# TECH SCIENCE

ISSN 3030-3702

# TEXNIKA FANLARINING DOLZARB MASALALARI

# TOPICAL ISSUES OF TECHNICAL SCIENCES

№ 5 (3) 2025

# TECHSCIENCE.UZ

*№ 5 (3)-2025*

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# TOPICAL ISSUES OF TECHNICAL SCIENCES

**TOSHKENT-2025**

**OAK Ro‘yxati**

Mazkur jurnal O‘zbekiston Respublikasi Oliy ta’lim, fan va innovatsiyalar vazirligi huzuridagi Oliy attestatsiya komissiyasi Rayosatining 2025-yil 8-maydagi 370-son qarori bilan texnika fanlari bo‘yicha ilmiy darajalar yuzasidan dissertatsiyalar asosiy natijalarini chop etish tavsiya etilgan ilmiy nashrlar ro‘yxatiga kiritilgan.

**Muassislar**: “SCIENCEPROBLEMS TEAM” mas’uliyati cheklangan jamiyati;
Jizzax politexnika insituti.

**TECHSCIENCE.UZ- TEXNIKA FANLARINING DOLZARB MASALALARI** elektron jurnali 15.09.2023-yilda 130343-sonli guvohnoma bilan davlat ro‘yxatidan o‘tkazilgan.

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TEXNIKA FANLARINING DOLZARB MASALALARI
3-jild, 5-son (Avgust, 2025). -119 bet.

## MUNDARIJA

TECH SCIENCE.UZ

Texnika fanlarining dolzarb masalalari
Topical Issues of Technical Sciences
2025-yil | 3-jild | 5-son
ISSN (onlayn): 3030-3702

# CALCULATIONS FOR HEAT EXCHANGER EXPANSION BELLOWS MADE OF B443 (UNS N06625) MATERIAL

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UDK 665.7.3:547.21

**Annotation.** This paper presents the minimum design requirements for bellows expansion joints used as integral components of heat exchangers and other pressure vessels. These requirements apply to single- or multi-layer bellows (unreinforced, reinforced, or toroidal, as shown in Figure 2), subjected to internal or external pressure and cyclic displacement. The bellows must consist of one or more identically formed convolutions and may be either as-formed or annealed. The suitability of an expansion joint for specified design pressure, temperature, and axial displacement is determined using the methods described herein.

**Keywords**: Bellow, B443 (UNS N06625), expansion joints, heat exchanger, pressure, CLAMSHELL.

# B443 (UNS N06625) MATERIALI ASOSIDA TAYYORLANGAN ISSIQLIK ALMASHTIRGICH KOMPENSATORLARINING HISOB-KITOBLARI

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**Annotatsiya.** Ushbu maqolada issiqlik almashtirgichlar va boshqa bosim ostida ishlovchi idishlarda tarkibiy element sifatida qo'llaniladigan kengayuvchi kompensatorlar (bellows) uchun minimal konstruktiv talablari bayon etilgan. Bu talablar ichki yoki tashqi bosim hamda tsiklik siljish ta'sirida ishlovchi bir yoki ko'p qatlamli kompensatorlarga (mustahkamlangan, mustahkamlanmagan yoki toroidal shakldagilarga, 2-rasmga qarang) nisbatan qo'llaniladi. Kompensatorlar bir xil shakllantirilgan bir yoki bir nechta konvolyutsiyalardan iborat bo'lishi va ishlab chiqarilgan holatda yoki tavlanma (annealed) bo'lishi mumkin. Kengayuvchi kompensatorning belgilangan ish bosimi, harorati va aksial siljishga mosligi ushbu maqolada bayon etilgan usullar orqali aniqlanadi.

**Kalit so'zlar:** Kompensator, B443 (UNS N06625), kengayuvchi birikmalar, issiqlik almashtirgich, bosim, CLAMSHELL.

**DOI:** https://doi.org/10.47390/ts-v3i5y2025N11

**Introduction.**

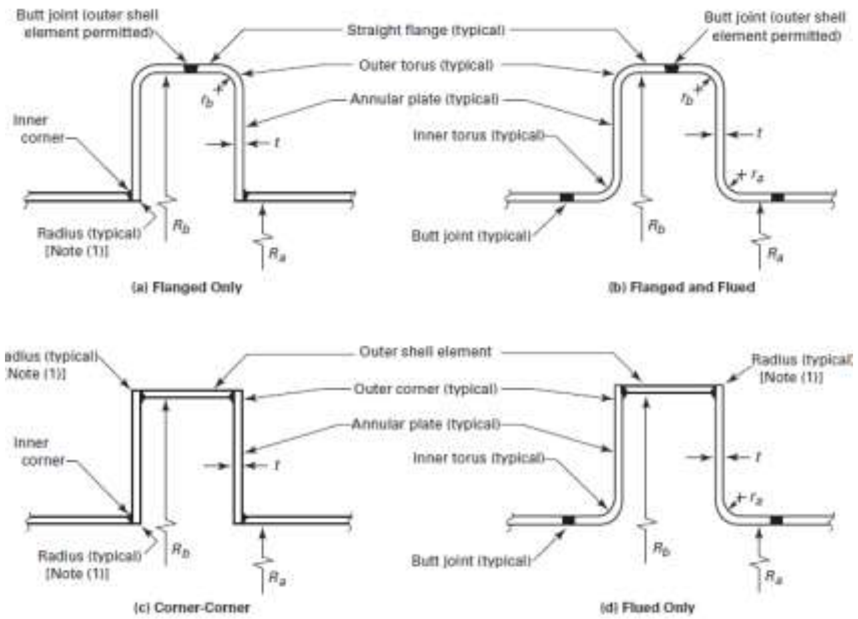
Flexible shell element expansion joints used as an integral part of heat exchangers or other pressure vessels shall be designed to provide flexibility for thermal expansions and also function as pressure-containing elements.

The rules in this Appendix are intended to apply to typical single-layer flexible shell element expansion joints shown in Picture 1 and are limited to applications involving only axial deflections. The suitability of the expansion joint for the specified design, pressure, and temperature shall be determined by methods described in this Appendix.

In all vessels with expansion joints, the hydrostatic end force caused by pressure and/or the joint spring force shall be contained by adequate restraining elements (i.e., tube bundle, tubesheets or shell, external bolting, anchors, etc.).

If expansion-joint flexible elements are to be extended, compressed, rotated, or laterally offset to accommodate connecting parts that are not properly aligned, such movements shall be considered in the design.

Elastic moduli, yield strengths, and allowable stresses shall be taken at the design temperatures. However, for cases involving thermal loading, it is permitted to use the operating metal temperature instead of the design temperature.




**Picture 1.** Typical Flexible Shell Element Expansion Joints

**Methods and materials.**

For carbon and low alloy steels, minimum thickness exclusive of corrosion allowance shall be 0.125 in. (3 mm) for all pressurecontaining parts [1; P.413-413.].

Minimum Thickness of Pressure-Retaining Components. Except for the special provisions listed below, the minimum thickness permitted for shells and heads, after forming and regardless of product form and material, shall be 1/16 in. (1.5 mm) exclusive of any corrosion allowance [1; P.415-415.].

B443 (UNS N06625) materials - is a high-grade nickel-based alloy with excellent corrosion resistance, high temperature strength, and good weldability [2; P.605-615.].

**Table 1**

**Chemical Requirements**

| № | Elements | Composition, % |
|---|---|---|
| 1 | Nickel | 64.05 |
| 2 | Chromium | 19.96 |
| 3 | Molybdenum | 8.45 |

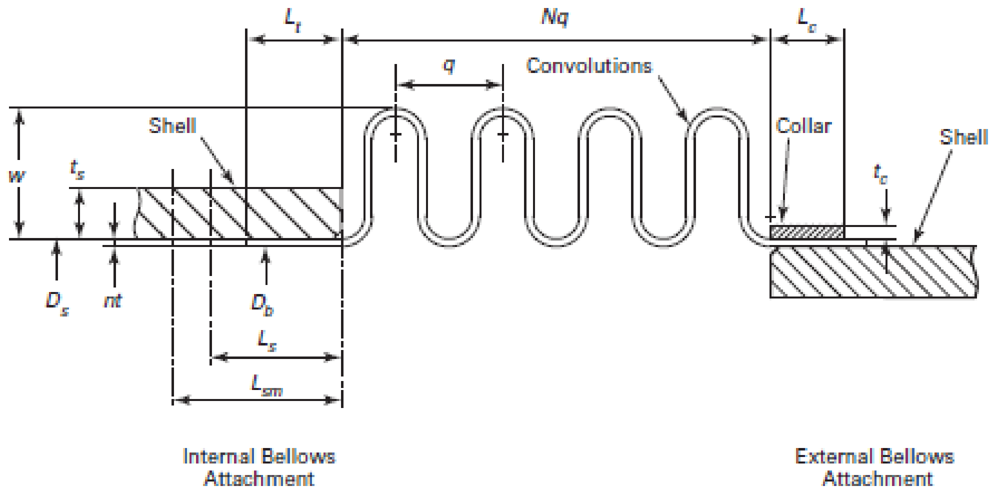
**Table 2**

**Tensile Requirements**

| | | |
|---|---|---|
| 1 | Tensile strength, ksi [MPa] | 110-120 (758-827) |
| 2 | Yield strength, min,A ksi [MPa] | 55-60 (379-414) |
| 3 | Elongation in 2 in. [50 mm], min, % | 30 |

The expansion joint shall be designed for the axial displacement range over all load cases from one of the following equations for the axial displacement over the length of the thin-walled bellows element [3; P.219-223.].

The rules in this Appendix cover the common types of bellows expansion joints but are not intended to limit the configurations or details to those illustrated or otherwise described herein.




**Picture 2.** Unreinforced Bellows

**Conditions of applicability**

The design rules of this Appendix are applicable only when the following conditions of applicability are satisfied:

(a) The bellows shall be such that Nq ≤ 3Db;

(b) The bellows nominal thickness shall be such that nt ≤ 0.2 in. (5.0 mm);

(c) The number of plies shall be such that n ≤ 5;

(e) These rules are valid for design temperatures up to the temperatures shown in Table 1;

(g) The length of the cylindrical shell on each side of the bellows shall not be less than 1.8;

(h) The torus radius shall be such that ri ≥ 3t;

(t) The convolution height shall be such that:

$$w \leq \frac{D_b}{3}$$

**Design conditions**

Expansion joints shall be designed to provide flexibility for thermal expansion and also to function as a pressure-containing element.

The vessel manufacturer shall specify the design conditions and requirements for the detailed design and manufacture of the expansion joint.

In all vessels with integral expansion joints, the hydrostatic end force caused by pressure and/or the joint spring force shall be resisted by adequate restraint elements (e.g., exchanger tubes or shell, external restraints, anchors, etc.).

The expansion joints shall be provided with bars or other suitable members for maintaining the proper overall length dimension during shipment and vessel fabrication. During a heat exchanger pressure test, these bars or members shall not carry load or limit expansion joint movement [2; P.503-503.].

Expansion bellows shall not be extended, compressed, rotated, or laterally offset to accommodate connecting parts that are not properly aligned, unless the design considers such movements.

Care should be taken to ensure that any torsional loads applied to expansion joints are kept to a minimum to prevent high shear stresses that may be detrimental to their use. If torsional loads are present or expected, they shall be considered in the design [4; P.40-45.].

Bellows longitudinal weld seams shall have a joint efficiency of 1.0.

**Results and discussions.**

The calculations performed for the bellows expansion joints made of B443 (UNS N06625) material reveal critical insights into their mechanical behavior under operating conditions typical for heat exchangers. Stress analysis showed that increasing the bellow thickness from 1.27 mm (3 plies) to 3 mm (single ply) significantly reduces the stress concentration at the weld seams, thereby improving the joint’s resistance to fatigue and leakage.

Furthermore, fatigue life estimations suggest that multi-ply configurations may offer superior durability due to better stress distribution across layers, although they may be more susceptible to corrosion and inter-ply defects. Overall, the results emphasize a holistic approach where material selection, thickness, ply configuration, design geometry, and welding practices must be optimized together to achieve durable and leak-proof bellows expansion joints in heat exchangers.

**Design conditions**

Design Internal Pressure U-2A MDR (barg) - 83,80;

Design Internal Temperature U-2A MDR (°C) - 238,00;

Minimum design metal temperature U-2A MDR (°C) -18,00;

Maximum allowable working pressure U-2A MDR (barg) - 99,78;

Internal test pressure value U-2A MDR (barg) - 129,71;

Internal corrosion allowance U-2A MDR (mm) CA - 0,00;
External corrosion allowance U-2A MDR (mm) CA - 0,00;

**Pressure test conditions**

Maximum allowable working pressure of the bellows (barg) - 116,24;
Maximum allowable working pressure of the unit U-2A MDR (barg) - 99,78;
Allowable stress of bellows at ambient temperature (MPa) - 236,00;
Allowable stress of bellows at MAWP temperature (MPa) - 228,96;
Lowest stress ratio of the bellows - 1,031;
Allowable stress of reinforcing rings at ambient temperature (MPa) - 138,00;
Allowable stress of reinforcing rings at MAWP temperature (MPa) - 138,00;
Lowest stress ratio of the reinforcing rings - 1,000;
Allowable stress of bolting at ambient temperature (MPa) - 172,00;
Allowable stress of bolting at MAWP temperature (MPa) – 172;
Lowest stress ratio -1,000;
Min. Test pressure acc. UG-99 b [36] (barg) - 108,94;
Max. Test pressure acc. UG-99 b (barg) - 151,12;
Internal test pressure value U-2A MDR (barg) - 129,71;

**Conditions**

(a) The bellows shall be such that 2403;
(b) The bellows nominal thickness shall be such that, mm - 5;
(c) The number of plies shall be such that - 5;
(e) These rules are valid for design temperatures up to the temperatures – 425 $^0$C;
(g) The length of the cylindrical shell on each side of the bellows shall not be less than -
(h) The torus radius shall be such that - 9;
(t) The convolution height shall be such that – 267.

**Design conditions**

Design Pressure (barg) - 83,80;
Design Temperature (°C) - 238,00;

**Convolution profile**

Inside diameter of cylindrical convolutions at neck (mm) - 801,00;
Inside diameter of cylindrical convolutions at convolution (mm) - 801,00;
Pitch (mm) - 55,00;
Height (mm) - 55,50;
Number of plies – 1;
Thickness of one ply (mm) - 3,00;
No. Of convolutions in one bellow – 1;
Active length of the bellows (mm) N·-55,00;
Bellows tangent length (mm) - 15,00;
Mean diameter of bellows tangent reinforcing collar (mm) - 927,00;
Mean diameter of bellows convolutions (mm) - 859,50;
Cross sectional metal area of one bellows convolution (mm$^2$) - 412,39;
Bellows effective area (cm$^2$) - 5.802,1;

**Reinforcement ring profile**

Type of ring - Equalizing ring bolted;

Height of the ring (mm) - 120,00;
Thickness of the collar ring (mm) - 60,00;
Thickness of the middle convolutions ring (mm) - 60,00;
Cross-sectional metal area of one tangent collar (mm^2) - 3870,00;
Cross-sectional metal area of one bellows reinforcing member (mm^2) - 3870,00;
Croos-sectional metal area of reinforcing fasteners in one ring (mm^2) - 2321,6.

**Mech. prop. of materials**

Bellow's material - SB443N06625Gr1;
Reinforcemnet ring's material - SA516Gr70;
Reinforcement fastener's material - SA193 B7 <=64;
Modulus of elasticity at room temperature of the bellow (MPa) - 207.000;
Modulus of elasticity at design temperature of the bellow (MPa) -194.720;
Modulus of elasticity at design temperature of the collar/ring (MPa) - 189.720;
Modulus of elasticity at design temperature of the ring member (MPa) - 190.720;
Allowable material stress at design temperature of the bellow (MPa) - 228,96;
Allowable material stress at design temperature of the collar/ring (MPa) - 138,00;
Allowable material stress at design temperature of the ring member(MPa) - 172,00;
Yield strength at design temperature after forming of the bellow (MPa) - 301,40;
Effective yield strength at design temperature of the bellow (MPa) - 693,22;
Treatment of the bellow after forming – As-formed;

**Welding factors**

Long. Weld joint eff. Factor for bellow - 1,00;
Long. Weld joint eff. Factor for collar - 0,70;
Long. Weld joint eff. Factor for ring - 0,70;

**Internal pressure capacity**

Bellows tangent circumferential membrane stress due to pressure (MPa) - 31,13;
Collar circumferential membrane stress due to pressure (MPa) S- 40,33;
Bellows circumferential membrane stress due to pressure - Bolted (MPa) - 67,75;
Reinforcing fastener membrane stress due to pressure (MPa) - 73,28;
Bellows meridional membrane stress due to pressure (MPa) - 47,96;
Bellows meridional bending stress due to pressure (MPa) - 424,45;

**Fatigue evaluation**

Meridional membrane stress due to presure (MPa) - 43,93;
Meridional bending stress due to presure (MPa) - 1.904,25;
Calculation of total stress range due to cyclic displacement (MPa) - 2.278,86.

**Internal pressure capacity max. stresses**

Max. Allowable Stress in S1 (MPa) - 228,96;
Max. Allowable Stress in S'1 (MPa) - 96,60;
Max. Allowable Stress in S2 - Bolted (MPa) - 228,96.;
Max. Allowable Stress in S''2 - Bolted (MPa) - 172,00;
Max. Allowable Stress in (S3+S4) (MPa) - 655,31.

**Conclusion.**

Selecting and properly calculating bellows expansion joints made from B443 (UNS N06625) is essential for ensuring reliable thermal compensation and avoiding costly failures in heat exchangers. Thickness, ply configuration, and weld quality significantly affect the joint's performance and lifespan.

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**ISSN:** 3030-3702 (Online)
**САЙТ:** https://techscience.uz

# TECHSCIENCE.UZ

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***№ 5 (3)-2025***

# TOPICAL ISSUES OF TECHNICAL SCIENCES

**TECHSCIENCE.UZ- TEXNIKA FANLARINING DOLZARB MASALALARI** elektron jurnali 15.09.2023-yilda 130345-sonli guvohnoma bilan davlat roʻyxatidan oʻtkazilgan.
**Muassislar:** "SCIENCEPROBLEMS TEAM" mas'uliyati cheklangan jamiyati;
Jizzax politexnika insituti.

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