BOA Group

Angular Expansion Joints

Table of
contents

Angular expansion joints are suited for the compensation of both long pipe sections of district heating systems as well as short boiler and turbine room pipelines in one or more planes. For installations with very limited space one should also check the possibility of the installation of tied universal or pressure balanced expansion joints. Contrary to axial and universal expansion joints that are suited to compensate for movements independently, angular expansion joints are only elements of an expansion system. A minimum of two and a maximum of three angular expansion joints form a static defined system. The function depends on the ability of the bellows to rotate and the amount of rotation is stated in the technical data sheets as permissible angular rotation.

Angular expansion joints are usually installed with 50% pre-stressing. This is accomplished by pre-stressing the entire expansion system after its completion. The pre-stressing amount can be determined from the pre-stressing graph in the section "assembly instructions" taking into account the installation temperature.

The longer the distance L_1 between two angular expansion joints (Fig. 1) is, the larger the movement that can be compensated for by the expansion system and the smaller the displacement forces become. The longitudinal reaction forces that orginate from the inner pressure are transmitted through the hinges.

The center of rotation of the hinges lies on the same axis as the center of the bellows. (Fig. 1)

Gimbal expansion joints utilize a round or square gimbal joint to restrain the reaction forces. This results in three dimensional rotations around the axes x and z (Fig. 2).
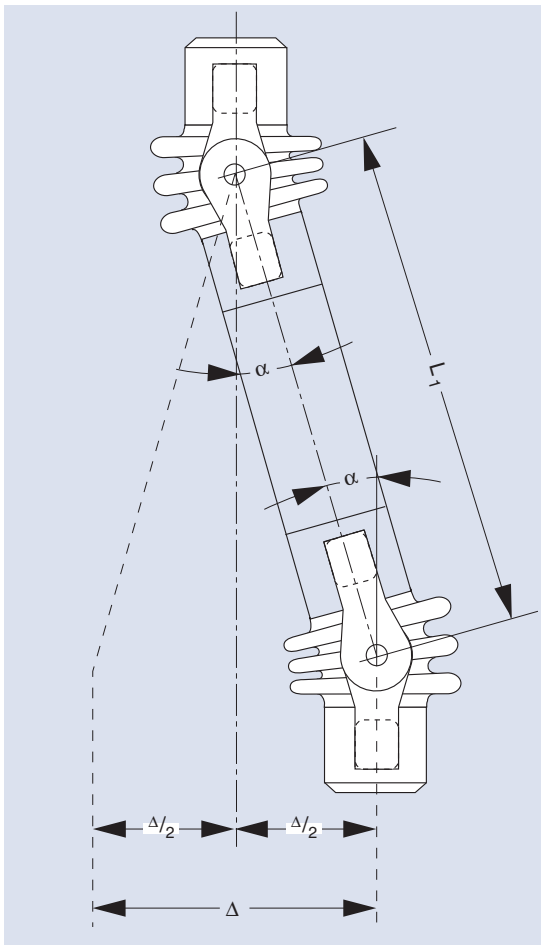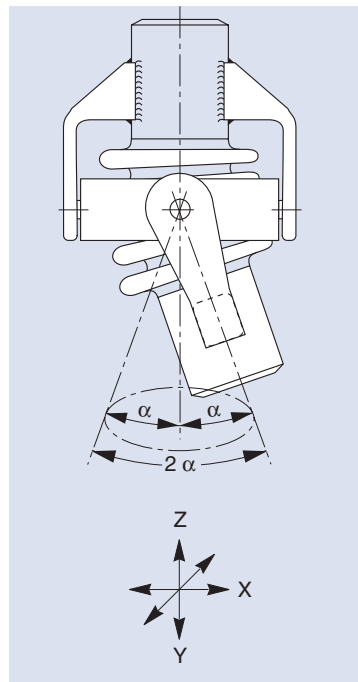

Fig. 1

Fig. 2

**Anchors,
pipe supports / guides**

Angular expansion joints make no special demands on pipe supports or guides in contrast to axial expansion joints. Even swing hangers can be sufficient.

Additional supports are unnecessary for short turbine house pipelines. The weight of the pipe sections between the angular expansion joints must be supported by supports or hangers which must not hinder the movements of the angular expansion joints. Pipe guides placed before and after each expansion system are necessary in long pipelines. Pipe guides which have been fitted too tightly may become jammed. They could then loosen in short bursts which could result in severe additional forces. Hinged expansion joints in a two pin Z expansion system follow an arc due to their angular rotation (Fig. 3).

following requirements:
1. Support the weight of the pipeline and the expansion joints.
2. Guide the expanding pipeline in its longitudinal axis.
3. Provide sufficient clearance [s] to assure that movements of the pipe that are not compensated for by expansion joints and that result from the thermal expansion ΔL and the height of the arc [h] can be compensated for by the continuing pipeline without causing the guide to jam.

$$S \geqq h + \Delta L$$
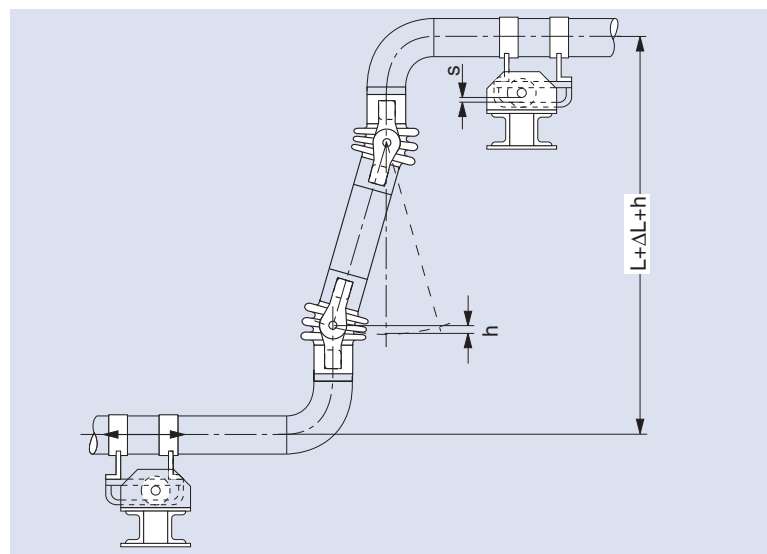
The pipeline guides should comply with the

Fig. 3

Sleeves

We recommend the installation of expansion joints with sleeves if high-frequency oscillations or turbulences are to be expected in the medium, or if the medium has a high flow velocity.

The diagram "Guidelines for use of sleeves" shows the limit curves for steam, gas, and liquids, above which the use of sleeves is absolutely recommended.

The sleeves serve to protect the bellows and reduce its tendency towards oscillation induced by the flow, and to also reduce deposits and wear.

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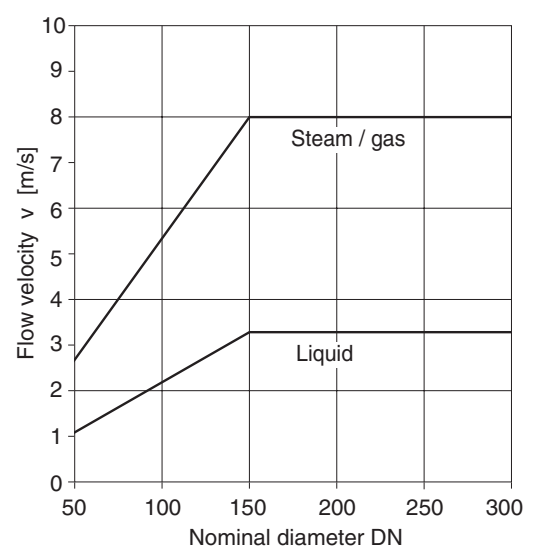
The following expansion joint arrangements are most common in the planning of angular expansion systems:
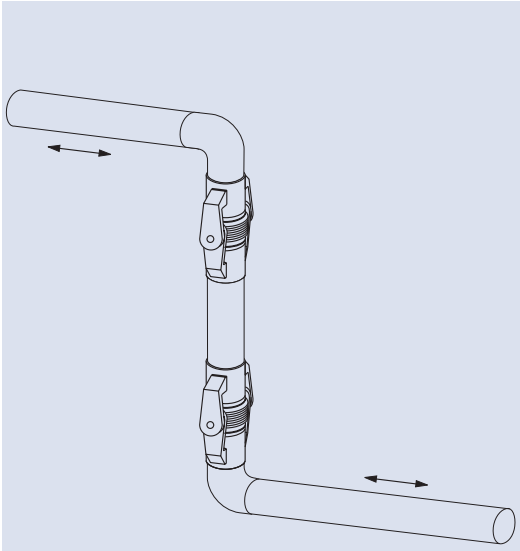
Two pin Z-system
for pipelines of any length under utilization of a given route.
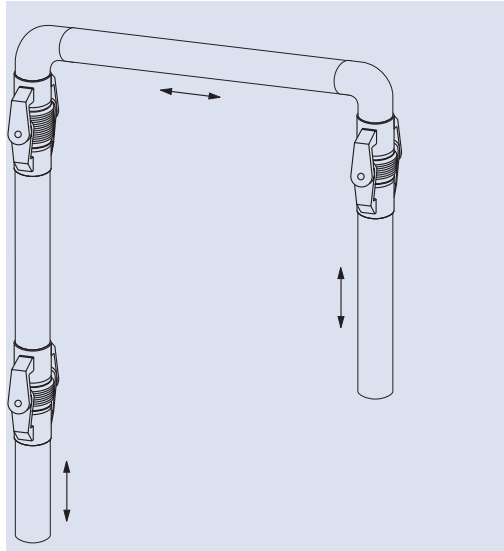
Three pin L-system
suited for the compensation of transfer pipelines between two tanks for example.
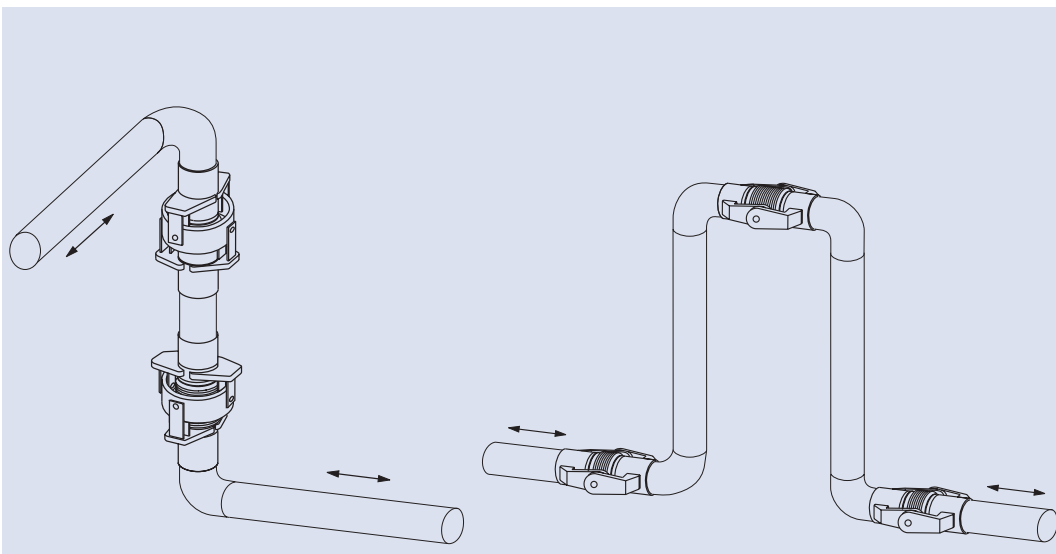
Two pin gimbal system
for the compensation of perpendicular movements in short pipeline sections.

Three pin U-system
preferably for the compensation of long pipelines.
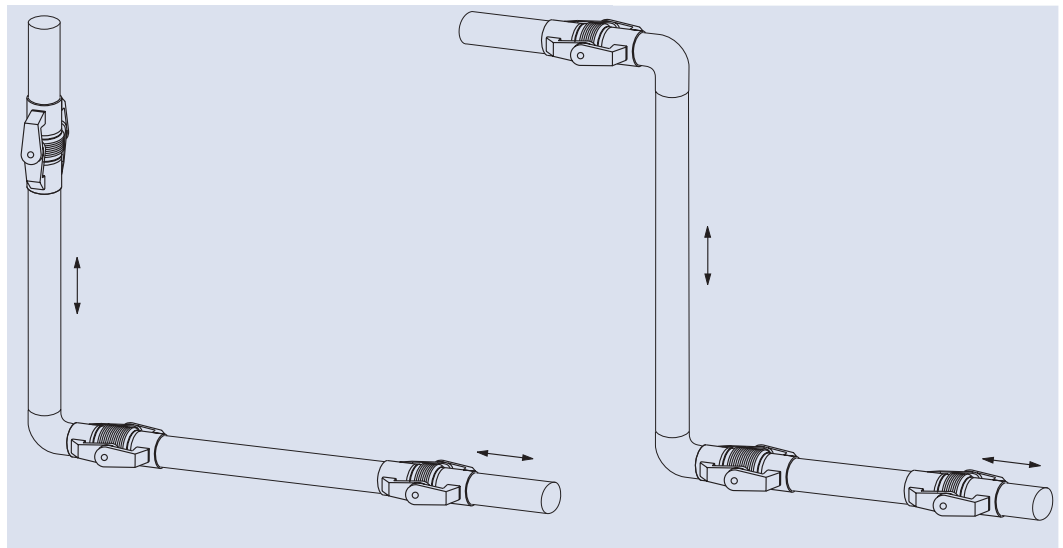
Three pin W-system

for the compensation of longest and shortest pipelines with concurrent movements from two directions.

Three pin Z-system

for the compensation of pipelines under utilization of given pipeline routings including the compensation of the vertical pipeline section.
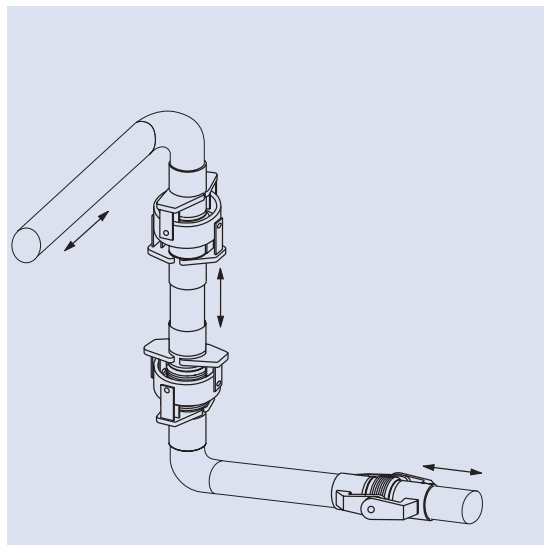
Three pin gimbal W-system

for the compensation of three dimensional systems, for example boiler and turbine house pipelines.

In the following example, the three pin W-system is used to explain the basic procedure for the design of expansion systems.

First of all, one has to choose a suitable expansion system under consideration of the given routing and the anticipated expansion of the pipeline. Note that both ends of the line must be limited by pipe anchors.

For our example, we assume an L-shaped pipe routing of which the thermal expansion Δ_1 and Δ_2 from the pipe sections L_{01} and L_{02} will be optimally compensated for by a system of three hinged expansion joints in the three pin W arrangement.
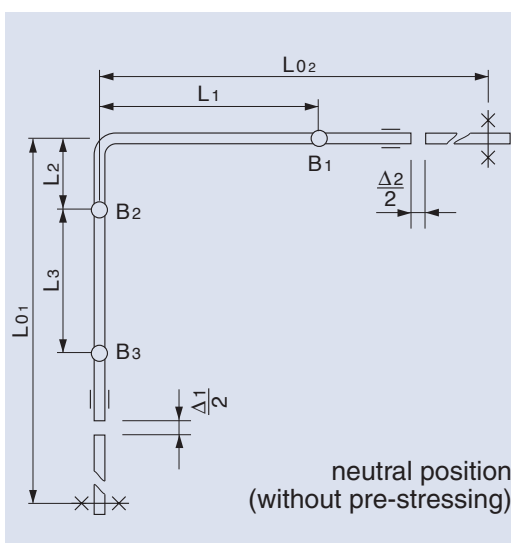

neutral position
(without pre-stressing)

Initially, one must determine the thermal expansion Δ_1 and Δ_2 under consideration of the maximum temperature difference of the pipeline (refer to "Expansion Joints" section "basic principals").

Then, one must calculate the expansion system. Two options are available:

1.) Choose the geometry of the system (the distances L_1, L_2 and L_3) and calculate the effective angular rotation $\pm\alpha_e$ of each hinged joint by using the given formulae (see the following pages).

Next, from the data sheets, select hinged expansion joints that are suited for the operating conditions (DN, PN) and that have a permissible angular rotation $\pm\alpha_{zul}$ that is equal to or greater than the effective rotation $\pm\alpha_e$.

$$\pm\alpha_e \leq \pm\alpha_{zul}$$

2.) Choose suitable hinged expansion joints and then calculate the required distances L_1 and L_3.

If the operating conditions exceed the nominal conditions, one must ensure that the nominal angular rotations $\pm\alpha$ as per the data sheets are converted to permissible values following the rules given in the section "basic principals, nominal conditions".

$$\pm\alpha_{zul} = \pm\alpha \cdot K_\Delta(t_B) \cdot K_L$$

In order to get small angles of rotation for the expansion joints, the distances between the pins of the joints L_1 and L_3 should be as long as reasonably possible and the distance L_2 as short as possible.

installed positions
(50% pre-stressed)
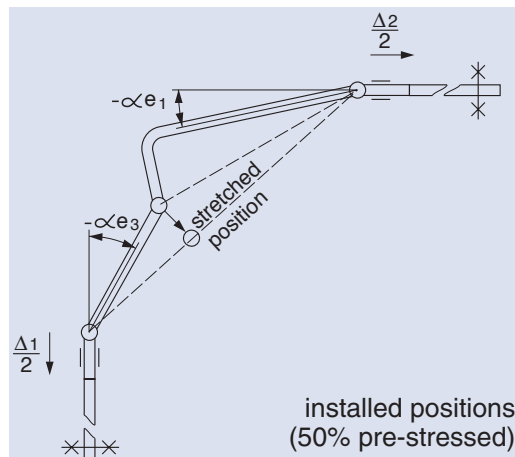
The calculation formulae for the determination of the angular rotation of three pin systems are approximates with sufficient accuracy for practical use. A more accurate calculation of the angular rotations becomes necessary for very straight systems if the center joint moves too close to the stretched out position when the system is pre-stressed.

Consult us in such cases. In order to achieve optimum utilization of the permissible angular rotation $\pm\alpha_{zul}$ of hinged expansion joints, a 50% pre-stressing of the system is required (see fig).

If pre-stressing is not possible, the angular rotation to one side of the centerline doubles. This normally requires an angular expansion joint with a larger nominal angular rotation.

Anchor and nozzle loads can be determined by using the formulae for the calculation of the displacement forces F and bending moments M.
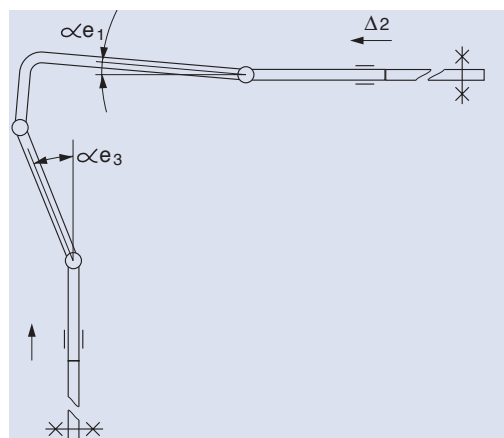
Calculations

Two pin Z-system 2 Z
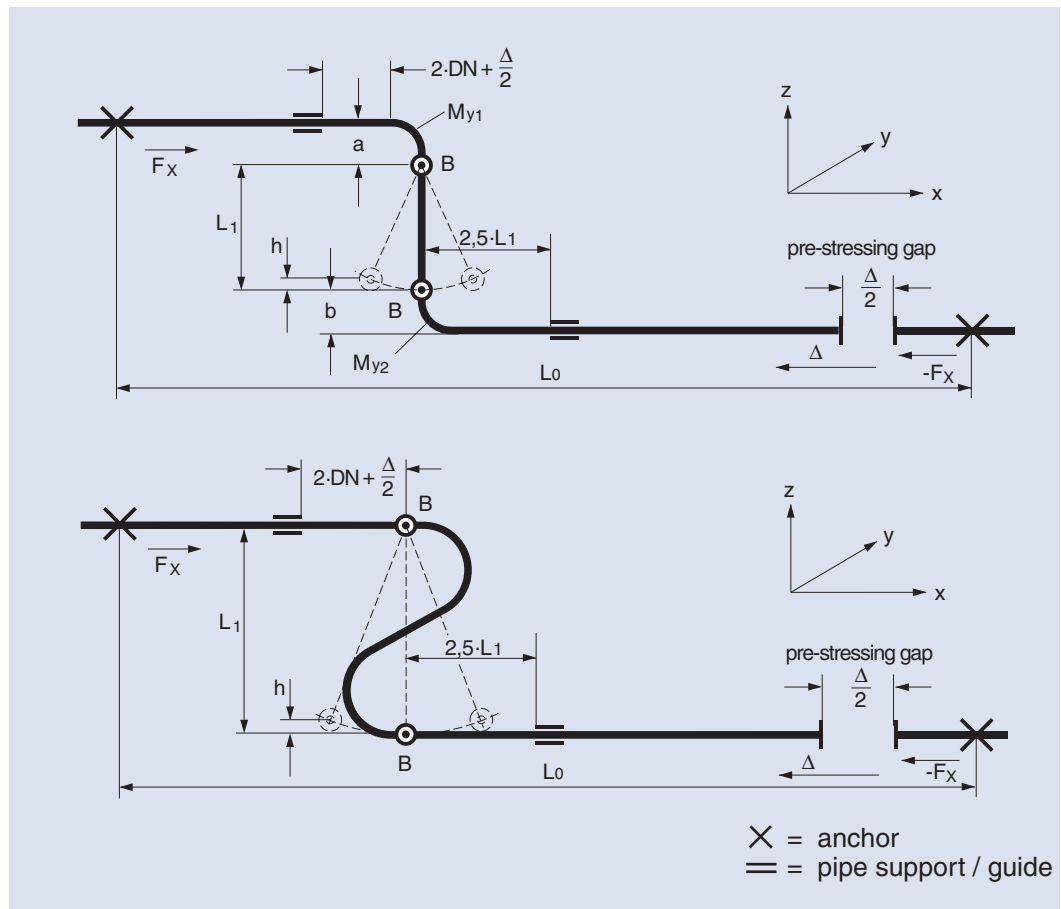
Two pin S-system 2 S
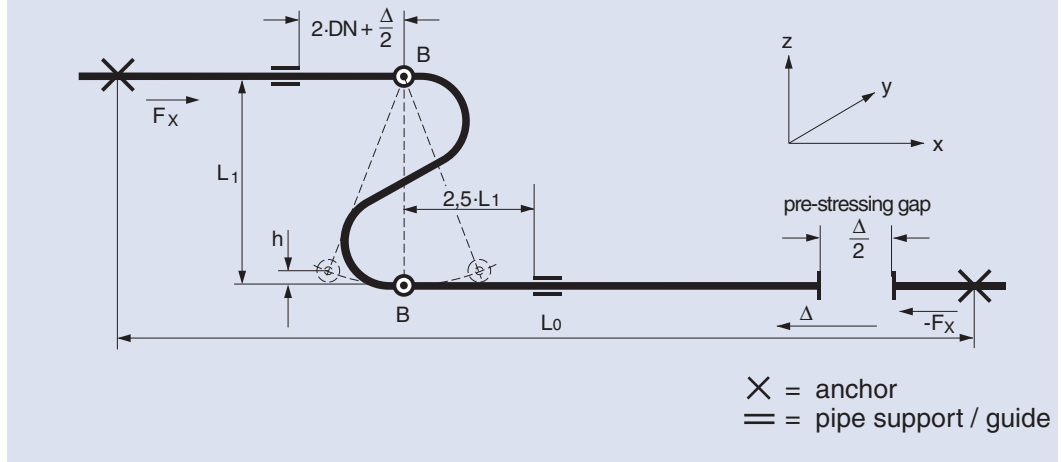
$\times$ = anchor
= = pipe support / guide

System calculation

Required hinge distance

Under consideration of the permissible angular rotation $[\alpha_{zul}]$ and a 50% pre-stressing, the minimum required distance between the hinges L_1 is:

$$L_1 = \frac{\Delta}{2 \cdot \sin\alpha_{zul}} \ [mm]$$

Resulting arc height

At the maximum effective angular rotation (α_e) the vertical distance between the hinges is reduced by the dimension h due to the circular motion of the expansion joints.

$$h = L_1 \cdot (1 - \cos\alpha_e) \ [mm]$$

The height of the arc and the thermal expansion of the pipe section L_1 must be compensated for by the pipe section $(2.5 \cdot L_1)$ or a sufficient clearance in the pipe guide must be available.

Effective angular rotation

If the pin distance L_1 ist given, the effective angular rotation of the angular expansion joints (B) is calculated as follows if the system is pre-stressed at 50%:

$$\alpha_e = \pm \arcsin\left(\frac{\Delta}{2 \cdot L_1}\right) \ [degr.]$$

At 100 % and at 0% pre-stressing, the angle of rotation of the angular expansion joints doubles, but in one direction only. The effective angle of rotation $[\alpha_e]$ must be multiplied by 2 in this case.

Bending moments of angular expansion joints

In order to calculate the bending moments and forces, the absolute values of the effective angular rotations (without signs) must be used in the following equation.

$$M_B = C_r \cdot p + C_\alpha \cdot \alpha_e + C_z \cdot p \cdot \alpha_e \ [Nm]$$

Forces at the connection points

$$F_x = \frac{2000 \cdot M_B}{L_1} \ [N]$$

Bending moments at the connection points

$$M_{y1} = M_B + F_x \cdot \frac{a}{1000} \ [Nm]$$

$$M_{y2} = M_B + F_x \cdot \frac{b}{1000} \ [Nm]$$

If the system ist pre-stressed at 50%, the moments and forces have different signs in the pre-stressed position and operating position of the system.

a, b	Center to center distance between bellows and connection point [mm]
C_α	Bending spring rate [Nm/degr.]
C_r	Hinge friction [Nm/bar]
C_z	Additional moment from rotation and pressure [Nm/(bar · degr.)]
F_x	Displacement force in x-direction [N]
h	Height of arc [mm]
L_1	Center to center distance between the bellows [mm]

$M_{y\,1,\,2}$	Bending moment at the connection point [Nm]
M_B	Bending moment of the expansion joint [Nm]
p	Operating pressure [bar]
α_e	Effective angular rotation of one expansion joint [degr.]
α_{zul}	Permissible angular rotation of one expansion joint [degr.]
Δ	Movement of the pipeline [mm]

Calculations

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**Two pin
gimbal-system
2 K**

X = anchor
═ = pipe support/guide

System calculation

Resulting expansion

$$\Delta = \sqrt{\Delta_1{}^2 + \Delta_2{}^2} \ \text{[mm]}$$

Required hinge distance
Under consideration of the permissible angular rotation [α_{zul}] and 50% pre-stressing, the minimum required distance between the hinges L_1 is:

$$L_1 = \frac{\Delta}{2 \cdot \sin\alpha_{zul}} \ \text{[mm]}$$

Resulting arc height
At the maximum effective angular rotation (α_e) the vertical distance between the hinges is reduced by the dimension h due to the circular motion of the expansion joints:

$$h = L_1 \cdot (1-\cos\alpha_e) \ \text{[mm]}$$

The height of the arc and the thermal expansion of the pipe section L_1 must be compensated for by the pipe section (2.5 · L_1) or a sufficient clearance in the pipe guide must be available.

Effective angular rotation
If the pin distance L_1 is given, the effective angular rotation of the angular expansion joints (B) is calculated as follows if the system is pre-stressed at 50%:

$$\alpha_e = \pm \arcsin\left(\frac{\Delta}{2 \cdot L_1}\right) \ \text{[degr.]}$$

$$\alpha_{ey} = \pm \arcsin\left(\frac{\Delta_1}{2 \cdot L_1}\right) \ \text{[degr.]}$$

$$\alpha_{ex} = \pm \arcsin\left(\frac{\Delta_2}{2 \cdot L_1}\right) \ \text{[degr.]}$$

At 100% and at 0% pre-stressing, the angles of rotation of the angular expansion joints doubles, but in one direction only. The effective angles of rotation [α_e, α_{ex}, α_{ey}] must be multiplied by 2 in this case.

Bending moments of angular expansion joints

In order to calculate the bending moments and forces, the absolute values of the effective angular rotations (without signs) are used in the following formulae:

$$M_{By} = C_r \cdot p + C_\alpha \cdot \alpha_{ey} + C_z \cdot p \cdot \alpha_{ey} \ [Nm]$$

$$M_{Bx} = C_r \cdot p + C_\alpha \cdot \alpha_{ex} + C_z \cdot p \cdot \alpha_{ex} \ [Nm]$$

Forces at the connection points

$$F_x = \frac{2000 \cdot M_{By}}{L_1} \ [N]$$

$$F_y = \frac{2000 \cdot M_{Bx}}{L_1} \ [N]$$

Bending moments at the connection points

$$M_{y1} = M_{By} + F_x \cdot \frac{a}{1000} \ [Nm]$$

$$M_{y2} = M_{By} + F_x \cdot \frac{b}{1000} \ [Nm]$$

$$M_{x1} = M_{Bx} + F_y \cdot \frac{a}{1000} \ [Nm]$$

$$M_{x2} = M_{Bx} + F_y \cdot \frac{b}{1000} \ [Nm]$$

If the system ist pre-stressed at 50%, the moments and forces have different signs in the pre-stressed position and operating position of the system.

a, b	Center to center distance between bellows and connection point [mm]
C_α	Bending spring rate [Nm/degr.]
C_r	Hinge friction [Nm/bar]
C_z	Additional moment from rotation and pressure [Nm/(bar · degr.)]
$F_{x, y}$	Displacement force in x and y-direction [N]
h	Height of arc [mm]
L_1	Center to center distance between the bellows [mm]

$M_{x,y1,2}$	Bending moment at the connection point [Nm]
$M_{Bx, y}$	Bending moment of the expansion joint [Nm]
p	Operating pressure [bar]
$\alpha_{ey, x}$	Effective angular rotation of one expansion joint [degr.]
α_{zul}	Permissible angular rotation of one expansion joint [degr.]
$\Delta_{1, 2}$	Movement of the pipeline [mm]

Calculations

**Three pin U-system
3 U**

$\times$ = anchor $=$ = pipe guide
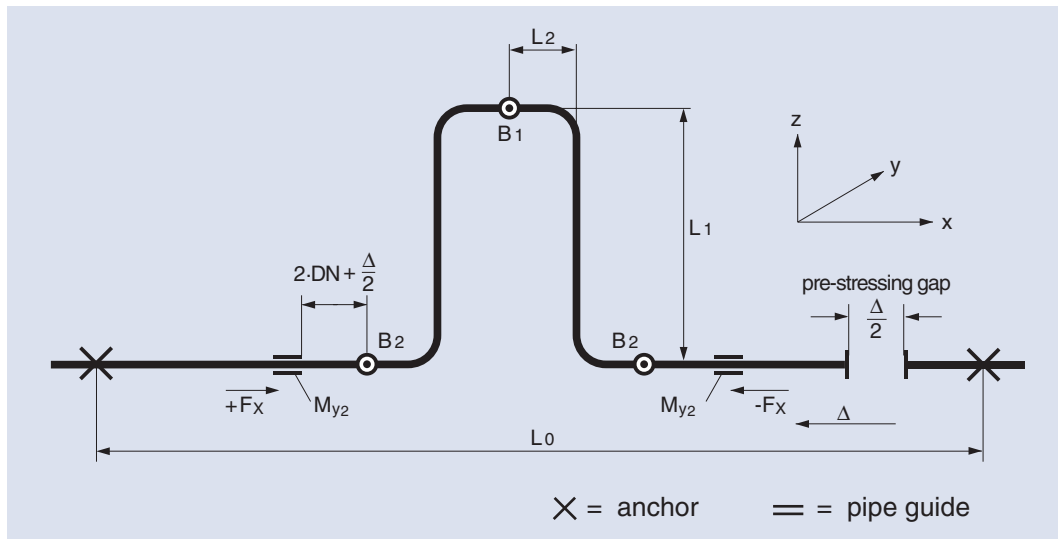
System calculation

Required hinge distance

If the permissible angular rotation [α_{zul}] of all three expansion joints is the same and the system is pre-stressed at 50%, then the minimum distance between the hinges is determined as follows L_1:

$$L_1 = \frac{\Delta}{2 \cdot \sin\alpha_{zul.}} \text{ [mm]}$$

L_2 should be chosen as short as possible.

Effective angular rotation

If the pin distance L_1 is given, the effective angular rotation of the angular expansion joints (B_1, B_2) is calculated as follows if the system is pre-stressed at 50%:

$$\alpha_{e1} = \pm \arcsin\left(\frac{\Delta}{2 \cdot L_1}\right) \text{[degr.]}$$

$$\alpha_{e2} = \pm \frac{\alpha_{e1}}{2} \text{ [degr.]}$$

At 100% and at 0% pre-stressing, the angle of rotation of the angular expansion joints doubles, but in one direction only. In this case, the effective angular rotation [α_e] must be multiplied by 2.

Bending moments of angular expansion joints

In order to calculate the bending moments and forces, the absolute values of the effective angular rotations (without signs) must be used in the following equations:

$$M_{B1} = C_r \cdot p + C_\alpha \cdot \alpha_{e1} + C_z \cdot p \cdot \alpha_{e1} \text{ [Nm]}$$

$$M_{B2} = C_r \cdot p + C_\alpha \cdot \alpha_{e2} + C_z \cdot p \cdot \alpha_{e2} \text{ [Nm]}$$

Forces at the connection points

$$F_x = \frac{1000 \cdot (M_{B1} + M_{B2})}{L_1} \text{ [N]}$$

Bending moment at the connection points

$$M_{y2} = M_{B2} \text{ [Nm]}$$

If the system is pre-stressed at 50%, the force and the moment will have different signs in the pre-stressed position and operating position.

C_α	Bending spring rate [Nm/degr.]	
C_r	Hinge friction [Nm/bar]	
C_z	Additional moment from rotation and pressure [Nm/(bar · degr.)]	
F_x	Displacement force in x-direction [N]	
L_1	Center to center distance between bellows [mm]	
M_{y2}	Bending moment at the connection point [Nm]	

$M_{B1, 2}$	Bending moment ot the expansion joint [Nm]
p	Operating pressure [bar]
$\alpha_{e1, 2}$	Effective angular rotation per bellows [degr.]
α_{zul}	Permissible angular rotation per bellows [degr.]
Δ	Movement of the pipeline [mm]

$$\times = \text{anchor}$$
$$= = \text{pipe guide}$$
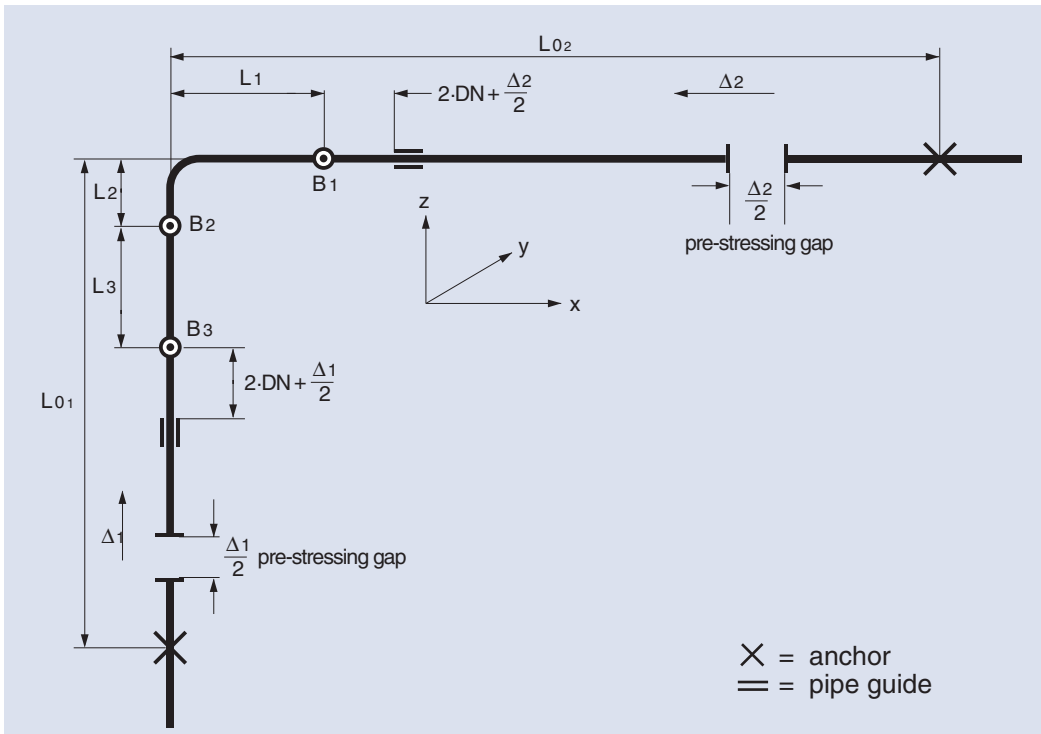
Required hinge distances

If the permissible angular rotation [α_{zul}] of all three expansion joints is the same and the system is pre-stressed at 50%, then the minimum distances L_1 and L_3 between the hinges are determined as follows:

$$L_1 = \frac{\Delta_1 \cdot (L_2 + L_3)}{2 \cdot \sin\alpha_{zul} \cdot L_3 - \Delta_2} \text{ [mm]}$$

when L_2 and L_3 have been chosen and

$$L_3 = \frac{\Delta_1 \cdot L_2 + \Delta_2 \cdot L_1}{2 \cdot \sin\alpha_{zul} \cdot L_1 - \Delta_1} \text{ [mm]}$$

when L_1 and L_2 have been chosen.

If the result of L_1 (or L_3) is negative or the distance is too long, then one must increase the distance L_3 (or L_1) accordingly or one must choose expansion joints with a larger permissible angular rotation.

In general, L_1 and L_3 should be as long as reasonably possible and L_2 should be as short as possible.

$L_{1,3}$	Center to center distance between the bellows [mm]
$\alpha_{e1,2,3}$	Effective angular rotation per bellows [degr.]
α_{zul}	Permissible angular rotation per bellows [degr.]
$\Delta_{1,2}$	Movement of pipeline [mm]

Effective angular rotation

If the pin distances L_1 and L_3 are given, the effective angular rotation of the angular expansion joints (B_1, B_2, B_3) is calculated as follows if the system is pre-stressed at 50%:

$$\alpha_{e1} = \pm \arcsin(\frac{\Delta_1}{2 \cdot L_1}) \text{ [degr.]}$$

$$\alpha_{e2} = \pm (\alpha_{e1} + \alpha_{e3}) \text{ [degr.]}$$

$$\alpha_{e3} = \pm \arcsin\left(\frac{\Delta_1 \cdot L_2 + \Delta_2 \cdot L_1}{2 \cdot L_1 \cdot L_3}\right) \text{ [degr.]}$$
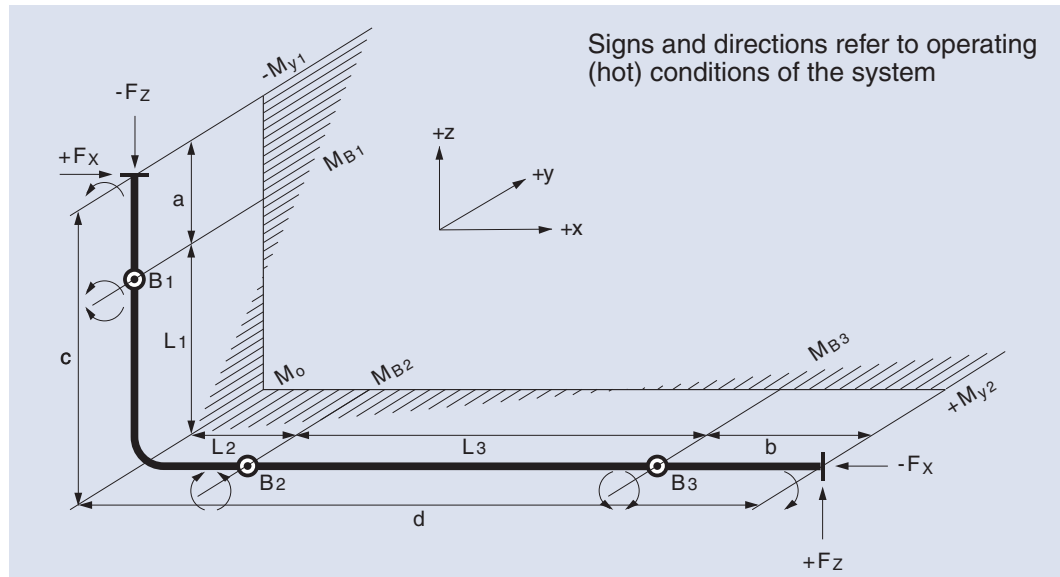
At 100% and at 0% pre-stressing, the angle of rotation of the angular expansion joints doubles, but in one direction only. In this case, the effective angular rotation ($\alpha_{e1,2,3}$) must be multipled by 2.

Calculations

Signs and directions refer to operating (hot) conditions of the system

Anchor and connection point loads

In installations with short pipe sections for example, between vessels, turbines and condensers, that are typical in power stations, the forces and moments of the expansion system at the connection points are of importance.

These forces and moments are the result of the bending moments of the angular expansion joints and the distance between those joints and the connection points.

In order to proceed with the following calculations the coordinates must be determined under consideration of the pipeline routing.

Bending moments of the angular expansion joints

In order to calculate the bending moments and forces, the absolute values of the effective angular rotations (without signs) must be used in the following formulae.

$$M_{B1} = C_r \cdot p + C_\alpha \cdot \alpha_{e1} + C_z \cdot p \cdot \alpha_{e1} \ [Nm]$$

$$M_{B2} = C_r \cdot p + C_\alpha \cdot \alpha_{e2} + C_z \cdot p \cdot \alpha_{e2} \ [Nm]$$

$$M_{B3} = C_r \cdot p + C_\alpha \cdot \alpha_{e3} + C_z \cdot p \cdot \alpha_{e3} \ [Nm]$$

a, b	Distance between the center of the bellows and the connection point [mm]
C_α	Bending spring rate [Nm/degr.]
C_r	Hinge friction [Nm/bar]
C_z	Additional moment from rotation and pressure [Nm/(bar · degr.)]
$F_{x,z}$	Displacement force in x and z direction [N]
$L_{1,3}$	Center to center distance between the bellows [mm]

The direction of the reaction forces at the connection points of the system are determined according to the direction of the movements (system in pre-stressed or operating position). The common rules of the equilibrium of forces should be taken into account.

Forces at the connection points

$$F_z = \frac{1000 \cdot (M_{B2} + M_{B3})}{L_3} \ [N]$$

$$M_0 = M_{B2} + F_z \cdot \frac{L_2}{1000} \ [N]$$

$$F_x = \frac{1000 \cdot (M_{B1} + M_0)}{L_1} \ [N]$$

Bending moments at the connection points

$$M_{y1} = - M_{B1} - F_x \cdot \frac{a}{1000} \ [Nm]$$

$$M_{y2} = M_{B3} + F_z \cdot \frac{b}{1000} \ [Nm]$$

If the system is pre-stressed at 50%, the force and the moment will have different signs in the pre-stressed position and operating position.

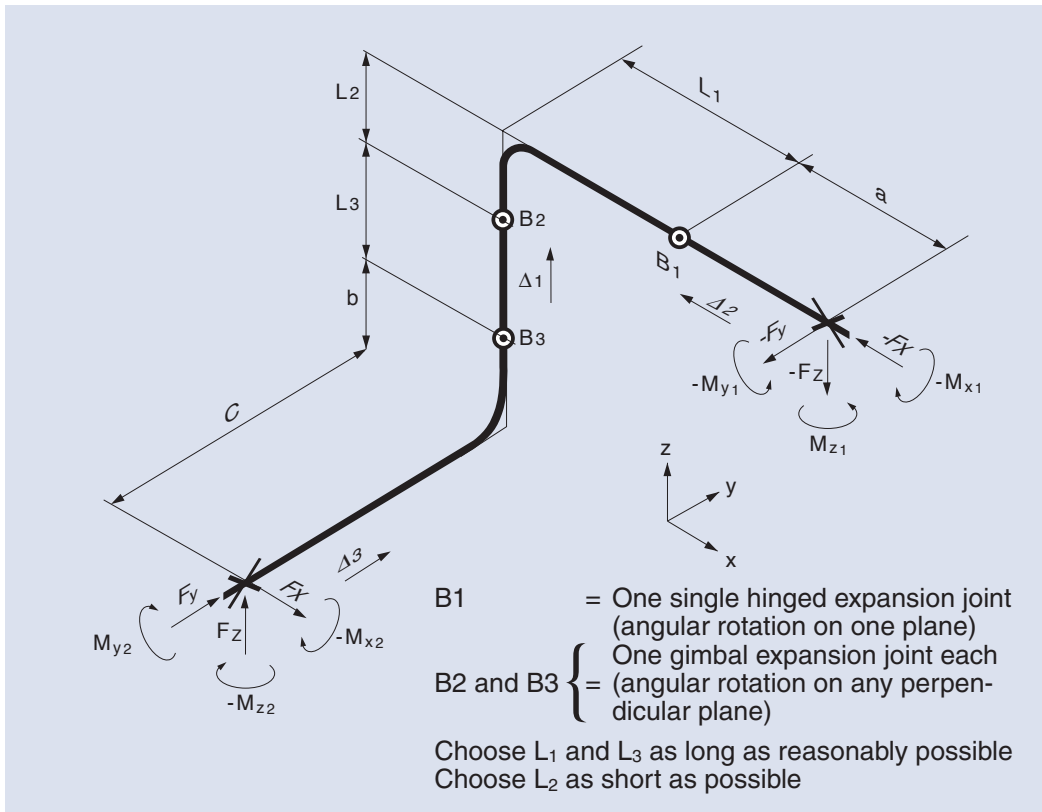|	
$M_{y1,2}$	Bending moments at the connection points [Nm]
$M_{B1,2,3}$	Bending moment of the expansion joints [Nm]
p	Operating pressure [bar]
$\alpha_{e1,2,3}$	Effective angular rotation per bellows [degr.]

B1 = One single hinged expansion joint (angular rotation on one plane)

B2 and B3 = One gimbal expansion joint each (angular rotation on any perpendicular plane)

Choose L_1 and L_3 as long as reasonably possible
Choose L_2 as short as possible

The thermal expansion or movement of the connection points, for example in turbine nozzles, should be added to the thermal expansion Δ_1, Δ_2 or Δ_3, of the pipe section if both move in the same direction and should be subtracted if they move in opposite directions.

Effective angular rotations

If the pin distances L_1 and L_3 are given, the effective angular rotation of the angular expansion joints (B_1, B_2, B_3) is calculated as follows if the system is pre-stressed at 50 %:

$$\alpha_{e1} = \pm \arcsin\left(\frac{\Delta_1}{2 \cdot L_1}\right) \text{ [degr.]}$$

$$\alpha_{e2y} = \pm (\alpha_{e1} + \alpha_{e3y}) \text{ [degr.]}$$

$$\alpha_{e3y} = \pm \arcsin\left(\frac{\Delta_1 \cdot L_2 + \Delta_2 \cdot L_1}{2 \cdot L_1 \cdot L_3}\right) \text{ [degr.]}$$

$$\alpha_{e2x} = \alpha_{e3x} = \pm \arcsin\left(\frac{\Delta_3}{2 \cdot L_3}\right) \text{ [degr.]}$$

$$\alpha_{e2} = \pm \sqrt{(\alpha_{e2x}^2 + \alpha_{e2y}^2)} \text{ [degr.]}$$

$$\alpha_{e3} = \pm \sqrt{(\alpha_{e3x}^2 + \alpha_{e3y}^2)} \text{ [degr.]}$$

At 100% and at 0% pre-stressing, the angle of rotation of the angular expansion joints doubles, but in one direction only. In this case, the effective angular rotation [$\alpha_{e1,2,3,x,y}$] must be multiplied by 2.

Calculations

Bending moments of the angular expansion joints

In order to calculate the bending moments and forces, the absolute values of the effective angular rotations (without signs) are used in the following formulae.

$$M_{B1y} = C_r \cdot p + C_\alpha \cdot \alpha_{e1} + C_z \cdot p \cdot \alpha_{e1} \ [Nm]$$

$$M_{B2y} = C_r \cdot p + C_\alpha \cdot \alpha_{e2y} + C_z \cdot p \cdot \alpha_{e2y} \ [Nm]$$

$$M_{B3y} = C_r \cdot p + C_\alpha \cdot \alpha_{e3y} + C_z \cdot p \cdot \alpha_{e3y} \ [Nm]$$

$$M_{B2x} = C_r \cdot p + C_\alpha \cdot \alpha_{e2x} + C_z \cdot p \cdot \alpha_{e2x} \ [Nm]$$

$$M_{B3x} = C_r \cdot p + C_\alpha \cdot \alpha_{e3x} + C_z \cdot p \cdot \alpha_{e3x} \ [Nm]$$

Bending moments at the connection points

$$M_{y1} = - M_{B1y} - F_z \cdot \frac{a}{1000} \ [Nm]$$

$$M_{y2} = M_{B3y} + F_x \cdot \frac{b}{1000} \ [Nm]$$

$$M_{x1} = - M_{B2x} - F_y \cdot \frac{L_2}{1000} \ [Nm]$$

$$M_{x2} = - M_{B3x} - F_y \cdot \frac{b}{1000} + F_z \cdot \frac{c}{1000} \ [Nm]$$

$$M_{z1} = F_y \cdot \frac{L_1 + a}{1000} \ [Nm]$$

$$M_{z2} = - F_x \cdot \frac{c}{1000} \ [Nm]$$

If the system is pre-stressed at 50%, the force and the moment will have different signs in the pre-stressed position and operating position.

Forces at the connection points

$$F_x = \frac{1000 \cdot (M_{B2y} + M_{B3y})}{L_3} \ [N]$$

$$F_y = \frac{1000 \cdot (M_{B2x} + M_{B3x})}{L_3} \ [N]$$

$$M_0 = M_{B2y} + F_x \cdot \frac{L_2}{1000} \ [N]$$

$$F_z = \frac{1000 \cdot (M_{B1y} + M_0)}{L_1} \ [N]$$

a,b	Distance between the center of the bellows and the connection point [mm]	$M_{x,y,z,1,2}$	Bending moments at the connection points [Nm]
C_α	Bending spring rate [Nm/degr.]	$M_{Bx,y1,2,3}$	Bending moment of the expansion joints [Nm]
C_r	Hinge friction [Nm/bar]	p	Operating pressure [bar]
C_z	Additional moment from rotation and pressure = [Nm/(bar · degr.)]	$\alpha_{ex,y;1,2,3}$	Effective angular rotation per bellows [degr.]
$F_{x,y,z}$	Displacement force in x, y and z direction [N]	α_{zul}	Permissible angular rotation per bellows [degr.]
$L_{1,3}$	Center to center distance between the bellows [mm]	$\Delta_{1,2,3}$	Movement of pipeline [mm]

X = anchor
$=$ = pipe guide
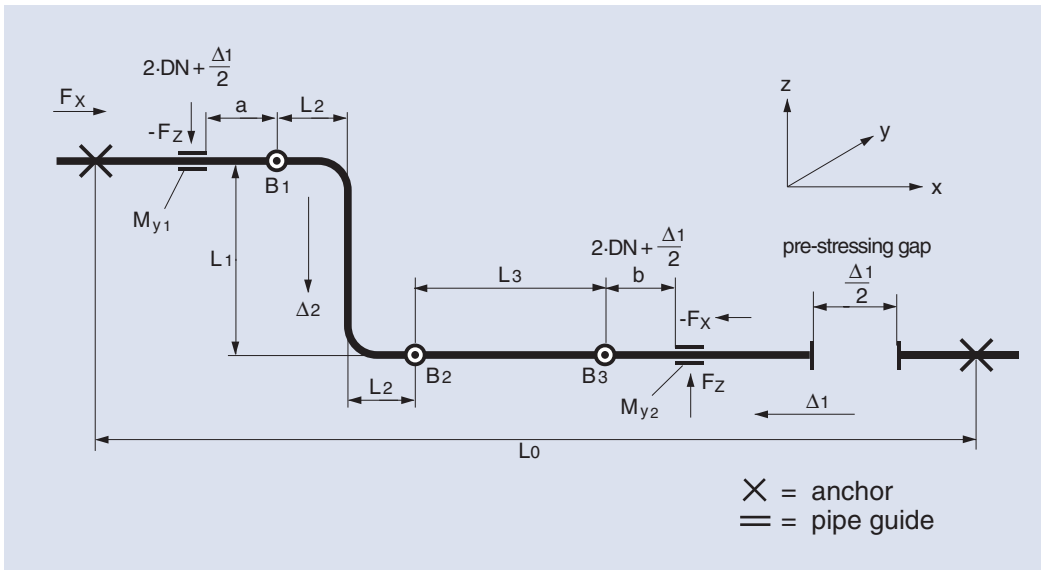
Required hinge distances

If the permissible angular rotation[α_{zul}] of all three expansion joints is the same and the system is pre-stressed at 50%, then the minimum distances L_1 and L_3 between the hinges are determined as follows:

$$L_1 = \frac{\Delta_1 \cdot (8 \cdot L_2 + \Delta_1 + 4 \cdot L_3)}{8 \cdot \sin\alpha_{zul} \cdot L_3 - 4 \cdot \Delta_2} \text{ [mm]}$$

when L_2 and L_3 have been chosen, and

$$L_3 = \frac{\Delta_1 \cdot (8 \cdot L_2 + \Delta_1) + 4 \cdot L_1 \cdot \Delta_2}{8 \cdot \sin\alpha_{zul} \cdot L_1 - 4 \cdot \Delta_1} \text{ [mm]}$$

when L_1 and L_2 have been chosen.

If the result of L_1 (or L_3) is negative or the distance is too long, then one must increase the distance L_3 (or L_1) accordingly or one must choose expansion joints with a larger permissible angular rotation.

In general L_1 and L_3 should be as long as reasonably possible while L_2 should be as short as possible.

Effective angular rotation

If the pin distances L_1 and L_3 are given, the effective angular rotation of the angular expansion joints (B_1, B_2, B_3) is calculated as follows if the system is pre-stressed at 50 %.

$$\alpha_{e1} = \pm \arcsin(\frac{\Delta_1}{2 \cdot L_1}) \text{ [degr.]}$$

$$\alpha_{e2} = \pm (\alpha_{e1} + \alpha_{e3}) \text{ [degr.]}$$

$$\alpha_{e3} = \pm \arcsin\left(\frac{\Delta_1 \cdot (8 \cdot L_2 + \Delta_1) + 4 \cdot L_1 \cdot \Delta_2}{8 \cdot L_1 \cdot L_3}\right) \text{ [degr.]}$$

At 100% and at 0% pre-stressing, the angle of rotation of the angular expansion joints doubles, but in one direction only. In this case, the effective angular rotation [$\alpha_{e1,2,3}$] must be multiplied by 2.

Calculations

Bending moments of the angular expansion joints

In order to calculate the bending moments and forces, the absolute values of the effective angular rotations (without signs) are used in the following formulae.

$$M_{B1} = C_r \cdot p + C_\alpha \cdot \alpha_{e1} + C_z \cdot p \cdot \alpha_{e1} \ [Nm]$$

$$M_{B2} = C_r \cdot p + C_\alpha \cdot \alpha_{e2} + C_z \cdot p \cdot \alpha_{e2} \ [Nm]$$

$$M_{B3} = C_r \cdot p + C_\alpha \cdot \alpha_{e3} + C_z \cdot p \cdot \alpha_{e3} \ [Nm]$$

Forces at the connection points

$$F_z = \frac{1000 \cdot (M_{B2} + M_{B3})}{L_3} \ [N]$$

$$F_x = \frac{1000 \cdot (M_{B1} + M_{B2}) + F_z \cdot 2 \cdot L_2}{L_1} \ [N]$$

Bending moments at the connection points
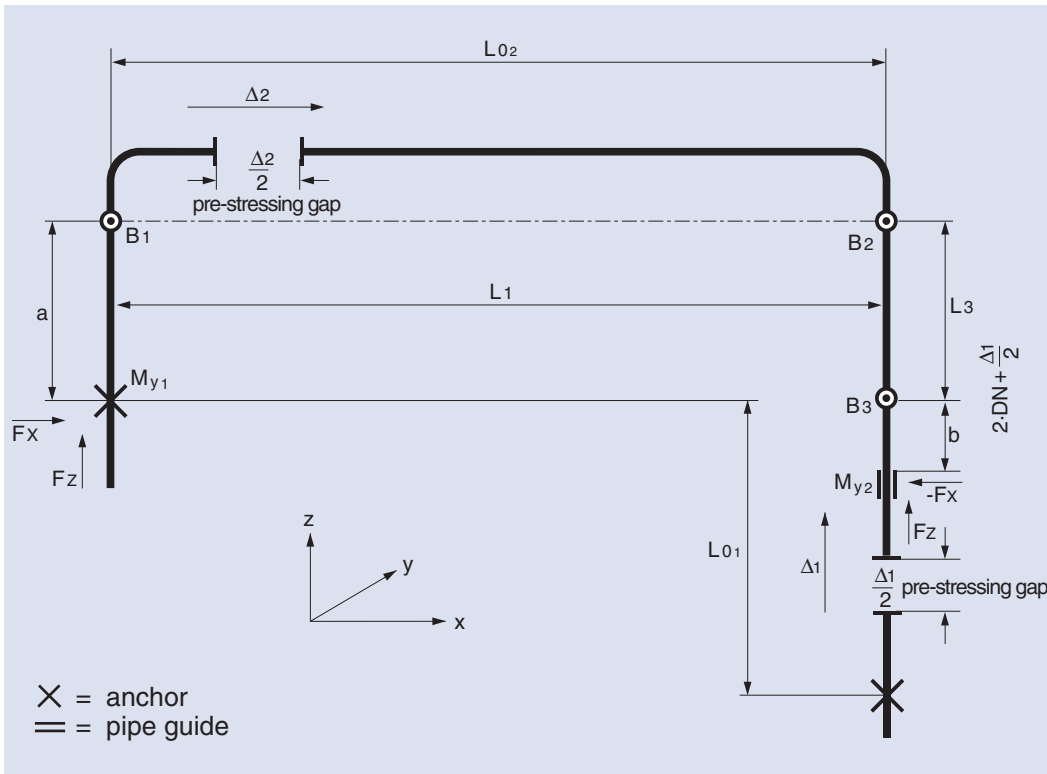
$$M_{y1} = M_{B1} + F_z \cdot \frac{a}{1000} \ [Nm]$$

$$M_{y2} = M_{B3} + F_z \cdot \frac{b}{1000} \ [Nm]$$

If the system is pre-stressed at 50%, the force and the moment will have different signs in the pre-stressed position and operating position.

a,b	Distance between the center of the bellows and the connection point [mm]
C_α	Bending spring rate [Nm/degr.]
C_r	Hinge friction [Nm/bar]
C_z	Additional moment from rotation and pressure [Nm/(bar · degr.)]
$F_{x,z}$	Displacement force in x and z direction [N]
$L_{1,3}$	Center to center distance between the bellows [mm]
$M_{y1,2}$	Bending moments at the connection points [Nm]
$M_{B1,2,3}$	Bending moment of the expansion joints [Nm]
p	Operating pressure [bar]
$\alpha_{e1,2,3}$	Effective angular rotation per bellows [degr.]
α_{zul}	Permissible angular rotation per bellows [degr.]
$\Delta_{1,2}$	Movement of pipeline [mm]

$\times$ = anchor
$=$ = pipe guide

Required hinge distances

If the permissible angular rotation $[\alpha_{zul}]$ of all three expansion joints is the same and the system is pre-stressed at 50%, then the minimum distances L_1 and L_3 between the hinges are determined as follows:

$$L_1 = \frac{\Delta_1 \cdot L_3}{2 \cdot \sin\alpha_{zul} \cdot L_3 - \Delta_2} \text{ [mm]}$$

when L_3 has been chosen, and

$$L_3 = \frac{\Delta_2 \cdot L_1}{2 \cdot \sin\alpha_{zul} \cdot L_1 - \Delta_1} \text{ [mm]}$$

when L_1 has been chosen.

If the result of L_1 (or L_3) is negative or the distance is too long, then one must increase the distance L_3 (or L_1) accordingly or one must choose expansion joints with a larger permissible angular rotation.

In general, L_1 and L_3 should be as long as reasonably possible while L_2 should be as short as possible.

Effective angular rotation

If the pin distances L_1 and L_3 are given, the effective angular rotation of the angular expansion joints (B_1, B_2, B_3) is calculated as follows if the system is pre-stressed at 50%:

$$\alpha_{e1} = \pm \arcsin\left(\frac{\Delta_1}{2 \cdot L_1}\right) \text{ [degr.]}$$

$$\alpha_{e2} = \pm (\alpha_{e1} + \alpha_{e3}) \text{ [degr.]}$$

$$\alpha_{e3} = \pm \arcsin\left(\frac{\Delta_2}{2 \cdot L_3}\right) \text{ [degr.]}$$

At 100% and at 0% pre-stressing, the angle of rotation of the angular expansion joints doubles, but in one direction only. In this case, the effective angular rotation $[\alpha_{e1,2,3}]$ must be multiplied by 2.

System calculation

17

Calculations

Bending moments of the angular expansion joints

In order to calculate the bending moments and forces, the absolute values of the effective angular rotations (without signs) are used in the following formulae.

$$M_{B1} = C_r \cdot p + C_\alpha \cdot \alpha_{e1} + C_z \cdot p \cdot \alpha_{e1} \; [Nm]$$

$$M_{B2} = C_r \cdot p + C_\alpha \cdot \alpha_{e2} + C_z \cdot p \cdot \alpha_{e2} \; [Nm]$$

$$M_{B3} = C_r \cdot p + C_\alpha \cdot \alpha_{e3} + C_z \cdot p \cdot \alpha_{e3} \; [Nm]$$

Forces at the connection points

$$F_x = \frac{1000 \cdot (M_{B2} + M_{B3})}{L_3} \; [N]$$

$$F_z = \frac{1000 \cdot (M_{B1} + M_{B2})}{L_1} \; [N]$$

Bending moments at the connection points

$$M_{y1} = M_{B1} + F_x \cdot \frac{a}{1000} \; [Nm]$$

$$M_{y2} = M_{B3} + F_x \cdot \frac{b}{1000} \; [Nm]$$

If the system is pre-stressed at 50%, the force and the moment will have different signs in the pre-stressed position and operating position.
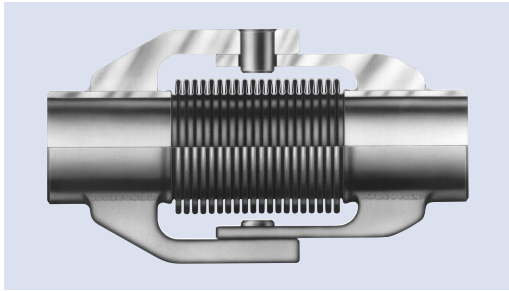
|			
a,b	Distance between the center of the bellows and the connection point [mm]	$M_{y1,2}$	Bending moments at the connection points [Nm]
C_α	Bending spring rate [Nm/degr.]	$M_{B1,2,3}$	Bending moment of the expansion joints [Nm]
C_r	Hinge friction [Nm/bar]	p	Operating pressure [bar]
C_z	Additional moment from rotation and pressure [Nm/(bar · degr.)]	$\alpha_{e1,2,3}$	Effective angular rotation per bellows [degr.]
$F_{x,z}$	Displacement force in x and z direction [N]	α_{zul}	Permissible angular rotation per bellows [degr.]
$L_{1,3}$	Center to center distance between the bellows [mm]	$\Delta_{1,2}$	Movement of pipeline [mm]

Program

Single hinged expansion joint
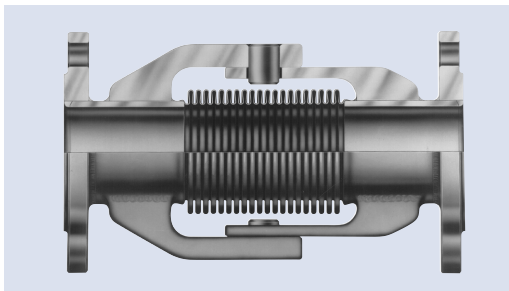with bellows of stainless steel 1.4541 (up to
DN 50 – 1.4571).
On both sides with weld ends of carbon
steel, external restraints of carbon steel,
suited for angular rotation around one axis.
Type 7510 (previous: 307/250)
DN ..... / PN ... / $\triangle$ ang ..... / BI .....
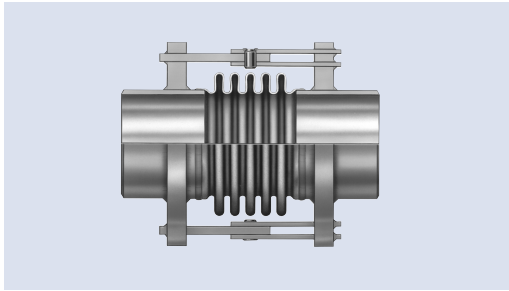
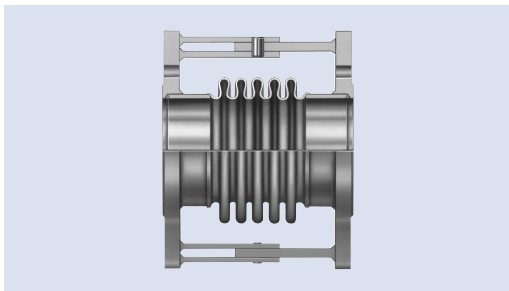Design of restraints varies with manufacturing program.

Single hinged expansion joint
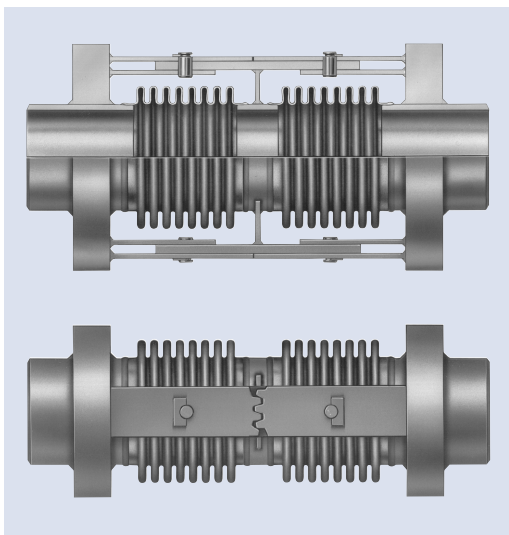with bellows of stainless steel 1.4541 (up to
DN 50 – 1.4571).
On both sides with flanges of carbon steel,
external restraints of carbon steel, suited
for angular rotation around one axis.
Type 7520 (previous: 307/251)
DN ..... / PN ... / $\triangle$ ang ..... / BI .....

Design of restraints varies with manufacturing program.

Single hinged expansion joint
with bellows of stainless steel 1.4541, on
both sides with weld ends of carbon steel,
external gear-restraints of carbon steel,
suited for large angular rotation around one
axis.
Type 7510 BAS (previous: 307/250 Z)
DN ..... / PN ... / $\triangle$ ang ..... / BI .....

On both sides with flanges:
Type 7520 BAS

Program

(Angular) gimbal expansion joints for perpendicular rotation
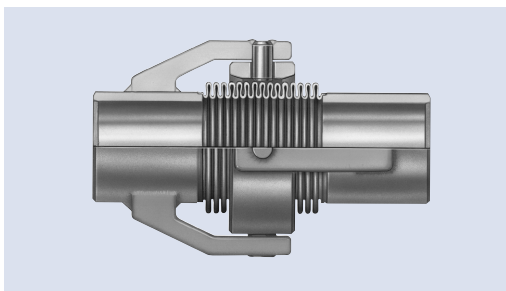
Gimbal expansion joint
with bellows of stainless steel 1.4541 (up to DN 50 – 1.4571).
On both sides with weld ends of carbon steel, external gimbal restraints of carbon steel, suited for perpendicular angular rotation.
Type 7610 (previous: 307/260)
DN ..... / PN ... / $\triangle$ ang ..... / BI .....
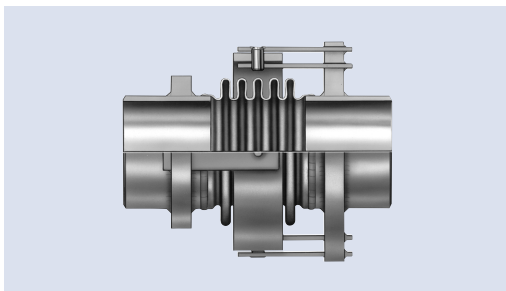
Design of restraints varies with manufacturing program.

Gimbal expansion joints
with bellows of stainless steel 1.4541 (up to DN 50 – 1.4571).
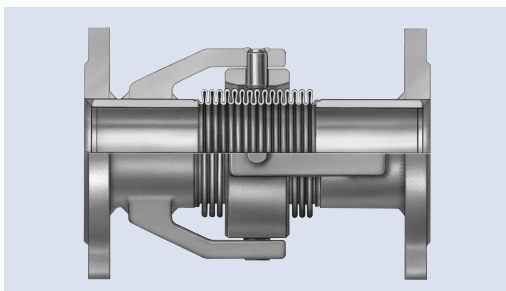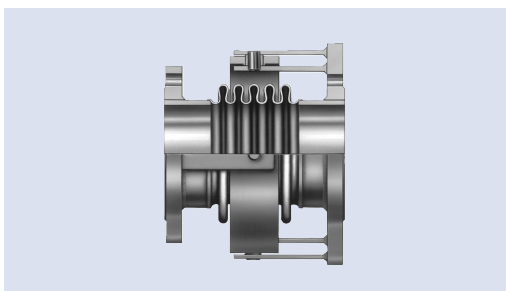On both sides with flanges of carbon steel, external gimbal restraints of carbon steel, suited for perpendicular angular rotation.
**Type 7620 (previous: 307/261)**
DN ..... / PN ... / $\triangle$ ang ..... / BI .....

Design of restraints varies with manufacturing program

Angular expansion joints that allow an angular rotation on one plane only (single hinged expansion joints) must be installed with a correct orientation respect to the direction of the movement that will be compensated for. The movement must always act perpendicular to the axis of the hinge pins.
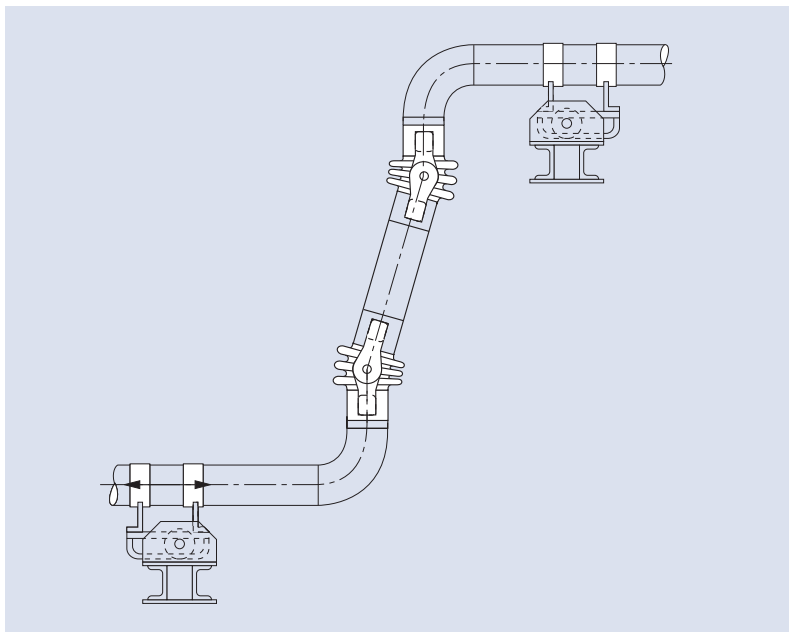
In contrast to axial expansion joints, angular expansion joints are less demanding with regards to pipe guides and supports. They have to support the weight of the pipeline including the insulation and flow, wind and other external loads if applicable, in such a way that they relieve the expansion joints from those loads without hindering their movement.

In short pipe routings such as in compact power house pipe systems, pipe supports and guides may not be necessary at all.
In long pipe lines, a pipe guide should be installed on each side of the expansion system.

Pipe supports and guides

Anchors

Only one expansion system should be installed between two anchors. These anchors must withstand the displacement forces of the system that result from the bending spring rates of the bellows and the friction in the hinges, as well as the friction forces in the pipe supports and guides.

Pipe guides with excessive friction as a result of overloading, deposits of dirt or corrosion may gall and cause excessive strain in the pipe, its anchors and connections.

Start-up of plant

Pipe anchors, supports and guides must be firmly installed prior to filling the system or commencing the pressure test. The permissible test pressure must not be exceeded.

The bellows must be protected against weld, mortel or plaster splatter, dirt or any form of mechanical damage during installation.

Steam pipe systems must be installed on an incline and must further be heated at a slow rate to remove condensate that might cause steam hammers. Sufficient insula-tion and the avoidance of water pockets are recommended. Steam cleaning should be avoided due to the risk of water hammers and unwanted vibration of the bellows.

Expansion joints with inner sleeves must be installed under consideration of the flow direction with the fixed end of the sleeve facing up-stream. Otherwise, common principles such as proper water treatment, electrical bridges in copper and galvanized pipes etc. for the avoidance of corrosion defects must be adhered to.

Operating pressure

The permissible operating pressure results from the nominal pressure, taking into account the reduction factors according to the technical data sheets.

Pre-stressing

Angular expansion joints in expansion systems are commonly pre-stressed at 50%. The actual temperature of the pipeline at the time of installation must be taken into account when pre-stressing is applied.

If the temperature at the time of installation deviates from the lowest possible temperature, then the amount of pre-stressing must be determined according to the following pre-stressing diagram.

Temperature difference between installation temperature and lowest temperature in °C

Expansion of pipe at installation temperature in mm

Length of pipe in m

Total movement capacity of expansion system in mm

Amount of pre-stressing of the expansion system in mm

only applicalbe for pipes of St 35 material
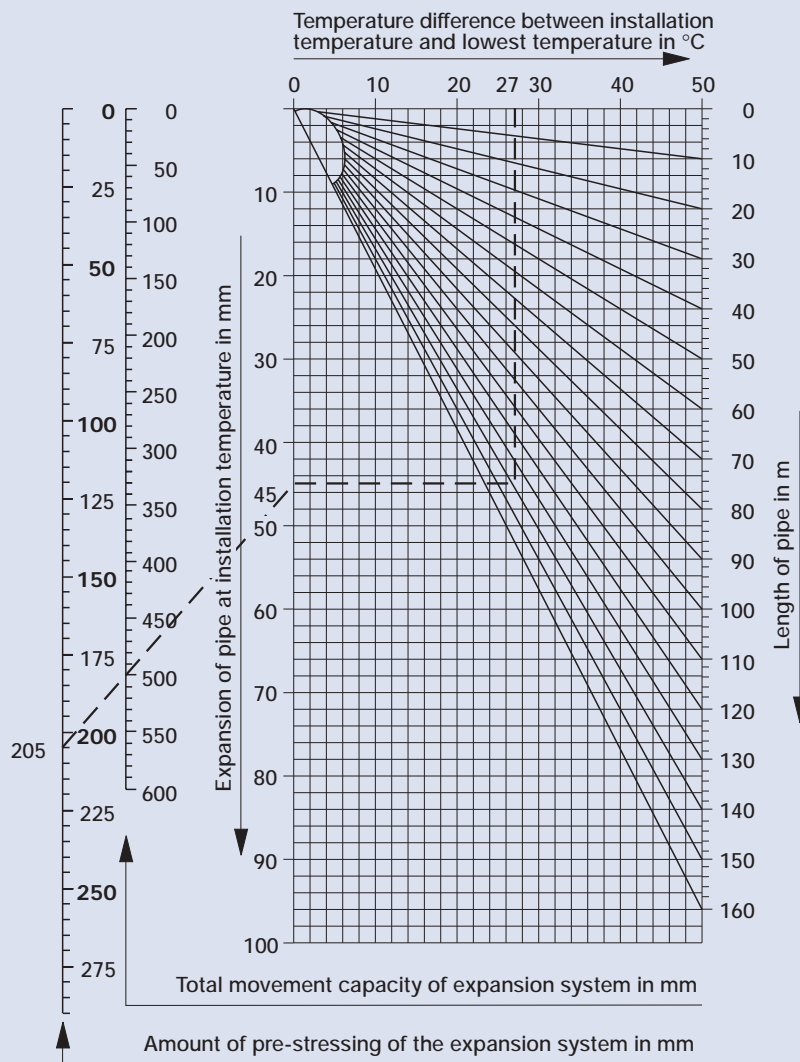
Given: – Expansion system for a 140 m long pipeline
– Lowest possible temperature: –7 °C
– Maximum temperature: +293 °C
– Maximum thermal expansion according to ∆T 300 °C = 500 mm.

Determine the correct amount of pre-stressing if the expansion system is to be pre-stressed at 50% of the total movement (= 250 mm) and when the actual temperature at the time of installation is +20 °C.

Answer: The thermal expansion of the pipeline between –7 °C and +20 °C (∆T = 27 °C) is 45 mm. To determine the correct amount of pre-stressing, this amount must be deducted from the total amount of pre-stressing, i.e. 250 – 45 = 205 mm.

The diagram provides a quick resolution without the need of a mathematical calculation:

1. Temperature difference between installation temperature (+20 °C) and lowest temperature (–7 °C) = 27 °C.
2. Total length of pipeline = 140 m.
3. Draw a vertical line from point "27 °C" at the top of the diagram downwards to the line that connects the point "0" and the point "140" at the right side of the diagram.
4. From this intersection draw a horizontal line to the left side of the diagram. The number 45 [mm] indicates the thermal expansion of the pipe at installation temperature.
5. Draw a line from point "45" to the point "500" in the next diagram to the left and extend this line to the far left diagram.

The number 205 [mm] indicates the amount of pre-stressing by which the expansion system must be pre-stressed into the opposite direction of the expected thermal growth of the pipeline.

Recommendations

Avoid the installation of standard expansion joints in the immediate proximity of pressure reducers, superheated steam condensers and quick actuated shut-off valves as high frequency vibrations might be generated by this equipment. Provide heavy wall sleeves for the expansion joints, perforated flow visors in the pipeline or equalizing sections to protect the bellows against failures.

If high frequency vibrations, turbulence or high flow velocities are anticipated, we recommend the installation of expansion joints with inner sleeves (liners).
For pipeline diameters equal to or larger than 150 mm, we recommend internal sleeves if the flow velocity exceeds 8 m/s for a gaseous flow and 3 m/s for liquids.

Type of expansion joint: _____

Nominal diameter   DN: _____

Design conditions

Design pressure   _____ bar

Design temperature   _____ ° C

Movements

– axial compress.+/– _____ mm

– axial extension +/– _____ mm

– lateral   +/– _____ mm

– angular   +/– _____ degr.

Vibrations frequency _____ Hz

                 amplitude _____ mm

Type of vibration   _____

Number of cycles   _____

Flow medium   _____

Flow velocity   _____

Limitations mechanical properties:

axial spring rate   _____N/mm

lateral spring rate   _____N/mm

angular spring rate   _____Nm/degr.

axial force   _____N

lateral force   _____N

angular moment   _____Nm

pressure thrust   _____N

Auxiliary items:

Inner sleeve   ◯ yes   ◯ no

External shroud   ◯ yes   ◯ no

Other items (specify) _____

_____

_____

_____

_____

End fittings: **Size/
material:**

◯ Weld ends

◯ Fixed flange

◯ Loose flange

◯ Other (specify)

Space:

maximum length: _____ mm

maximum diameter: _____ mm

Quality tests:

Hydraulic press. test ◯ yes   ◯ no

Leak test

   with air   ◯ yes   ◯ no

   with helium   ◯ yes   ◯ no

   permissible leak rate _____ mbar l/s

Additional NDE		BL	RL	BRR	RR	other items
X-ray examination	%					
dye penetrant examination	%					
ultrasonic examination	%					
magnetic particle examination	%					

BL = bellows longitudinal weld seam   RL = pipe longitudinal weld seam
BRR = bellows to pipe circumferential weld seam   RR = pipe circumferential weld seam

QA/QC requirements

Design code _____

Special specifications _____

Certification _____

Authorized inspection party _____

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