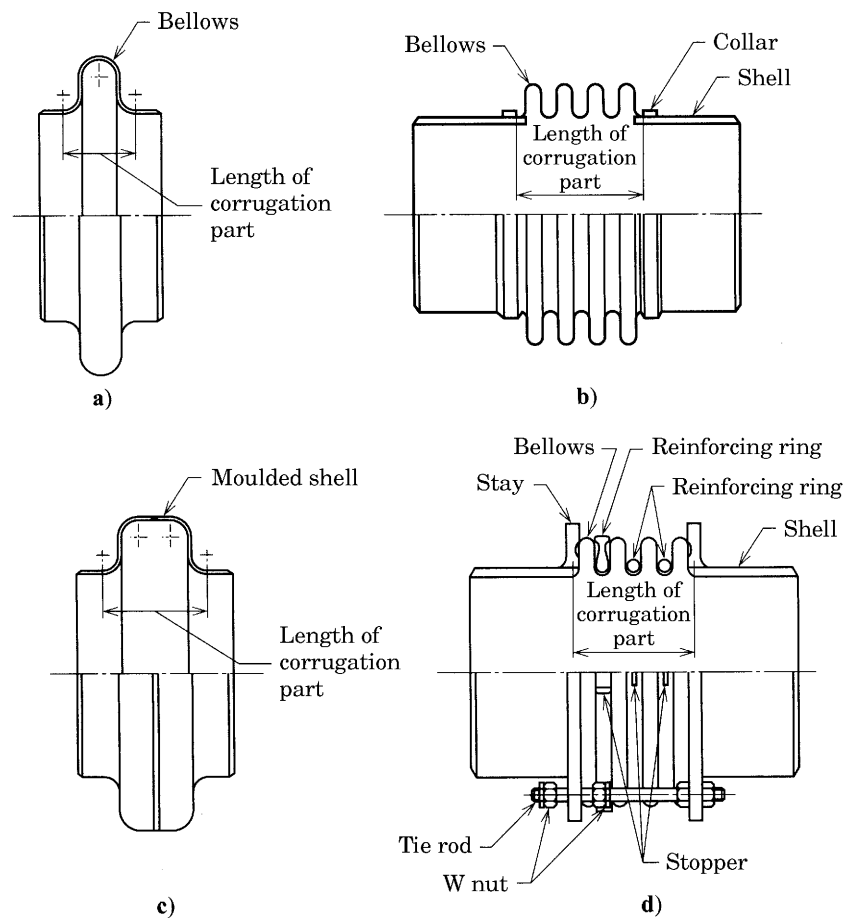


Figure 1 Type example and part name of expansion joint

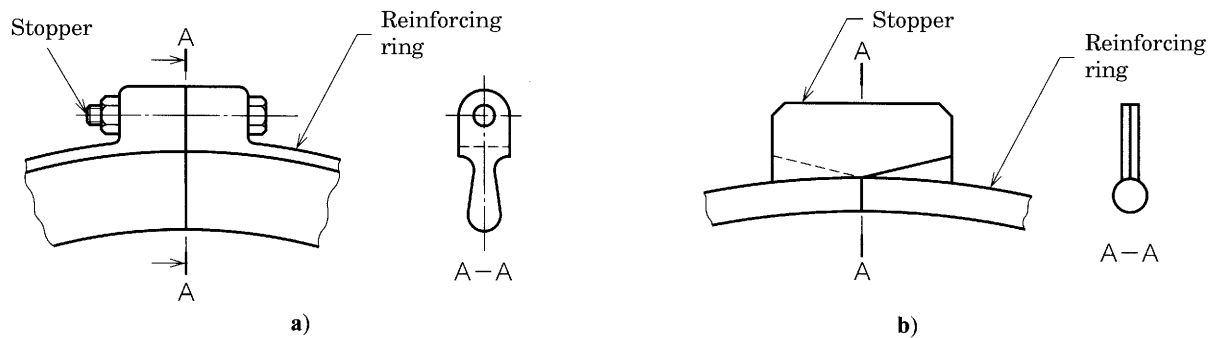
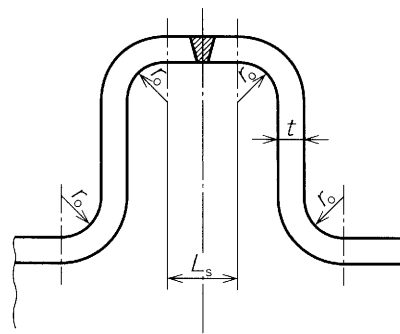
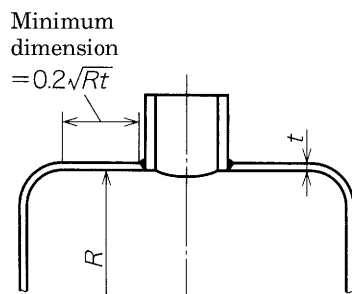


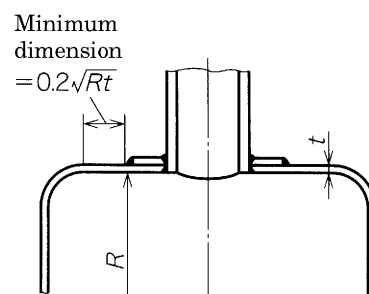
Figure 2 Application example of stopper of reinforcing ring



a) When circumferential joint is set



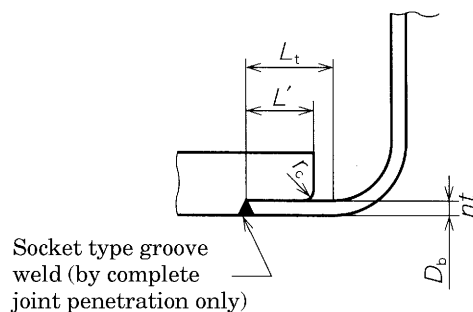
b) When nozzle without reinforcement is set



c) When nozzle with reinforcement is set

R : bore of outside cylindrical part of moulded shell (mm)
 t : thickness of outside cylindrical part of moulded shell (mm)

Figure 3 Construction when welded joint is set on outside cylindrical part of moulded shell type expansion joint



(When receiving internal pressure)

$$0 \leq (L_t - L') \leq 0.5\sqrt{D_b nt}, \quad L' \geq 5nt$$

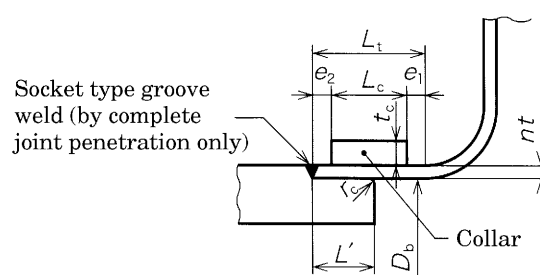
(When receiving external pressure)

$$L_t \leq 0.5\sqrt{D_b nt}, \quad L' \geq 5nt$$

$$\text{When } 5nt > 0.5\sqrt{D_b nt}, \quad L' = L_t = 0.5\sqrt{D_b nt}.$$

$$r_c \geq 1.5 \text{ mm}$$

a)



(When receiving internal pressure and $L_t > 0.5\sqrt{D_b nt}$)

$$e_1 \leq 0.5\sqrt{D_b nt}$$

$$e_2 \leq 0.5\sqrt{D_b nt}$$

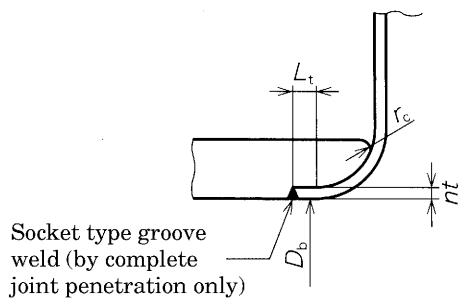
$$L' \geq 5nt$$

$$L_c \geq 0.75L_t$$

$$r_c \geq 1.5 \text{ mm}$$

b)

Figure 4 Installing construction of expansion joint to cylindrical shell



(When receiving internal pressure)

$$L_t \geq 1.5 nt$$

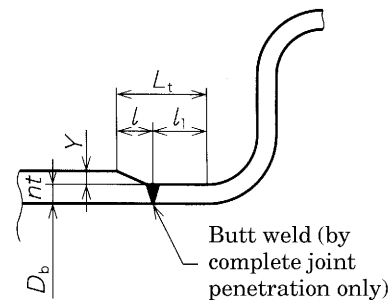
(When receiving external pressure)

$$L_t \leq 0.5\sqrt{D_b nt}, \quad L_t \geq 5 nt$$

When $5 nt > 0.5\sqrt{D_b nt}$, $L_t = 0.5\sqrt{D_b nt}$.

$$r_c \geq 1.5 \text{ mm}$$

c)

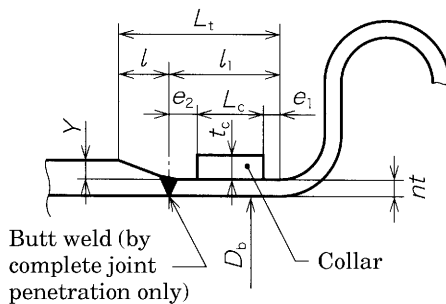


(When receiving internal or external pressure)

$$L_t \leq 0.5\sqrt{D_b nt}, \quad l_1 \geq 1.5 nt$$

$$l = 3Y$$

d)



(When receiving internal pressure and $L_t > 0.5\sqrt{D_b nt}$)

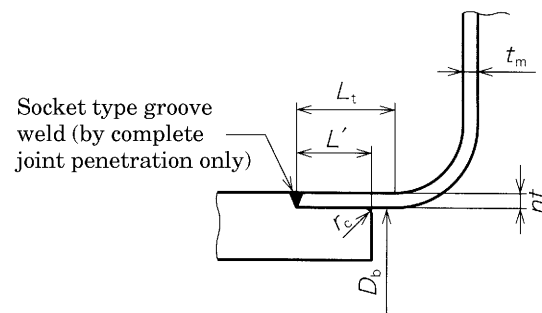
$$e_1 \leq 0.5\sqrt{D_b nt}$$

$$l + e_2 \leq 0.5\sqrt{D_b nt}$$

$$L_c \geq 0.75 l_1$$

$$l \geq 3Y$$

e)



(When receiving external pressure)

$$0 \leq (L_t - L') \leq 0.5\sqrt{D_b nt}, \quad L' \geq 5 nt$$

When $5 nt > 0.5\sqrt{D_b nt}$, $L' = 0.5\sqrt{D_b nt}$.

$$r_c \geq 1.5 \text{ mm}$$

f)

Figure 4 (concluded)

6 Design of bellows type expansion joint

6.1 General matters on design

General matters on design of the bellows type expansion joint (in this clause, also referred to as the expansion joint briefly) shall be as follows.

- The expansion joint shall be designed so as to have the flexibility for thermal expansion as a part of pressure withstanding part of the pressure vessel, which is represented by the heat exchanger.
- The orderer shall specify the design conditions and requirements of the expansion joint to the designer and the manufacturer thereof.

- c) When the expansion joint is integrated with the pressure vessel, it shall have adequate restraint measures to the force at both ends of expansion joint caused by pressure and the spring force of the expansion joint (such as the tube or shell of heat exchanger, the external holder, and the anchor). The stress generated on these restraint elements shall not exceed the allowable stress at the design temperature thereof.
- d) In the case of installation and the like, the bellows type expansion joint shall not be extended, compressed, rotated, or laterally offset to accommodate the connecting parts, unless the design considers such movements.
- e) Unless otherwise specified, the minimum thickness limitation of the pressure withstanding part of the pressure vessel is not applicable to the expansion joint designed herein.
- f) When designing the expansion joint different in basic requirements of the shape, dimension and the like specified in this clause, the design shall be performed according to the appropriate method such as the stress analysis.
- g) The joint efficiency of longitudinal weld specified in **9.2 b)** shall be 1.0.

6.2 General matters on fatigue

General matters on fatigue of the expansion joint shall be as follows.

- a) If there are two or more types of stress cycles which produce the significant stresses repeatedly, their cumulative fatigue damage shall be evaluated as follows.
 - 1) The repetition number of each stress cycles expected during the life of expansion joint is designated as $n_1, n_2, n_3, \dots$.

In determining $n_1, n_2, n_3, \dots$, consideration shall be given to the superposition of cycles of various origins which may produce the total stress fluctuation range greater than the stress fluctuation range of the individual cycle. For example, if one type (type 1) of stress cycle produces the stress fluctuation range of 0 N/mm² to 400 N/mm² in 1 000 cycles and another type (type 2) of stress cycle produces the stress fluctuation range of 0 N/mm² to -350 N/mm² in 10 000 cycles, the two types of cycles to be considered shall be defined as follows.

$$\text{Type 1: } n_1 = 1\,000, S_{t1} = |400| + |-350| = 750$$

$$\text{Type 2: } n_2 = 10\,000 - 1\,000 = 9\,000, S_{t1} = |0| + |-350| = 350$$

- 2) The allowable repetition number shall be obtained by using the design fatigue curve [calculation formula for **6.2 c)**] for the stress fluctuation range of each stress cycle, and these shall be taken as $N_1, N_2, N_3, \dots$
- 3) For each type of stress cycle, the usage factors below shall be obtained.
$$U_1 = n_1/N_1,$$
$$U_2 = n_2/N_2,$$
$$U_3 = n_3/N_3, \dots$$

- 4) The cumulative usage factor for the fatigue life shall be obtained as follows.

$$U = U_1 + U_2 + U_3 + \dots$$

- 5) The cumulative usage factor obtained in 4) shall not exceed 1.
- b) The calculation of fatigue life of the expansion joint may be performed by any method based on the theory of elasticity. However, the method to be used shall substantiate the predictability of rupture stress and fatigue life by performing the rupture test or the strain measurement test on each series of bellows of the same basic design by the manufacturer. The case shall be as follows.
 - 1) The substantiation of any analytical procedure to be used shall be based on the data obtained from five separate tests on bellows of the same basic design.
 - 2) When substantiating the design of bellows with three convolutions or more in series, the test data shall have been obtained from the bellows with a minimum of three convolutions.
 - 3) The test data to be compared with the data obtained from the calculation shall demonstrate that the rupture pressure of the bellows is equal to or greater than three times the maximum allowable working pressure at room temperature.
 - 4) When the allowable repetition number N_{alw} is obtained in accordance with specifications of **6.4.5**, **6.5.5** and **6.6.5** by using the stress fluctuation range S_i obtained by the method other than this specification, the allowable repetition number shall be smaller than that of the fatigue life calculated based on the test data.
 - 5) Regardless of the test result, the allowable repetition number shall not be increased from the allowable repetition number obtained by the formulae of **6.4.5**, **6.5.5** and **6.6.5**.
- c) The calculation formula of allowable repetition number N_{alw} specified in **6.4.5 c)**, **6.5.5 b)** and **6.6.5 b)** is applicable when the material used for the bellows shall be the austenitic stainless steels and the high nickel alloy as cold formed or heat treated after forming.

The high nickel alloy herein is the material specified in **f) 5)** of clause 4.

6.3 Meaning of symbols

The meaning of symbols used in the calculation of the expansion joint shall be as follows.

- A : cross-sectional area per convolution of bellows $A = \left[\left(\frac{\pi - 2}{2} \right) q + 2w \right] nt_p$ (mm²)
- A_c : cross-sectional area of collar of toroidal shape bellows (mm²)
- A_f : cross-sectional area of fastener (e.g. bolt) of one reinforcing ring (mm²)
- A_r : cross-sectional area of one reinforcing ring (mm²)
- B_1, B_2, B_3 : coefficient for toroidal shape bellows (see table 1)
- C_p, C_r, C_d : coefficient for corrugation part of U-shaped bellows (see figure 7, figure 8 and figure 9)
- C_r : coefficient for convolution height of reinforced bellows

$$C_r = 0.3 - \left(\frac{100}{1048P^{1.5} + 320} \right)^2$$

C_1, C_2 : coefficient for determination of C_p, C_f and C_d according to the formulae below

$$C_1 = \frac{q}{2W}$$

$$C_2 = \frac{q}{2.2\sqrt{D_m t_p}}$$

C_{wc} : longitudinal weld joint coefficient for collar

C_{wr} : longitudinal weld joint coefficient for reinforcing ring

D_b : bore of bellows part and end tangent part (mm)

D_c : mean diameter of collar $D_c = D_b + 2nt + t_c$ (mm)

D_m : mean diameter of U-shaped bellows $D_m = D_b + w + nt$ (mm)

mean diameter of toroidal shape bellows (see figure 5)

E_b : modulus of longitudinal elasticity of material of bellows at design temperature (N/mm²)

E_c : modulus of longitudinal elasticity of material of collar at design temperature (N/mm²)

E_f : modulus of longitudinal elasticity of material of fastener of reinforcing ring of bellows at design temperature (N/mm²)

E_r : modulus of longitudinal elasticity of material of reinforcing ring of bellows at design temperature (N/mm²)

E_o : modulus of longitudinal elasticity of material of bellows at room temperature (N/mm²)

H : force by internal pressure acting on bellows part and reinforcing material part

$$H = PD_m q \text{ (N)}$$

K_b : spring constant of bellows (N/mm)

k : coefficient considering reinforcing effect of end convolution and installation weld on pressure capacity of end tangent of bellows

$$k = \text{MIN} \left[\left(\frac{L_t}{1.5\sqrt{D_b t}} \right), (1.0) \right]$$

L_c : width of collar of bellows (collar length) (mm)

L_t : length of end tangent part of bellows (mm)

L_f : effective length of fastener of reinforcing ring (see figure 5) (mm)

L_w : distance between installation welds of toroidal shape bellows (mm)

N : number of convolutions

N_{alw} : allowable repetition number for fatigue

N_{spe} : specified number of repetitions

n : number of plies of bellows

P : design pressure (MPa)

q : pitch of convolution of bellows (see figure 5) (mm)

R : ratio of force resisted by bellows to force resisted by reinforcing material part for internal pressure according to R_1 and R_2 below

for integrated reinforcing ring, $R = R_1$

$$R_1 = \frac{AE_b}{A_r E_r}$$

for reinforcing ring connected by fastener, $R = R_2$

$$R_2 = \frac{AE_b}{D_m} \left(\frac{L_f}{A_f E_f} + \frac{D_m}{A_r E_r} \right)$$

r : mean radius of toroidal shape bellows (mm)

S : allowable tensile stress of material of bellows at design temperature (N/mm²)

S_c : allowable tensile stress of material of collar at design temperature (N/mm²)

S_f : allowable tensile stress of material of fastener of reinforcing ring at design temperature (N/mm²)

S_r : allowable tensile stress of material of reinforcing ring at design temperature (N/mm²)

S_t : stress fluctuation range due to repetition of expansion and contraction (N/mm²)

σ_1 : circumferential membrane stress of end tangent part of bellows due to design pressure P (N/mm²)

σ_1' : circumferential membrane stress of collar of bellows due to design pressure P (N/mm²)

σ_2 : circumferential membrane stress of bellows due to design pressure P (N/mm²)

σ_2' : circumferential membrane stress of reinforcing ring due to design pressure P (N/mm²)

σ_2'' : circumferential membrane stress of material of fastener of reinforcing ring due to design pressure P (N/mm²)

σ_3 : meridional membrane stress of bellows due to design pressure P (N/mm²)

σ_4 : meridional bending stress of bellows due to design pressure P (N/mm²)

σ_5 : meridional membrane stress due to equivalent displacement Δq per convolution of bellows (N/mm²)

σ_6 : meridional bending stress due to equivalent displacement Δq per convolution of bellows (N/mm²)

t : thickness of bellows before forming, provided that thickness of one ply when bellows is multilayered (nominal thickness) (mm)

t_c : thickness of collar (mm)

t_p : thickness per one ply of bellows considering thinning during forming

$$t_p = t \sqrt{\frac{D_b}{D_m}} \text{ (mm)}$$

w : height of convolution of bellows (mm)

Δq : total equivalent axial displacement per convolution of bellows (mm)

ν_b : Poisson's ratio of material of bellows

NOTE : Main subscripts shall be as follows.

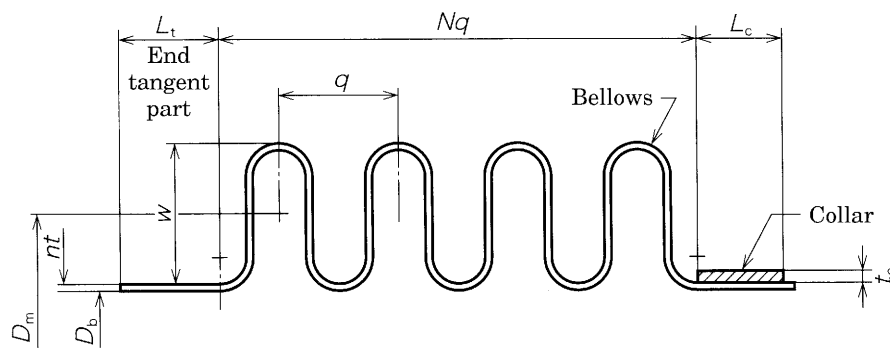
b : bellows

c : collar

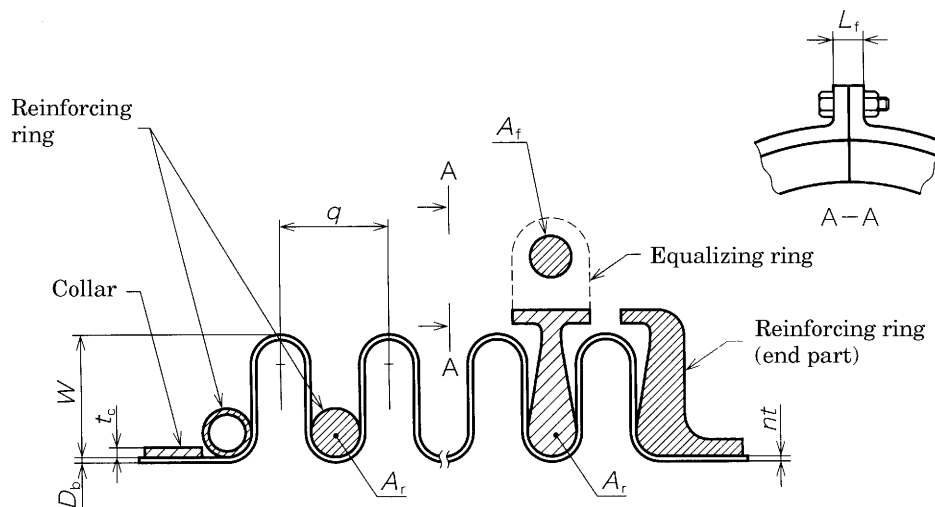
f : material of fastener

r : reinforcing ring

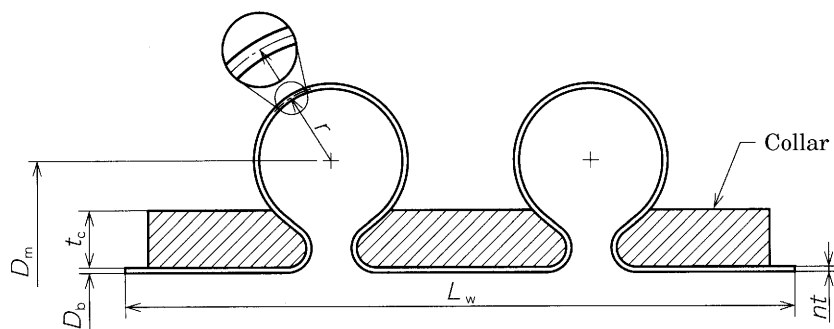
t : end tangent part



a) Unreinforced bellows



b) Reinforced bellows



c) Toroidal shape bellows

Figure 5 Form of bellows type expansion joint†

6.4 Design of unreinforced U-shaped bellows

The design of unreinforced U-shaped bellows shall be as follows.

6.4.1 General matters

General matters related to the design of unreinforced U-shaped bellows shall be as follows.

- a) The unreinforced U-shaped bellows shall be so constructed that each convolution consists of a sidewall and two tori of nearly the same radius at the crest and at the bottom thereof in the neutral position so that the convolution profile presents a smooth geometrical shape as shown in figure 5 a).
- b) In addition to the requirements specified in clause 4 and clause 5, the following conditions shall be satisfied.
 - 1) The difference between the crest radius r_{ic} and the bottom radius r_{ir} of convolution shall be within 10 % (see figure 6 for r_{ic} and r_{ir}).
 - 2) The convolution radius shall be $r_i \geq 3t$,

$$\text{where, } r_i = \frac{r_{ic} + r_{ir}}{2}.$$

- 3) The offset angle of sidewall α at the neutral position shall be $-15^\circ \leq \alpha \leq +15^\circ$ (see figure 6).

In this case, the pitch of convolution of bellows q shall be the length of one waveform when sidewalls thereof are parallel.

- 4) The height of convolution of bellows shall be $w \leq \frac{D_b}{3}$.

6.4.2 Stress calculation and stress evaluation for internal pressure

The stress calculation and stress evaluation for internal pressure shall be as follows (see figure 10).

- a) The circumference membrane stress of end tangent part of bellows generated due to internal pressure shall be as follows.

$$\sigma_1 = \frac{1}{2} \frac{(D_b + nt)^2 L_t E_b k}{nt(D_b + nt)L_t E_b + t_c D_c L_c E_c k} P$$

where, $\sigma_1 \leq S$

- b) The circumference membrane stress of collar generated due to internal pressure shall be as follows.

$$\sigma_1' = \frac{1}{2} \frac{D_c^2 L_t E_c k}{nt(D_b + nt)L_t E_b + t_c D_c L_c E_c k} P$$

where, $\sigma_1' \leq C_{wc} S_c$

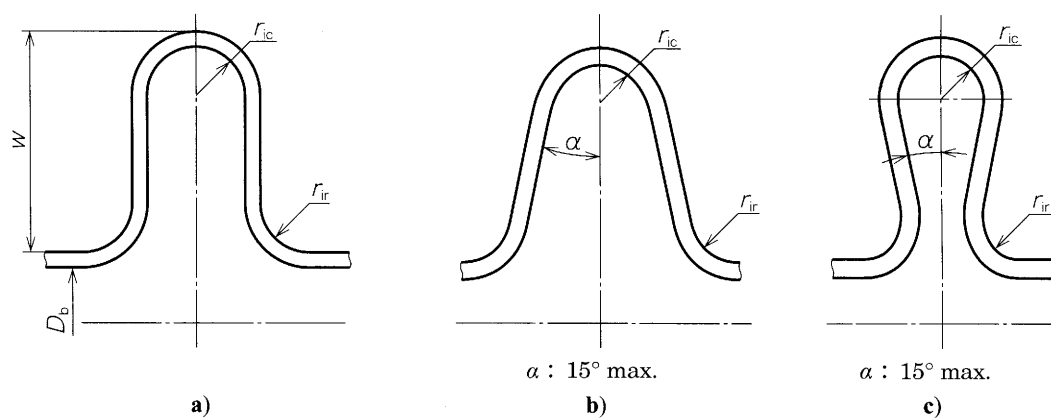


Figure 6 Profile of U-shaped bellows (neutral position)†