

STANDARDS OF THE EXPANSION JOINT MANUFACTURERS ASSOCIATION, INC.

TENTH EDITION



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FOREWORD

Since 1958, when the Expansion Joint Manufacturer's Association (EJMA®) first published these Standards, continuing technological improvements in the application and design of Expansion Joints have been reported through the cooperative efforts of its association members by expanding the scope and content of this publication. Founded three years earlier in 1955, the Expansion Joint Manufacturer's Association began with a group of companies experienced in the application, design, and fabrication of Expansion Joints. The first EJMA® Standard edition was, of necessity, somewhat brief and covered only applications involving axial movement. But as research and extensive testing results were catalogued, more detailed design data has been included in the EJMA® Standard. The EJMA® Standards are intended for application to metallic bellows expansion joints having only the convolution shapes shown in the Standards and having convolution welds only in the meridional direction with the exception of the bellows attachment welds.

The EJMA® Technical Committee is dedicated to continuously improving the utility and technical content of the Standards. Suggestions and comments from industry users are welcomed and should be forwarded to the Secretary of this Association in writing.

It is important to note that the EJMA® Standard is a trade association document containing recommendations for application of expansion joint products and in-depth technical information for use in designing expansion joint products. It is not a manufacturing standard or a quality assurance document. The type of non-destructive examination and the extent of quality assurance testing to be applied to given product should be addressed by other documents such as the ASME B31.3 Piping Code, the ASME Pressure Vessel Code, or another user-provided specification. The Standard does not limit or dictate the manufacturing process to be used for construction of expansion joints, nor does it establish specific engineering requirements deemed necessary for the safe application, design, and manufacture of Expansion Joints. If there is a strong preference for a certain type of manufacturing process, the user should provide this information. Industry users are cautioned that these Standards should not be considered as a design handbook, and must not replace sound engineering judgment, education, and experience.

As of this writing, the EJMA® Standard thoroughly covers the design of expansion joint bellows elements. However, the Standard does not cover the design of hardware associated with restraint of pressure thrust. Pressure thrust restraint hardware is as important as the bellows element in the design and fabrication of an expansion joint assembly. Users are strongly advised to obtain documented design results for bellows elements and pressure thrust restraint hardware for any critical application.

NO WARRANTY EXPRESSED OR IMPLIED

The engineering Standards herein are recommended by the Expansion Joint Manufacturers Association, Inc. to assist users, engineers, architects and others who specify, design and install Expansion Joints in piping systems to obtain the most efficient service from Expansion Joint installations. These Standards are based upon sound engineering principles, research and field experience in the manufacture, design, installation and use of Expansion Joints. These Standards may be subject to revision as further investigation or experience may show is necessary or desirable. Utilization of these Standards remains entirely optional. Nothing herein shall constitute a warranty of any kind, expressed or implied. Accordingly, all warranties of whatever nature, expressed or implied, are herewith specifically disclaimed and disavowed.

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SECTION 1 – SCOPE, DEFINITIONS, AND NOMENCLATURE

1.1 SCOPE

The EJMA® Standards are only intended for application to metallic bellows expansion joints.

1.2 DEFINITION OF TERMS

The Expansion Joint Manufacturers Association, Inc. has adopted the following definitions of Expansion Joint components and related equipment.

ANGULAR ROTATION

The displacement of the longitudinal axis of the Expansion Joint from its initial straight line position into a circular arc. Angular rotation is occasionally referred to as "rotational movement." This is not torsional rotation which is described further in this section.

AXIAL COMPRESSION

The dimensional shortening of an Expansion Joint along its longitudinal axis. Axial compression has been referred to as axial movement, traverse or compression.

AXIAL EXTENSION

The dimensional lengthening of an Expansion Joint along its longitudinal axis. Axial extension has been referred to as axial movement, traverse, elongation or extension.

BELLOWS

The flexible element of an Expansion Joint consisting of one or more convolutions and the end tangents with $L_b / D_b \leq 3$, $nt \leq 0.375$ in. (9.53 mm), r_{ic} and $r_{ir} \geq 3t$, $|r_{ic} - r_{ir}| \leq 0.2r_m$, with no more than five plies.

CONTROL RODS

Devices, usually in the form of rods or bars, attached to the Expansion Joint assembly whose primary function is to distribute the movement between the two bellows of a universal Expansion Joint. Control rods are not designed to restrain bellows pressure thrust.

CONVOLUTION

The smallest flexible unit of a bellows. The total movement capacity of a bellows is proportional to the number of convolutions.

COVER

A device used to provide limited protection of the exterior surface of the bellows of an expansion joint from foreign objects or mechanical damage. A cover is sometimes referred to as a shroud.

DIRECTIONAL ANCHOR

A directional or sliding anchor is one which is designed to absorb loading in one direction while permitting motion in another. It may be either a main or intermediate anchor, depending upon the application involved. When designed for the purpose, a directional anchor may also function as a pipe alignment guide. In the design of a directional anchor, an effort should be made to minimize the friction between its moving or sliding parts, since this will reduce the loading on the piping and equipment and insure proper functioning of the anchor.

DOUBLE EXPANSION JOINT

A double Expansion Joint consists of two bellows joined by a common connector which is anchored to some rigid part of the installation by means of an anchor base. The anchor base may be attached to the common connector either at installation or at time of manufacture. Each bellows acts as a single Expansion Joint and absorbs the movement of the pipe section in which it is installed independently of the other bellows. Double Expansion Joints should not be confused with universal Expansion Joints.

EQUALIZING AND REINFORCING RINGS

Devices used on some expansion joints fitting in the roots of the convolutions. The primary purpose of these devices is to reinforce the bellows against internal pressure. Equalizing rings are made of cast iron, steel, stainless steel or other suitable alloys and are approximately "T" shaped in cross section. Reinforcing or root rings are fabricated from tubing or solid round bars of carbon steel, stainless steel or other suitable alloys.

EXPANSION JOINTS

Any device containing one or more bellows used to absorb dimensional changes, such as those caused by thermal expansion or contraction of a pipeline, duct or vessel.

FLANGED ENDS

The ends of an expansion joint equipped with flanges for the purpose of bolting the expansion joint to the mating flanges of adjacent equipment or piping (See Section 9.3).

GIMBAL EXPANSION JOINT

A gimbal Expansion Joint is designed to permit angular rotation in any plane by the use of two pairs of hinges affixed to a common floating gimbal ring. The gimbal ring, hinges and pins must be designed to restrain the thrust of the Expansion Joint due to pressure and extraneous forces, where applicable.

HINGED EXPANSION JOINT

A hinged Expansion Joint contains one bellows and is designed to permit angular rotation in one plane only by the use of a pair of pins through hinge plates attached to the Expansion Joint ends. The hinges and hinge pins must be designed to restrain the thrust of the Expansion Joint due to pressure and extraneous forces, where applicable. Hinged Expansion Joints should be used in sets of two or three to function properly.

IN-LINE PRESSURE BALANCED EXPANSION JOINT

An in-line pressure balanced Expansion Joint is designed to absorb axial movement and/or lateral deflection while restraining the pressure thrust by means of tie devices interconnecting the line bellows with outboard compensating bellows also subjected to line pressure. Each bellows set is designed to absorb the axial movement and usually the line bellows will absorb the lateral deflection. This type of Expansion Joint is used in a straight run of piping.

INTERMEDIATE ANCHOR

An intermediate anchor is one which must withstand the bellows thrust due to flow, spring forces, and all other piping loads, but not the thrust due to pressure.

An intermediate anchor base for connection to the anchor structure can be furnished as an integral part of a single or double Expansion Joint, if desired. The Expansion Joint manufacturer must be advised of the magnitude and direction of all forces and moments which will be imposed upon the anchor base, so that it can be adequately designed to suit the specific application.

INTERNAL SLEEVE

A device which minimizes contact between the inner surface of the bellows of an expansion joint and the fluid flowing through it (See Section 4.9 for application). These devices have also been referred to as liners or baffles.

INTERNALLY GUIDED EXPANSION JOINT

An internally-guided Expansion Joint is designed to provide axial guiding within the Expansion Joint by incorporating a heavy internal guide sleeve, with or without the use of bearing rings. The use of such Expansion Joints will assure installation without initial lateral or angular misalignment and can be installed in pipelines where reverse flow will be encountered. The use of an internally-guided Expansion Joint does not eliminate the necessity of using adequate external pipe guides in accordance with the instructions given in Section 2.10. Its use will not prevent bellows instability.

LATERAL DEFLECTION

The relative displacement of the two ends of an Expansion Joint perpendicular to its longitudinal axis. This has been referred to as lateral offset, lateral movement, parallel misalignment, direct shear, or transverse movement.

LIMIT RODS

Devices, usually in the form of rods or bars, attached to the expansion joint assembly whose primary function is to restrict the bellows movement range (axial, lateral and angular) during normal operation. In the event of a main anchor failure, they are designed to prevent bellows over-extension or over-compression while restraining the full pressure loading and dynamic forces generated by the anchor failure.

MAIN ANCHOR

A main anchor is one which must withstand the full bellows thrust due to pressure, flow, spring forces, and all other piping loads.

A main anchor base for connection to the anchor structure can be furnished as an integral part of a single or double Expansion Joint, if desired. The Expansion Joint manufacturer must be advised of the magnitude and direction of all forces and moments which will be imposed upon the anchor base, so that it can be adequately designed to suit the specific application.

MOTION INDICATORS

Devices attached to an Expansion Joint for the purpose of indicating the movement of the Expansion Joint. These devices are useful in determining if the piping system is behaving as planned and if the actual movements being imposed upon the bellows are within the limits of the original design criteria. An example of motion indicators used on hinge or gimbal hardware is an indicator attached to the hinge pin with an angular scale attached to the hinge arm. This allows one to quickly determine the extent of angular offset.

Another common example of motion indicators is found on slotted hinge assemblies. With the hinge pin used as an indicator, permanent marks are scribed upon the hinge hardware to record the original cold position. The relative distance between the pin and the cold position mark can then be used to determine the movements imposed upon the bellows.

PANTOGRAPH LINKAGES

A scissors-like device. A special form of control rod attached to the expansion joint assembly whose primary function is to positively distribute the movement equally between the two bellows of the universal joint throughout its full range of movement. Pantograph linkages, like control rods, are not designed to restrain pressure thrust.

PIPE ALIGNMENT GUIDE

A pipe alignment guide is a form of framework fastened to some rigid part of the installation which permits the pipe line to move freely only along the axis of the pipe. For further information, see the definition of planar pipe guide below.

PIPE SECTION

A pipe section is that portion of a pipeline between two anchors. All dimensional changes in a pipe section must be absorbed between these two anchors.

PLANAR PIPE GUIDE

A planar pipe guide permits transverse movement and/or bending of the pipeline in one plane. It is commonly used in applications involving lateral deflection or angular rotation resulting from "L" or "Z" shaped piping configurations.

PRESSURE BALANCED EXPANSION JOINT

A pressure balanced Expansion Joint is designed to absorb axial movement and/or lateral deflection while restraining the pressure thrust by means of tie devices inter-connecting the flow bellows with an opposed bellows also subjected to line pressure.

PURGE CONNECTIONS

Purge connections, where required, are usually installed at the sealed end of each internal sleeve of an expansion joint for the purpose of injecting a liquid or gas between the bellows and the internal sleeve to keep the area clear of erosive and corrosive media and/or solids that could pack the convolutions. Purging may be continuous, intermittent or just on start-up or shut down, as required. These are sometimes called aeration connections.

RATED MOVEMENT

The maximum amount of movement (axial extension, axial compression, lateral deflection, angular rotation, or any combination thereof) which an Expansion Joint is capable of absorbing. This rating may be different for each size, type and make of Expansion Joint and is established by the manufacturer.

SHIPPING DEVICES

Rigid support devices installed on an expansion joint to maintain the overall length of the assembly for shipment. These devices may also be used to precompress, pre-extend or laterally offset the bellows. See Section 8.2. They should not be used to resist pressure thrust during testing.

SINGLE EXPANSION JOINT

The simplest form of Expansion Joint, of single bellows construction, for the purpose of absorbing any combination of the three basic movements of the pipe section in which it is installed.

SLOTTED HINGES

Devices installed as diametrically opposed pairs on an Expansion Joint permitting axial and one plane angular movement. Slotted hinges can be designed to perform as control devices, distributing movements between two bellows of a universal Expansion Joint but do not restrain pressure thrust. They may also be designed as limiting devices that restrict the bellows movement range and restrain the full pressure loading and dynamic forces generated by an anchor failure. These devices can be used to transmit extraneous loads and forces such as system dead weight, wind loads, and seismic loads that are transverse to the Expansion Joint axis.

STABILIZER

A device, internally or externally attached to the Expansion Joint assembly, whose primary function is to increase the stability of a universal Expansion Joint assembly.

SWING EXPANSION JOINT

A swing Expansion Joint is one containing two bellows joined by a common connector designed to absorb lateral deflection and/or angular rotation in one plane. Pressure thrust and extraneous forces are restrained by the use of a pair of swing bars, each of which is pinned to the Expansion Joint ends.

TANGENT REINFORCEMENT

A reinforcing member located around the circumference of the bellows tangent for the purpose of reducing excessive pressure stresses which could lead to circumferential yielding.

TANGENTS

The straight un-convoluted portions at the end of the bellows.

TIE RODS

Devices, usually in the form of rods or bars, attached to the expansion joint assembly whose primary function is to continuously restrain the full bellows pressure thrust during normal operation while permitting only lateral deflection. Angular rotation can be accommodated only if two tie rods are used and located 90° opposed to the direction of rotation.

TORSIONAL ROTATION

The twisting of one end of the Expansion Joint with respect to the other end about its longitudinal axis. This twisting generally produces extremely high shear stresses in the bellows. For this reason it is extremely important that special hardware be used to limit the amount of torsional shear stress in the bellows. The equations in Section 4.13.4 may be used as a guide in calculating this stress.

UNIVERSAL EXPANSION JOINT

A universal Expansion Joint is one containing two bellows joined by a common connector for the purpose of absorbing any combination of the three basic movements: axial movement, lateral deflection and angular rotation. Universal Expansion Joints are usually furnished with control rods to distribute the movement between the two bellows of the Expansion Joint and stabilize the common connector. This definition does not imply that only a universal Expansion Joint can absorb combined movement.

WELD ENDS

The ends of an expansion joint equipped with pipe suitably beveled for welding to adjacent equipment or piping.

1.3 NOMENCLATURE

A_c = Cross sectional metal area of one bellows convolution, in.² (mm²)

$$= \left[2\pi(r_m) + 2\sqrt{\left[\frac{q}{2} - 2(r_m)\right]^2 + [w - 2(r_m)]^2} \right] t_p n \quad \text{for round bellows}$$

$$= \left[2\pi(r_m) + 2\sqrt{\left[\frac{q}{2} - 2(r_m)\right]^2 + [w - 2(r_m)]^2} \right] t \quad \text{for rectangular bellows}$$

A_e = Bellows effective area, corresponding to the mean diameter of the convolutions of the Expansion Joint, in.² (mm²)

$$= \pi \frac{(D_m)^2}{4}$$

A_f = Cross sectional metal area of one reinforcement fastener, in.² (mm²)

A_p = Internal area of pipe, in.² (mm²)

A_r = Cross sectional metal area of one bellows reinforcing member, in.² (mm²)

A_{tc} = Cross sectional metal area of one tangent collar, in.² (mm²)

A_{tp} = Cross sectional metal area of the pipe based on length L_p , in.² (mm²)

A_{tr} = Cross sectional metal area of the reinforcing ring based on length L_r , in.² (mm²)

B_1 = Factor used in specific design calculations to relate toroidal bellows convolution segment behavior to a simple strip beam

B_2 = Factor used in specific design calculations to relate toroidal bellows convolution segment behavior to a simple strip beam

B_3 = Factor used in specific design calculations to relate toroidal bellows convolution segment behavior to a simple strip beam

C_a = 2.0 when tangent is fully supported against the pressure

= 1.5 when tangent is not fully supported against the pressure

C_c = Factor used to account for curvature of tangent collar

$$= -0.2431 + 0.0168n_g + 0.3024n_g^2$$

C_d = Factor used in specific design calculations to relate U-shaped bellows convolution segment behavior to a simple strip beam

C_f = Factor used in specific design calculations to relate U-shaped bellows convolution segment behavior to a simple strip beam

C_m = Material strength factor at temperatures below the creep range

= 1.5 for bellows in the annealed condition (without cold work)

= 1.5 Y_{sm} (1.5 min., 3.0 max.) for bellows in the as-formed condition (with cold work)

C_p = Factor used in specific design calculations to relate U-shaped bellows convolution segment behavior to a simple strip beam

C_r = Convolution height factor

$$= 0.36 \ln\left(\frac{w}{e}\right)$$

C_{sf} = Stress concentration factor derived from manufacturer's fatigue test results. It is a function of corner configuration and weld joint efficiency.

C_{sp} = Stress concentration factor derived from manufacturer's fatigue test results. It is a function of the effect of applied pressure.

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- C_w = Longitudinal weld joint efficiency factor from applicable code. Subscripts b , c , f , p , and r denote the bellows, reinforcement collar, fastener, pipe, and reinforcing ring material, respectively.
- C_θ = Column instability pressure reduction factor based on imposed angular rotation
 = Lesser of R_θ or 1.0 for single bellows
 = 1.0 for universal bellows
- D_b = Inside diameter of cylindrical tangent and bellows convolutions, in. (mm)
- D_c = Mean diameter of bellows tangent reinforcing collar, in. (mm)
 = $D_b + 2nt + t_c$
- D_i = Pipe inside diameter, in. (mm)
- D_m = Mean diameter of bellows convolutions, in. (mm)
 = $D_b + w + nt$ for “U” profile
- D_n = Tie rod nut or welded tie rod ring outside diameter, in. (mm)
- D_p = Mean diameter of pipe or hinge pin outside diameter, in. (mm)
- D_r = Mean diameter of reinforcing ring, in. (mm)
- E = Modulus of Elasticity at design temperature, unless otherwise specified, for material, psi (MPa). Subscripts b , c , f , p , s , and r denote the bellows, reinforcement collar, fastener, pipe sleeve, and reinforcing ring material, respectively.
- F = Axial force required to move a single convolution axially the amount of e_x , lbf (N)
- F_a = Axial force at the end of the convoluted length of an Expansion Joint resulting from axial deflection x , lbf (N)
- F_g = Axial force per tangent collar gusset, lbf (N)
 = $\frac{1}{n_g} \left[0.25\pi (D_m^2 - D_b^2) P + e_c f_w \right]$ below the creep range
 = $\frac{0.25\pi P}{n_g} (D_m^2 - D_b^2)$ in the creep range
- F_l = Lateral force from all the tie rods, lbf (N)
- F_t = Total axial force on all the restraint hardware including pressure thrust and all external loads, lbf (N)
- G = Modulus of Rigidity at design temperature for material, psi (MPa)
- H = Resultant total internal pressure force acting on the bellows and reinforcement for one convolution, lbf (N)
 = $PD_m q$
- H_t = Hold time at temperature between cycles, hours

I = Moment of inertia of rectangular bellows convoluted cross-section, in⁴ (mm⁴)

$$= N \left[\frac{t(2w-q)^3}{48} + 0.4qt(w-0.2q)^2 \right] \text{ for "U" profile}$$

$$= N \left[\frac{t(w-2r_m)^2 \sqrt{4(w-2r_m)^2 + (q-4r_m)^2}}{12} + 1.6r_mt(w-0.7r_m)^2 \right] \text{ for "V" profile}$$

I_p = Moment of inertia of pipe cross section, in.⁴ (mm⁴)

K_2 = Inplane instability factor

$$= \frac{S_2}{P}$$

K_4 = Inplane instability factor

$$= \frac{C_p}{2n} \left[\frac{w}{t_p} \right]^2$$

K_f = Forming method factor

= 1 for expanding mandrel or roll forming

= 0.6 for hydraulic, elastomeric, or pneumatic tube forming

K_r = Circumferential stress factor

= The greater of the following but not less than 1.0

$$\frac{2(q+e_x) + K_\theta e_\theta + e_y}{2q} \text{ where } e_x \text{ and } e_y \text{ are based on axial extension concurrent with pressure P}$$

$$\frac{2(q-e_x) + K_\theta e_\theta + e_y}{2q} \text{ where } e_x \text{ and } e_y \text{ are based on axial compression concurrent with pressure P}$$

K_s = Shape factor for cross section (see Table III)

$$= \frac{Nw}{2I} \left[\frac{t(w-2r_m) \sqrt{4(w-2r_m)^2 + (q-4r_m)^2}}{4} + 3.1416r_mt(w-0.7268r_m) \right] \text{ for rectangular bellows}$$

K_{sr} = Overall bellows spring rate, lbf/in. (N/mm)

$$= \frac{f_i}{N}$$

K_u = Factor establishing relationship between equivalent axial displacement per convolution due to lateral deflection and the ratio $L_u/(2L_b)$

K_{um} = Factor for determining the moment reaction for a universal expansion joint with angular rotation about one end

$$= \frac{0.0123 + 1.958R_u^{-1.1528}}{2.9359 + R_u^{-1.1528}}$$

$K_{u\theta}$ = Factor for determining the moment and equivalent axial movement for a universal expansion joint with angular rotation about one end

$$= \frac{-0.6042 + 2R_u^{1.1598}}{0.3914 + R_u^{1.1598}}$$

K_{uv} = Factor for determining the lateral force for a universal expansion joint with angular rotation about one end

$$= 0.7713(1.2876)^{\frac{1}{R_u}} R_u^{-1.0641}$$

K_{θ} = Angular rotation internal pressure effect factor

$$= \frac{e_{\theta} + e_{yp}}{e_{\theta}} \text{ for single bellows}$$

$$= 1.0 \text{ for universal bellows}$$

$K_{\theta l}$ = Lateral Deflection Pitch Change Factor

$$= 1 + 0.24y \left(\frac{L_b}{D_m} \right)^{1.33} \text{ for single bellows, in.}$$

$$= 1 + 0.0094y \left(\frac{L_b}{D_m} \right)^{1.33} \text{ for single bellows, mm}$$

$$= 1.0 \text{ for universal bellows}$$

L_b = Bellows convoluted length, in. (mm)

$$= Nq$$

L_c = Bellows tangent collar length, in. (mm)

L_d = Maximum length from the attachment weld to the center of the first convolution for externally attached bellows, in. (mm)

L_f = Effective length of one reinforcing ring fastener, in. (mm)

L_g = Maximum distance across the inside opening of a toroidal convolution considering all movements, in. (mm)

L_l = Mean length of long side of rectangular bellows, in. (mm)

$$= \text{long inside length} + \text{convolution height}$$

L_{ml} = Effective length of long side, in. (mm)

$$= \frac{L_l}{3} \left(\frac{3L_s + L_l}{L_s + L_l} \right)$$

L_{ms} = Effective length of short side, in. (mm)

$$= \frac{L_s}{3} \left(\frac{3L_l + L_s}{L_s + L_l} \right)$$

L_p = Effective pipe length, in. (mm)

$$= \frac{1}{3} \sqrt{D_p t_{pe}}$$

L_{pm} = Minimum required pipe length having thickness t_{pe} , in. (mm)

$$= 1.5 \sqrt{D_p t_{pe}}$$

L_r = Effective reinforcing ring length, in. (mm)

$$= \frac{1}{3} \sqrt{D_r t_r}$$

L_{rt} = Overall length of the reinforcing ring, in. (mm)

L_s = Mean length of short side of rectangular bellows, in. (mm)

$$= \text{short inside length} + \text{convolution height}$$

L_t = Bellows tangent length, in. (mm)

L_{tm} = Maximum length of bellows tangent that extends past the collar, in. (mm)

$$= 1.5 \sqrt{\frac{nt^2 S_{ab}}{P}}$$

L_{tr} = Length of tie rods between attachment locations, in. (mm)

L_u = Distance between outermost ends of the convolutions in a universal Expansion Joint, in. (mm)

$$L^* = L_u - L_b$$

M_{Li} = Moment at the ends of the convoluted length of an Expansion Joint resulting from lateral deflection, y_l , parallel to the long side, lbf-in (N•mm)

M_{Ls} = Moment at the ends of the convoluted length of an Expansion Joint resulting from lateral deflection, y_s , parallel to the short side, lbf-in (N•mm)

M_l = Moment at the ends of the convoluted length of an Expansion Joint resulting from lateral deflection, y , lbf-in (N•mm)

M_p = Maximum resisting frictional moment from both hinge pins (in-lbs)

M_θ = Moment at the ends of the convoluted length of an Expansion Joint resulting from angular rotation, θ , lbf-in (N•mm)

$M_{\theta l}$ = Moment at the ends of the convoluted length of an Expansion Joint resulting from angular rotation, θ_l , of the long side, lbf-in (N•mm)

$M_{\theta s}$ = Moment at the ends of the convoluted length of an Expansion Joint resulting from angular rotation, θ_s , of the short side, lbf-in (N•mm)

N = Number of convolutions in one bellows

N_c = Fatigue life, number of cycles to failure

P = Pressure, psig (MPa)

P_d = Design pressure based on the most severe conditions, whether operational or test, psig (MPa)

P_{sc} = Limiting internal design pressure based on column instability, psig (MPa)

P_{si} = Limiting design pressure based on inplane instability and local plasticity, psig (MPa)

P_t = Test pressure, psig (MPa).

R = Ratio of the internal pressure force resisted by the bellows to the internal pressure force resisted by the reinforcement. Use R_1 or R_2 as designated in the equations.

$$= R_1 \text{ for integral reinforcing members} = \frac{A_c E_b}{A_r E_r}$$

$$= R_2 \text{ for reinforcing members joined by fasteners} = \frac{A_c E_b}{D_m} \left(\frac{L_f}{A_f E_f} + \frac{D_m}{A_r E_r} \right)$$

R_s = Spherical radius of spherical washers, in. (mm)

$$R_u = \frac{L_u}{2L_b}$$

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R_θ = Limiting internal design pressure ratio for single bellows

$$= \frac{1.18N^2(q \pm e_x)^2}{\pi^2 D_m K_{\theta l} \sin(\theta/2)(L_b \pm x)} \quad \text{with imposed angular rotation}$$

where $+e_x$ and $+x$ are axial extension; $-e_x$ and $-x$ are axial compression

$$= 1.0 \text{ with no imposed angular rotation}$$

S_a = Allowable material stress at design temperature, unless otherwise specified, from the applicable code, psi. (MPa). Subscripts b , c , f , p , and r denote bellows, reinforcement collar, fastener, pipe, and reinforcing member material.

S_c = Allowable stress of pipe/vessel material at test temperature, psi. (MPa)

S_h = Allowable stress of pipe/vessel material at design temperature, psi. (MPa)

S_y = Yield strength at design temperature, unless otherwise determined, of the actual bellows material after completion of bellows forming and any applicable heat treatment, psi. (MPa)

$$= \frac{0.67 C_m S_{ym} S_{yh}}{S_{yc}}$$

S_{yc} = Yield strength at room temperature of the bellows material in the annealed condition from the applicable code or standard reference, psi. (MPa)

S_{yh} = Yield strength at design temperature of the bellows material in the annealed condition from the applicable code or standard reference, psi. (MPa)

S_{ym} = Yield strength at room temperature of the actual bellows material in the annealed condition from the certified test report, psi. (MPa)

$T_{inst.}$ = Installation temperature, °F (°C)

$T_{max.}$ = Maximum design temperature, °F (°C)

$T_{min.}$ = Minimum design temperature, °F (°C)

V_{Ll} = Lateral force at the ends of the convoluted length of the Expansion Joint resulting from lateral deflection, y_l , in a direction parallel to the long side, lbf (N)

V_{Ls} = Lateral force at the ends of the convoluted length of the Expansion Joint resulting from lateral deflection, y_s , in a direction parallel to the short side, lbf (N)

V_l = Lateral force at the ends of the convoluted length of the Expansion Joint resulting from lateral deflection, y , lbf (N)

W = Elevated temperature weld joint strength reduction factor from applicable design code. Subscripts b , c , and r denote bellows, reinforcement collar, and reinforcing ring material, respectively.

W_{cs} = Total dead weight of the center spool including pipe, refractory, insulation, attachments, and media, lbf (N)

X, Y, Z = Lengths in coordinate directions

Y_{sm} = Yield strength multiplier

$$= 1 + 9.94 \cdot 10^{-2}(K_f \epsilon_f) - 7.59 \cdot 10^{-4}(K_f \epsilon_f)^2 - 2.4 \cdot 10^{-6}(K_f \epsilon_f)^3 + 2.21 \cdot 10^{-8}(K_f \epsilon_f)^4 \text{ for austenitic stainless steel}$$

$$= 1 + 6.8 \cdot 10^{-2}(K_f \epsilon_f) - 9.11 \cdot 10^{-4}(K_f \epsilon_f)^2 + 9.73 \cdot 10^{-6}(K_f \epsilon_f)^3 - 6.43 \cdot 10^{-8}(K_f \epsilon_f)^4 \text{ for nickel alloys}$$

$$= 1 \text{ for other materials. Higher values may be used if supported by test data.}$$

Z_c = Section modulus of tangent collar about the neutral axis in the lateral direction, in.³ (mm³)

- e = Total equivalent axial movement per convolution, in. (mm)
 e_c = Equivalent axial compression per convolution, in. (mm)
 e_e = Equivalent axial extension per convolution, in. (mm)
 e_x = Axial movement per convolution resulting from imposed axial movement, x . This movement may be measured as compression or extension, in. (mm).
 e_y = Axial movement per convolution resulting from imposed lateral deflection, y , in. (mm)
 e_{yl} = Axial movement per convolution for a rectangular bellows resulting from imposed lateral deflection, y , in a direction parallel with the long side, in. (mm)
 e_{yp} = Axial movement per convolution resulting from internal pressure on a single bellows with imposed angular rotation, in. (mm)
 e_{ys} = Axial movement per convolution for a rectangular bellows resulting from imposed lateral deflection, y , in a direction parallel with the short side, in. (mm)
 e_θ = Axial movement per convolution resulting from imposed angular rotation, θ , in. (mm)
 $e_{\theta l}$ = Axial movement per convolution for a rectangular bellows resulting from imposed angular rotation, θ , in a direction parallel with the long side, in. (mm)
 $e_{\theta s}$ = Axial movement per convolution for a rectangular bellows resulting from imposed angular rotation, θ , in a direction parallel with the short side, in. (mm)
 f_c = Factor for modification of the lower bound of the fatigue curve
 = 1 when providing EJMA calculations unless otherwise indicated by specification
 f_i = Bellows theoretical initial axial elastic spring rate per convolution, lbf/in. (N/mm) of movement per convolution. Subscripts u , r , and t denote unreinforced, reinforced, and toroidal bellows respectively.
 f_w = Bellows working spring rate of movement per convolution, lbf/in. (N/mm)
 = f_i for $S_t \leq 1.5S_y$
 = $0.67f_i$ for $S_t > 1.5S_y$
 g = Acceleration due to gravity, 32.2 ft/sec² (9.8 m/sec²)
 k = A factor which considers the stiffening effect of the attachment weld and the end convolution on the pressure capacity of the bellows tangent
 = $\frac{L_t}{1.5\sqrt{D_b t}}$ If $k \geq 1$, use $k = 1$
 m = Mass, lbm (kg)
 n = Number of bellows material plies of thickness, t
 n_g = Number of equally spaced gussets per tangent collar
 q = Convolution pitch, the distance between corresponding points of any two adjacent convolutions in a bellows, in. (mm)
 r = Mean radius of toroidal bellows convolution, in. (mm)
 r_{ic} = The crest convolution inside radius, in. (mm)
 r_{ir} = The root convolution inside radius, in. (mm)
 r_m = Mean radius of bellows convolution, in. (mm)
 = $\frac{r_{ic} + r_{ir} + nt}{2}$
 t = Bellows nominal material thickness of one ply, in. (mm)
 t_c = Bellows tangent reinforcing collar material thickness, in. (mm)

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$$t_e = 0.778t \left(\frac{Nq + 2L_t}{Nw} \right)^{\frac{1}{3}} \text{ in. (mm)}$$

Note: if tangent is fully supported against the pressure, set $L_t = 0$

t_p = Bellows material thickness for one ply, corrected for thinning during forming, in. (mm)

$$= t \sqrt{\frac{D_b}{D_m}} \text{ for bellows formed from tubes with inside diameter equal to } D_b$$

= t for rectangular expansion joint rails

t_{pe} = Pipe thickness, in. (mm)

t_r = Reinforcing ring thickness, in. (mm)

v = Velocity of media flow, ft/sec (m/sec)

w = Convolution height (see Figures 4.13, 4.14, and 5.9), in. (mm)

x = Applied axial movement in compression or extension, in. (mm)

y = Applied lateral deflection, in. (mm)

y_{bml} = Bellows beam mode deflection due to pressure at the center of long span and mid-point of bellows live length, in. (mm)

y_{bms} = Bellows beam mode deflection due to pressure at the center of short span and mid-point of bellows live length, in. (mm)

y_l = Applied lateral deflection in a direction parallel with the long side, in. (mm)

y_s = Applied lateral deflection in a direction parallel with the short side, in. (mm)

α = Inplane instability stress interaction factor

$$= 1 + 2\delta^2 + (1 - 2\delta^2 + 4\delta^4)^{0.5}$$

δ = Inplane instability stress ratio

$$= \frac{K_4}{3K_2}$$

ε_f = Bellows forming strain (%)

$$= 100 \sqrt{\left[\ln \left(1 + \frac{2w}{D_b} \right) \right]^2 + \left[\ln \left(1 + \frac{nt_p}{2r_m} \right) \right]^2} \quad \text{For bellows formed from tubes with an inside diameter of } D_b$$

μ_p = Coefficient of static friction for the hinge pin connections

μ_s = Coefficient of static friction for the spherical washers

θ = Applied angular rotation per individual bellows, rad

θ_c = Angle of rotation for an unrestrained center spool, rad

θ_l = Applied angular rotation per individual bellows in a plane parallel with the long side, rad

θ_s = Applied angular rotation per individual bellows in a plane parallel with the short side, rad

θ_u = Angle of the universal expansion joint centerline with respect to horizontal, rad

ν = Poisson's Ratio

ρ = Density of fluid, lbm/in.³ (kg/m³)

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SECTION 2 - SELECTION AND APPLICATIONS**2.1 SELECTION OF EXPANSION JOINTS**

The first step in the selection of Expansion Joints is to choose tentative locations for the pipe anchors. Any piping system, regardless of its complexity, can be divided into a number of individual expanding pipe sections having relatively simple configurations (ie: straight runs, "L" shaped bends, "Z" shaped bends and other means), by means of anchors. The number of pipe anchors selected, as well as their locations, will depend upon the piping configuration, the amount of expansion which can be accommodated by a single Expansion Joint, the availability of structural members suitable for use as anchors, the location of various pipe fittings, the location of connected equipment, the location of branch connections and other considerations.

The major pieces of connected equipment such as turbines, pumps, compressors, heat exchangers, reactors, and similar devices can be considered as anchors in most applications. It is usually necessary to supplement these equipment anchor points by locating additional anchors at valves, at changes in the direction of the pipe, at blind ends of pipe and at major branch connections. It is generally advisable to start out with the assumption that the use of single and double Expansion Joints in straight axial movement will provide the simplest and most economical layout, unless there are obvious advantages to be gained from another approach.

After the anchor points have been tentatively located, the resulting pipe configurations should be reviewed to determine whether they conform to the standard pipe sections shown in Sections 2.2 and 2.10. At this point, consideration should be given to the relative merits of systems utilizing single and double Expansion Joints for axial movement only, as opposed to those utilizing universal, pressure balanced, hinged and gimbal Expansion Joints. A final decision on anchor locations and the types of Expansion Joints to be used can only be made after a comparison of various alternative solutions. Cost, the ability to comply with cyclic life and force requirements, space restrictions, and similar items should be considered.

The next step is to calculate the actual change in length of each leg of each individual pipe section due to temperature changes. The minimum and installation temperatures are assumed to be 70° F unless otherwise specified. An allowance, added by the system designer, should then be included in the actual calculated movements to account for the following possibilities:

- (a) The minimum and/or installation temperatures used in the design calculations may have been based on the erroneous assumption that the metal temperature of the pipe is the same as the ambient temperature.
- (b) During erection of the piping, it may be necessary to relocate some of the anchor points because of construction problems encountered at the job site.
- (c) During operation the system may be subject to a different temperature range than the designer anticipated, particularly during start-up.

Refer to Appendix J Example 11 for a sample calculation.

2.2 SELECTION FOR AXIAL MOVEMENT ONLY

(For an explanation of the symbols used in the diagrams, refer to Appendix B.)

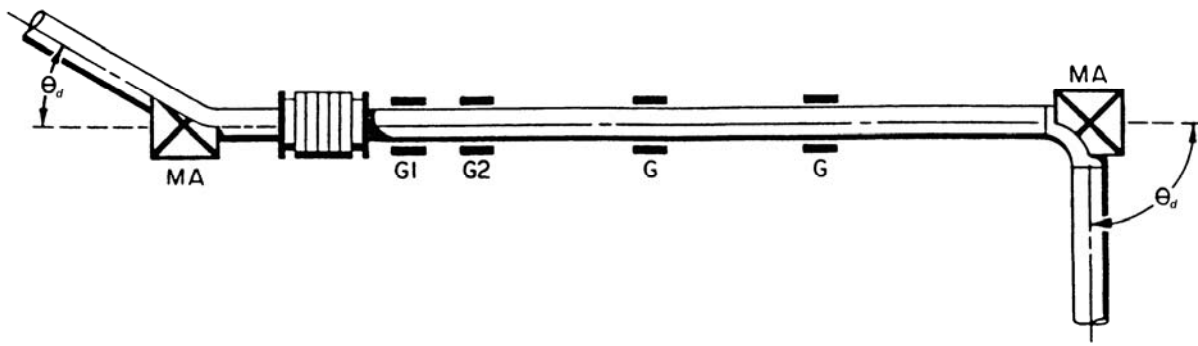


FIGURE 2.1

Figure 2.1 typifies good practice in the use of a single Expansion Joint to absorb axial pipe line expansion. Note the use of one Expansion Joint between two main anchors (MA), the nearness of the Expansion Joint to an anchor, the closeness of the first alignment guide (G1), the spacing between the first alignment guide and the second alignment guide (G2), and the spacing of intermediate guides (G) along the balance of the line. See Figures 2.30 and 2.31, and/or equation (2-7).

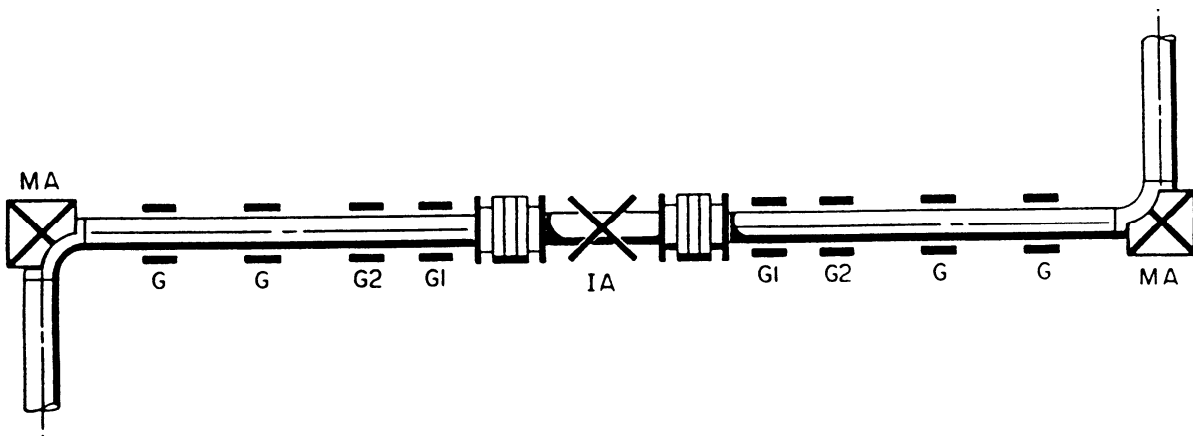


FIGURE 2.2

Figure 2.2 typifies good practice in the use of a double Expansion Joint to absorb axial pipe line expansion. Note the addition of the intermediate anchor (IA) which, in conjunction with the two main anchors, divides the pipe line into individual expanding sections, so that there is only one Expansion Joint between any two anchors. Note also the closeness of the first alignment guide (G1) to each Expansion Joint, the spacing between the first alignment guide and the second alignment guide (G2) and the spacing of intermediate guides (G) along the balance of each pipe section. See Figures 2.30 and 2.31 and/or equation (2-7).

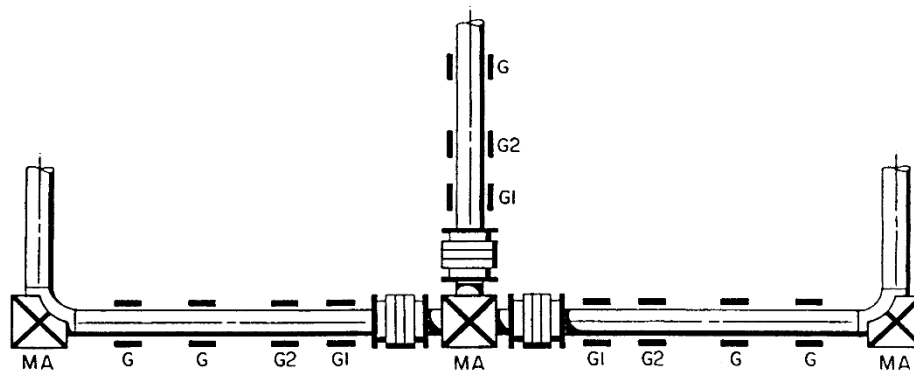


FIGURE 2.3

Figure 2.3 typifies good practice in the use of Expansion Joints to absorb axial pipe line expansion in a pipe line with a branch connection. The anchor at the junction, which in this case is a tee, is a main anchor (MA) designed to absorb the thrust from the Expansion Joint in the branch line. Note the nearness of each Expansion Joint to an anchor, the closeness of each first alignment guide (G1), the spacing between the first alignment guide and the second alignment guide (G2) and the spacing of intermediate guides (G) along the balance of each pipe section. See Figures 2.30 and 2.31 and/or equation (2-7).

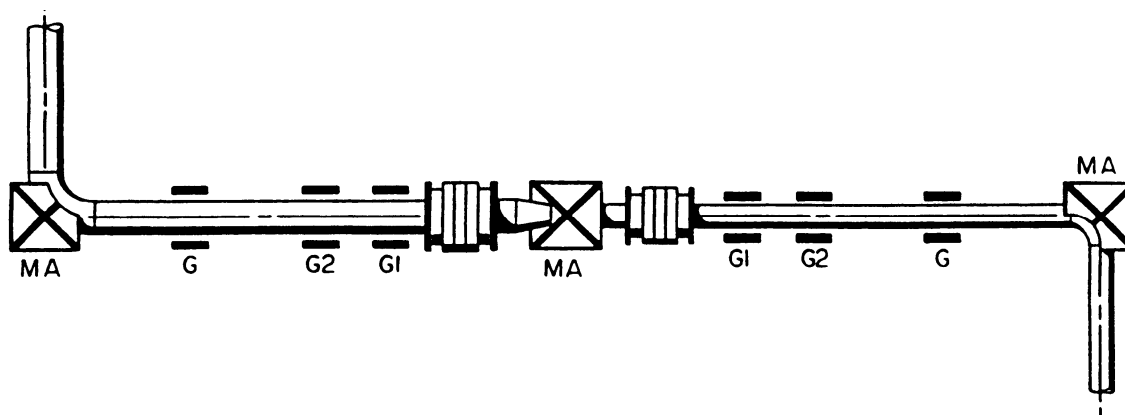


FIGURE 2.4

Figure 2.4 typifies good practice in the use of Expansion Joints to absorb axial pipe line expansion in a pipe line containing a reducer. The anchor at the reducer is a main anchor (MA) designed to absorb the difference in the thrusts of the Expansion Joints on each side of the reducer. Note the nearness of each Expansion Joint to an anchor, the closeness of each first alignment guide (G1), the spacing between the first alignment guide and the second alignment guide (G2) and the spacing of intermediate guides (G) along the balance of each pipe section. See Figures 2.30 and 2.31 and/or equation (2-7).

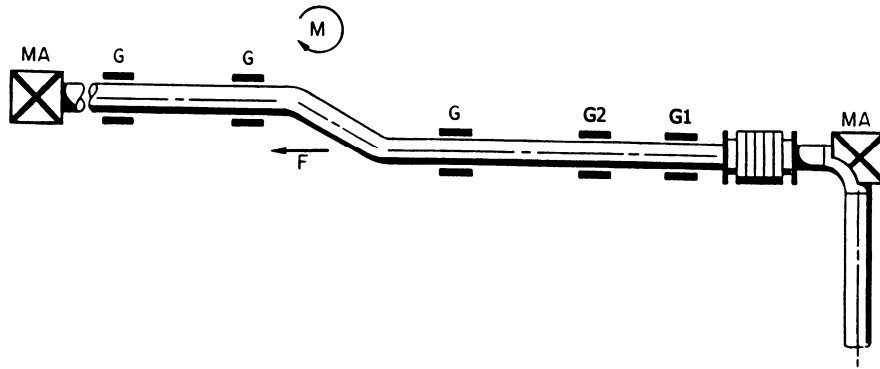


FIGURE 2.5

Figure 2.5 shows the application of a single Expansion Joint to a pipe line containing an offset. It should be noted that applications of this type are not usually recommended and will perform satisfactorily only within certain limits. As in Figure 2.1, the line is provided with main anchors at each end to absorb the pressure, movement loading, and guide friction. Where the line contains an offset, this load must first be transmitted through the offset leg, resulting in a moment on the piping. Where the line size is small, the offset appreciable, or where the pressure and movement forces are relatively high, this configuration may result in over-stressing, or distortion of the piping and guides.

Note the nearness of the Expansion Joint to an anchor (MA), the closeness of the first alignment guide (G1), the spacing between the first alignment guide and the second alignment guide (G2) and the spacing of intermediate guides (G) along the balance of the line. Guides should be installed near both ends of the offset leg to minimize the effects of the bending moment on the system. For spacing of other guides, see guide chart Figure 2.31, and/or equation (2-7).

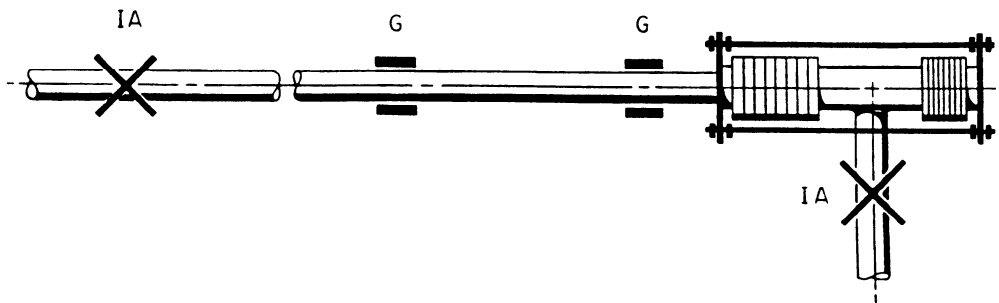


FIGURE 2.6

Figure 2.6 typifies good practice in the use of a pressure balanced Expansion Joint to absorb axial pipe line expansion. Note that the Expansion Joint is located at a change in direction of the piping and that the elbow and the end of the pipe line are secured by intermediate anchors. Since the pressure thrust is absorbed by the Expansion Joint itself, and only the forces required to deflect the Expansion Joint are imposed on the piping, a minimum of guiding is required. Frequently, directional guiding adjacent to the Expansion Joint, as shown, may suffice. In long, small-diameter pipe lines, additional guiding may be necessary.

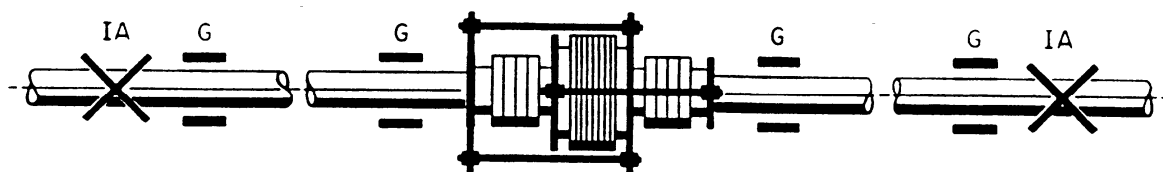


FIGURE 2.7

Figure 2.7 shows the use of an in-line pressure balanced Expansion Joints to absorb axial pipe line movements in a long, straight piping run. By utilizing this arrangement the two anchors shown are relieved of pressure loading and are designed as intermediate anchors. Since the piping is relieved of compressive pressure loading, a minimum of guiding is required, primarily to direct the thermal expansion of the piping into the Expansion Joints in an axial direction.

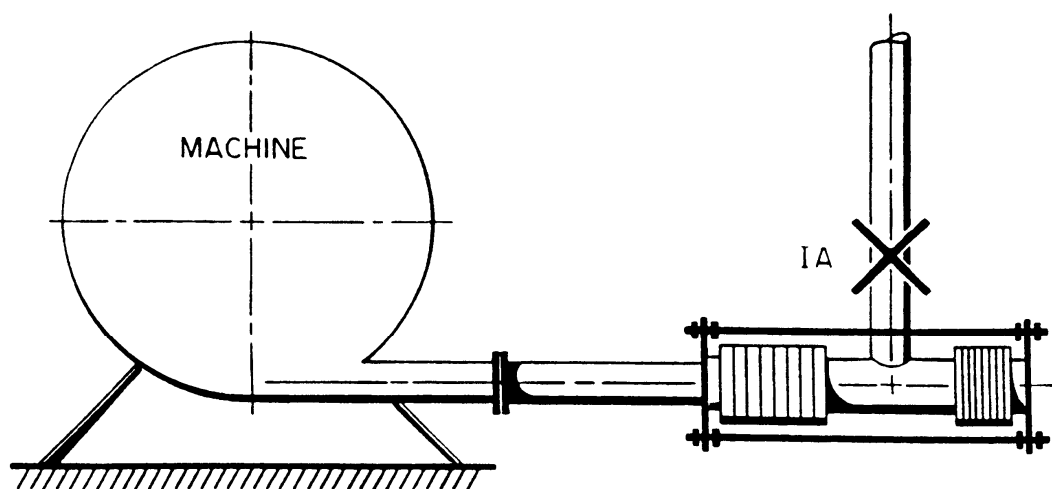


FIGURE 2.8

Figure 2.8 typifies good practice in the use of a pressure balanced Expansion Joint to absorb the thermal expansion of equipment such as turbines, pumps, compressors, etc. The primary function of the Expansion Joint is to minimize loading upon the equipment casing. Note that only an intermediate anchor is required at the change of piping direction and that, if the Expansion Joint is located immediately adjacent to the machine, no guiding is required. Care should be taken to provide sufficient flexibility in both the flow bellows and the balancing bellows, so that the forces required to compress the Expansion Joint do not exceed loading limits for the equipment as established by the equipment manufacturer. See Section 2.6 for further information.

2.3 SELECTION FOR LATERAL DEFLECTION, ANGULAR ROTATION AND COMBINED MOVEMENTS

The selection and proper application of Expansion Joints for lateral deflection, angular rotation and combined movements, involves the evaluation of a number of variables. These can include the piping configuration, the operating conditions, desired cyclic life, load limitations upon piping and equipment, and available supporting structure. In some cases, two or more types of Expansion Joints may be suitable for a particular application. The selection then becomes purely an economic one. More frequently one or the other of the available designs possesses unique characteristics which make it particularly suitable for a given application.

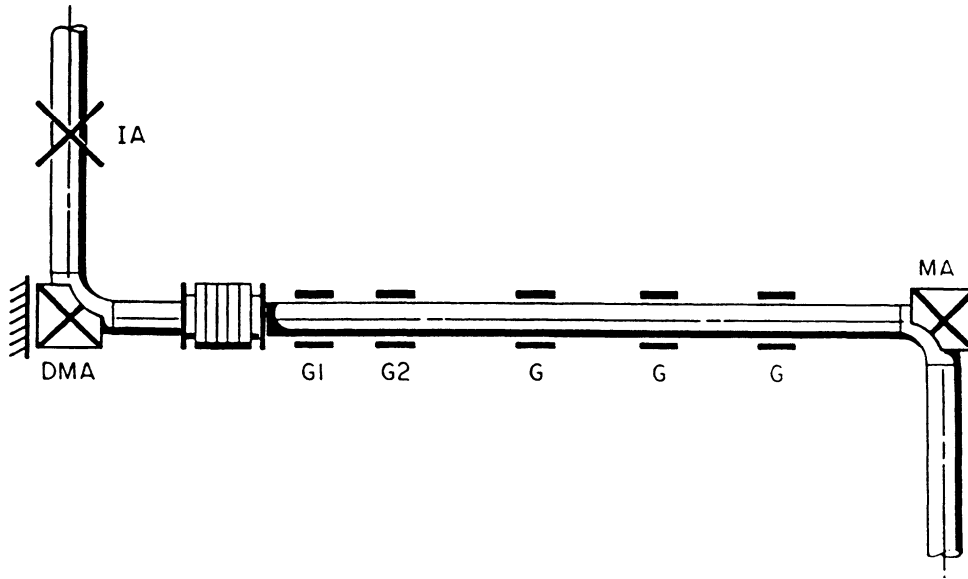
2.4 APPLICATIONS USING SINGLE EXPANSION JOINTS

FIGURE 2.9

The single Expansion Joint is usually considered first for any application because it offers the lowest Expansion Joint cost. Figure 2.9 shows a typical application of a single Expansion Joint absorbing combined axial movement and lateral deflection. The system closely resembles the arrangements shown for axial movement only in the preceding section.

The Expansion Joint is located at one end of the long piping leg with main anchors at each end and guides properly spaced for both movement control and protection of the piping against buckling. The anchor at the left end of the line is a directional main anchor (DMA) which, while absorbing the main anchor loading in the direction of the Expansion Joint axis, permits the thermal expansion of the short piping leg to act upon the Expansion Joint as lateral deflection. Because the main anchor loading exists only in the piping segment containing the expansion joint, the anchor at the end of the shorter piping leg is an intermediate anchor.

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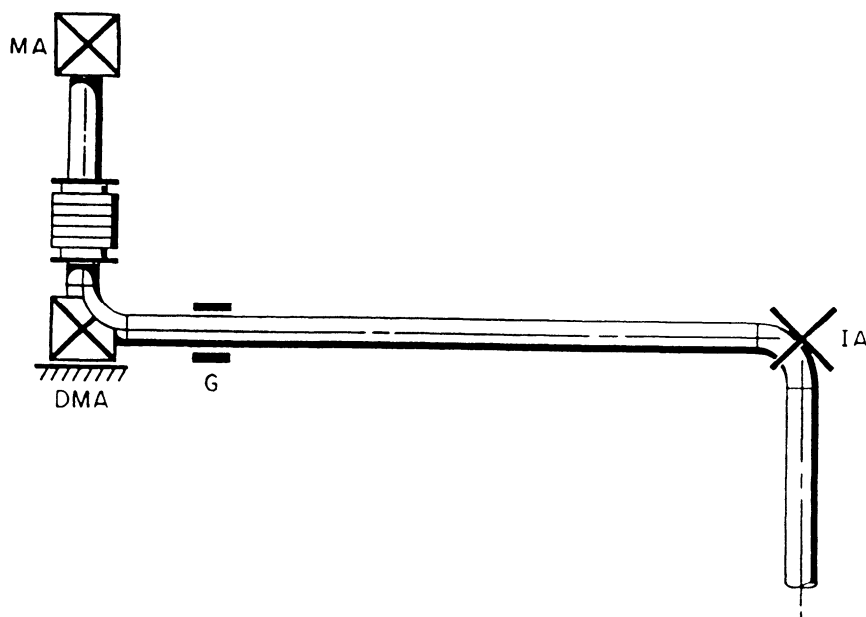


FIGURE 2.10

Figure 2.10 shows an alternate arrangement in which the Expansion Joint is installed in the short piping leg and the principal expansion is absorbed as lateral deflection. The longer piping leg is free of compressive pressure loading and requires only an intermediate anchor and directional guiding. The functions of the directional main anchor and the pipe guide may be combined in a single device.

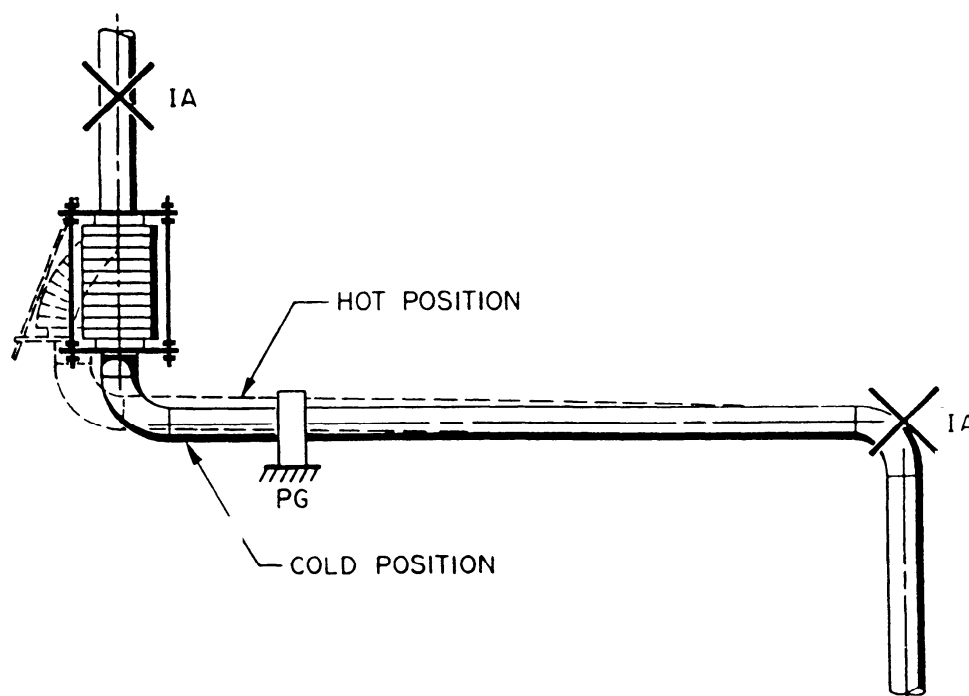


FIGURE 2.11

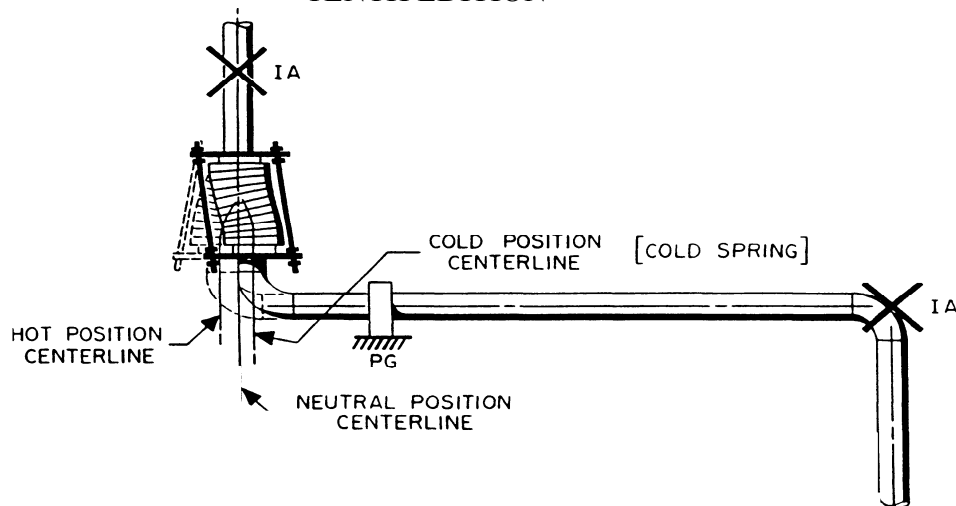


FIGURE 2.12

Figures 2.11 and 2.12 represent modifications of Figure 2.10 in which the main anchors at either end of the Expansion Joint are replaced by tie rods. Where the piping configuration permits, the use of tie rods adjusted to prevent axial movement frequently simplifies and reduces the cost of the installation. Because of these tie rods, the Expansion Joint is not capable of absorbing any axial movement other than its own thermal expansion. The thermal expansion of the piping in the shorter leg is, as a result, imposed as deflection on the longer piping leg. Where the longer piping leg is not sufficiently flexible and where the dimension of the shorter leg is suitable, tie rods may be installed spanning the entire short leg so that no deflection is imposed on the longer run from this source.

Where appreciable amounts of lateral deflection are imposed upon the Expansion Joint, some shortening of the Expansion Joint results from the displacement of the tie rods as shown in Figure 2.11. Care should be taken to insure that sufficient piping flexibility exists to absorb this deflection and that adequate clearances are provided in the guide to permit deflection of the piping. The amount of this deflection can be minimized by cold springing the Expansion Joint in the lateral direction as shown in Figure 2.12.

The principal restriction upon the use of single Expansion Joints for lateral deflection or combined axial movement and lateral deflection is the limited amount of lateral deflection which such an Expansion Joint can absorb. The allowable lateral deflection is directly proportional to the ratio of convoluted length to diameter which, in turn, is restricted by considerations of stability and manufacturing limitations. While eminently suitable for applications such as Figure 2.9 where the principal movement is axial, the relatively small available lateral movement severely limits the type of application illustrated in Figures 2.10, 2.11 and 2.12. Where operating pressures and temperatures are high, or where availability of suitable structures precludes the use of main anchors and multiple guides, the application shown in Figure 2.9 may not be feasible and another type of Expansion Joint may result in far more economical installation.

2.5 APPLICATIONS USING UNIVERSAL EXPANSION JOINTS

The universal Expansion Joint is particularly well adapted to the absorption of lateral deflection. In addition, this design may be used to absorb axial movement, angular rotation or any combination of the three. A common application of the universal Expansion Joint is its use as a tied Expansion Joint in a 90 degree piping offset with the tie rods adjusted to prevent external axial movement. Two such applications are shown in Figures 2.13 and 2.14.

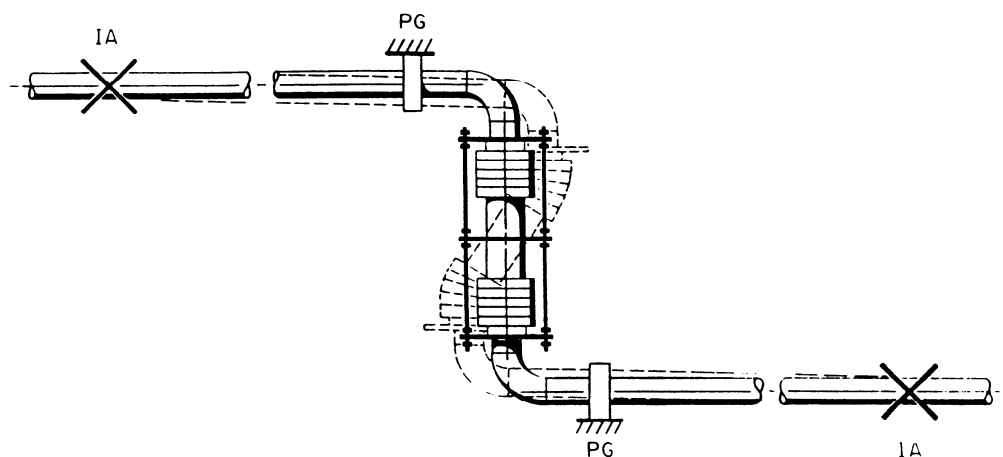


FIGURE 2.13

Figure 2.13 shows a tied universal Expansion Joint used to absorb lateral deflection in a single plane "Z" bend. Where dimensionally feasible, the Expansion Joint should be designed to fill the entire offset leg so that its expansion is absorbed within the tie rods as axial movement. The tie rod should be extended to the elbow center line when practical. The thermal movement of the horizontal lines is absorbed as lateral deflection by the Expansion Joint.

Both anchors are intermediate anchors since the pressure loading is absorbed by the tie rods. Only directional guiding is required since the compressive load on the pipe consists only of the force necessary to deflect the Expansion Joint. Any thermal expansion of the offset leg external to the tie rods, such as that of the elbows at either end, must be absorbed by bending of the horizontal pipe legs. Provision should be made in the design of the guides to allow for both this deflection and the reduced length of the Expansion joint in its deflected position. In addition, particularly in the case of long universal Expansion Joints under high pressure, additional allowance may be necessary to compensate for stretching of the tie rods under load. The Expansion Joint manufacturer should be consulted for recommended minimum guide clearances.

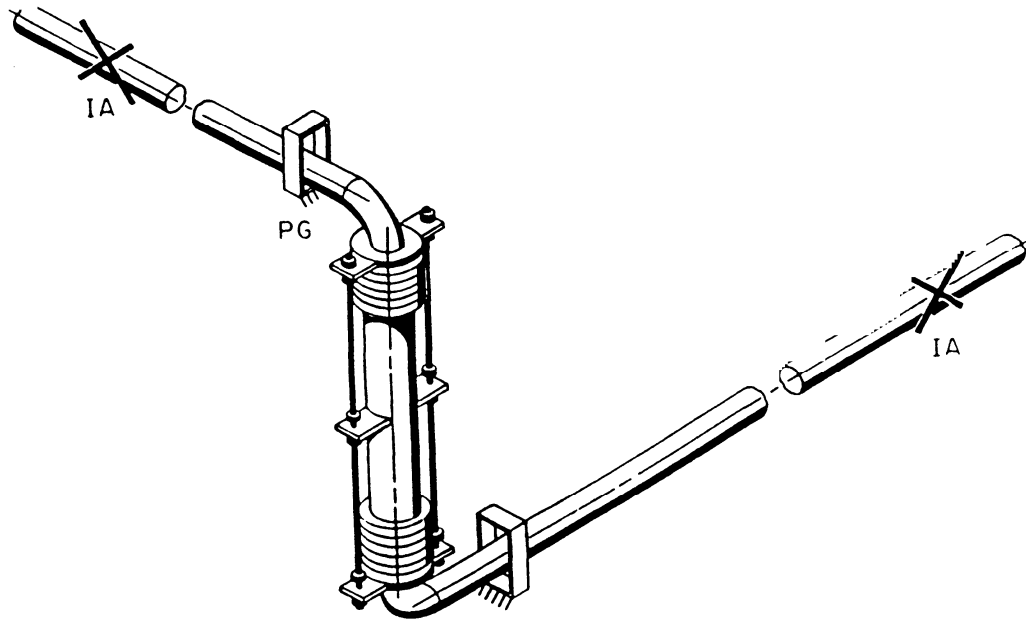


FIGURE 2.14

Figure 2.14 shows a typical application of a tied universal Expansion Joint in a three-plane "Z" bend. Since the universal Expansion Joint can absorb lateral deflection in any direction, the two horizontal piping legs may lie at any angle in the horizontal plane.

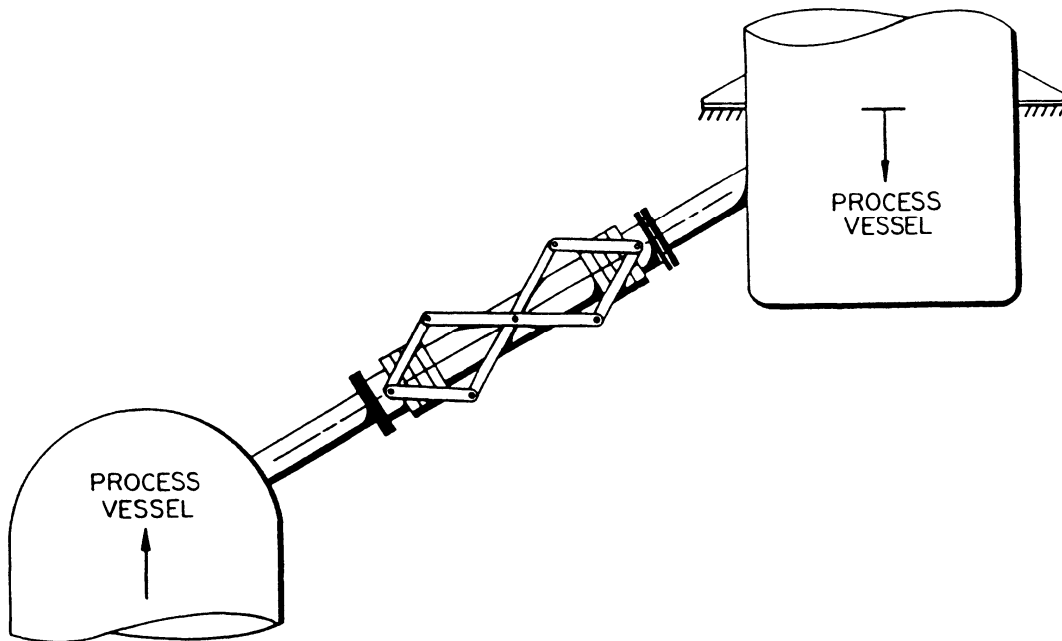


FIGURE 2.15

In cases where a universal Expansion Joint must absorb axial movement other than its own thermal growth, it cannot function as a tied Expansion Joint and must be used in combination with main anchors to absorb pressure loading.

One such case is shown in Figure 2.15. The relative expansion between the two vessels results in both axial movement and lateral deflection on the Expansion Joint. Both vessels must be designed to absorb main anchor loading. Control rods or pantographic linkages may be used to distribute the movement between the bellows and control their movements.

Numerous variations are possible in the design of universal Expansion Joints. Rods, pantographic linkages, slotted hinges or external structural members may be used in a horizontal installation, for example, where it is desirable to support the center pipe section of the Expansion Joint independently of the bellows. In a single plane system, the rods may be replaced by two bars with pinned connections at either end of the Expansion Joint. This construction is so commonly used that it has been given the standard nomenclature of "Swing Expansion Joint". In some cases two sets of short control rods, each set spanning one of the two bellows in the universal Expansion Joint are used instead of the overall rods shown in most of the illustrations. This arrangement is frequently used where the Expansion Joint must absorb axial movement and where the control rods are used for control and stability and not for absorption of pressure loading. This can result when the universal Expansion Joint is very long in relation to its diameter, or a large number of convolutions are used at each bellows of the Expansion Joint, or where the Expansion Joint is subject to external forces.

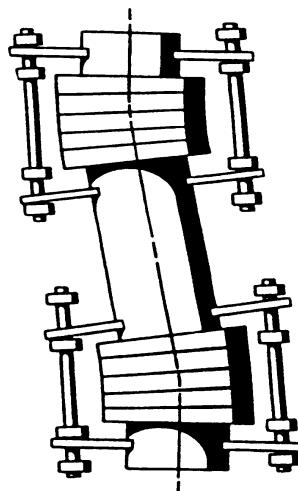


FIGURE 2.16A

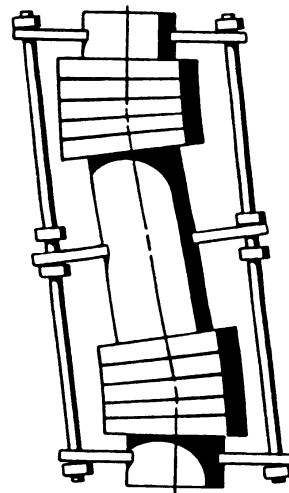


FIGURE 2.16B

It may be desirable to incorporate control devices in the Expansion Joint to prevent excessive displacement of the bellows and the relatively free pipe section between them. Figures 2.16A and 2.16B show two forms of controls which may be used for this purpose. In Figure 2.16A, short rods are used spanning each of the bellows in the Expansion Joint. Stops are provided on the rods so that, once the Expansion Joint has reached its rated lateral deflection, the stops will be engaged by members rigidly fastened to the pipe portions of the Expansion Joint.

Figure 2.16B shows a similar device adapted to an Expansion Joint with overall rods. The rod stops are engaged by a plate or lug attached to the center pipe portion and movement of this part beyond its design deflection is restrained. In order to obtain maximum control from these devices, the stops are usually oriented to lie in the plane of resultant movement of the Expansion Joint, affording maximum leverage as well as greater sensitivity to small movement. Devices of

this nature are usually furnished by the manufacturer dependent upon the design characteristics of the Expansion Joint.

Despite the versatility of the universal Expansion Joint, its use is sometimes precluded by the configuration of the piping, the operating conditions or even by manufacturing and transportation limitations. It may be undesirable or impossible to fabricate, ship to the job site and install a universal Expansion Joint which would span the full length of the offset where, for example, the length of the offset leg in a "Z" bend is extremely long. When the Expansion Joint is very long in relation to its diameter, the flexibility of overall rods may reduce the effectiveness of the control so that the center pipe section becomes unstable. Other types of Expansion Joints may offer a more desirable solution when such limits are encountered.

2.6 APPLICATIONS USING PRESSURE BALANCED EXPANSION JOINTS

The pressure balanced Expansion Joint is used most frequently in applications similar to those shown for the single Expansion Joint, but where pressure loading upon piping or equipment is considered excessive or objectionable. The major advantage of the pressure balanced design is its ability to absorb externally imposed axial movement without imposing pressure loading on the system. The force resulting from the bellows spring rate is not eliminated. In fact, it is usually increased over that of a single Expansion Joint, since both the flow bellows and the balancing bellows must be compressed or elongated and the combined axial force acts upon the piping or equipment. Since the forces to move the bellows are generally of a low order of magnitude, these are usually not objectionable, except in cases involving extremely light equipment with close clearance moving parts which might be affected by small forces.

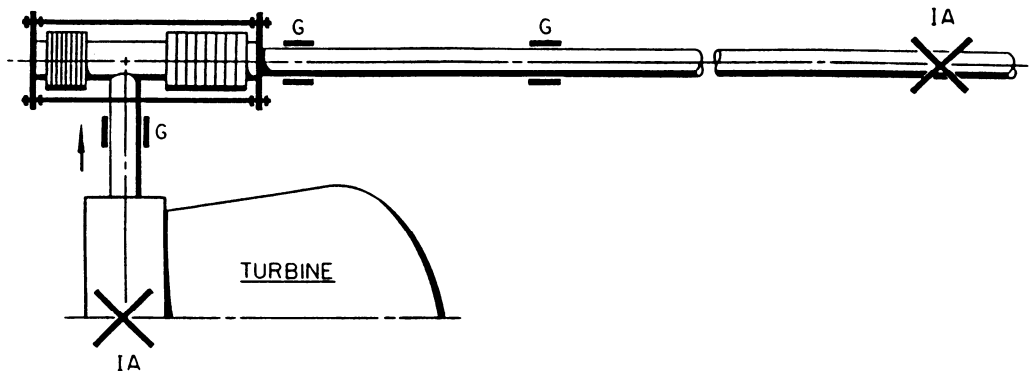


FIGURE 2.17

Figure 2.17 shows a typical application of a pressure balanced Expansion Joint for combined axial movement and lateral deflection. Both the anchor at the end of the piping run and that on the turbine are intermediate anchors and only directional guiding is required. By proper design, the guide directly above the turbine can be made to absorb the axial movement forces of the Expansion Joint without imposing these on the turbine. The only force imposed on the turbine is that which is required to deflect the Expansion Joint laterally.

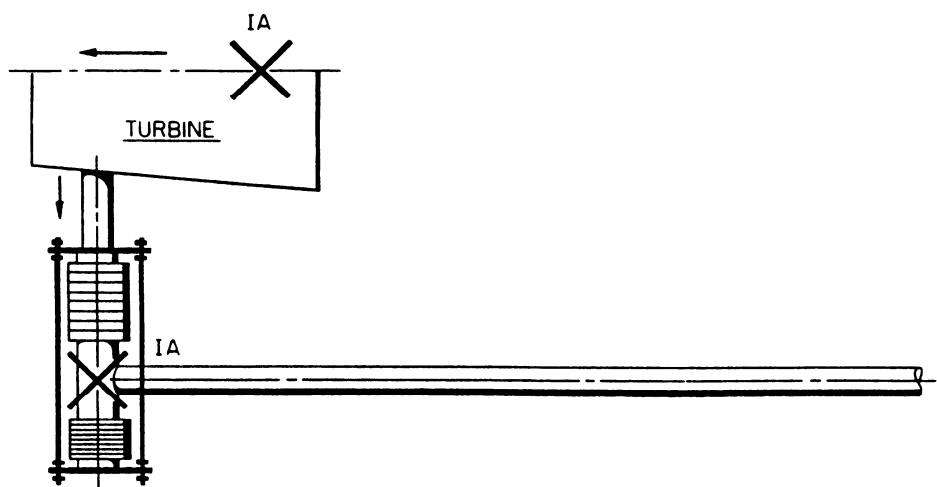


FIGURE 2.18

Figure 2.18 shows another turbine application but, in this case, the anchor point of the turbine is located some distance from the Expansion Joint and the expansion of the turbine between its anchor and the Expansion Joint is absorbed as lateral deflection. An intermediate anchor is used at the center fitting of the Expansion Joint. Since the Expansion Joint is located close to the turbine, guiding between the turbine and Expansion Joint is not required.

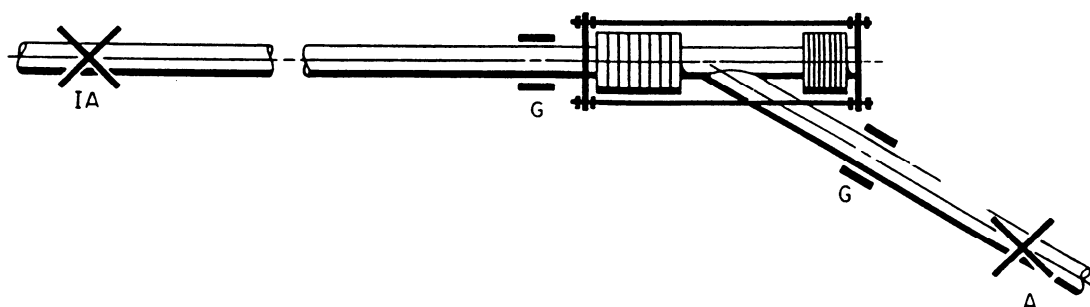


FIGURE 2.19

Figure 2.19 shows that a pressure balanced Expansion Joint can be used at changes in direction other than 90 degrees. In this case, the growth of the longer piping run is absorbed as axial movement on the Expansion Joint, while the thermal expansion of the offset piping run introduces both axial and lateral components or deflection on the Expansion Joint. Only intermediate anchors are required at the ends of the lines and directional guiding is used. The guide on the offset run may be used to absorb the axial movement forces of the Expansion Joint, if the piping is not sufficiently stiff to transmit this directly to the intermediate anchor.

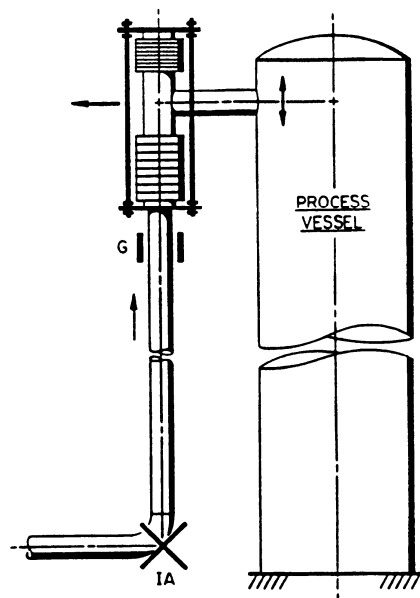


FIGURE 2.20

Figure 2.20 shows a common application for which a pressure balanced Expansion Joint is well suited. Under various process conditions, the vessel and the vertical pipe may expand at different rates. By installing a pressure balanced Expansion Joint as shown, the differential vertical movement is absorbed as axial movement on the Expansion Joint and the thermal expansion from the center line of the process vessel to the piping is absorbed as lateral deflection. The piping may then be secured by an intermediate anchor at the bottom and furnished with a directional guide adjacent to the Expansion Joint.

In many cases, no external structure is available at the upper elevation of the process vessel and the guide must be connected to the vessel itself. Using this arrangement may result in some bending load upon the piping, especially where the vessel is tall and is subject to wind loading deflection or similar effects. Where the guide is attached to a rigid external structure, the Expansion Joint must be designed to absorb wind loading deflection, and other similar loading, as lateral deflection.

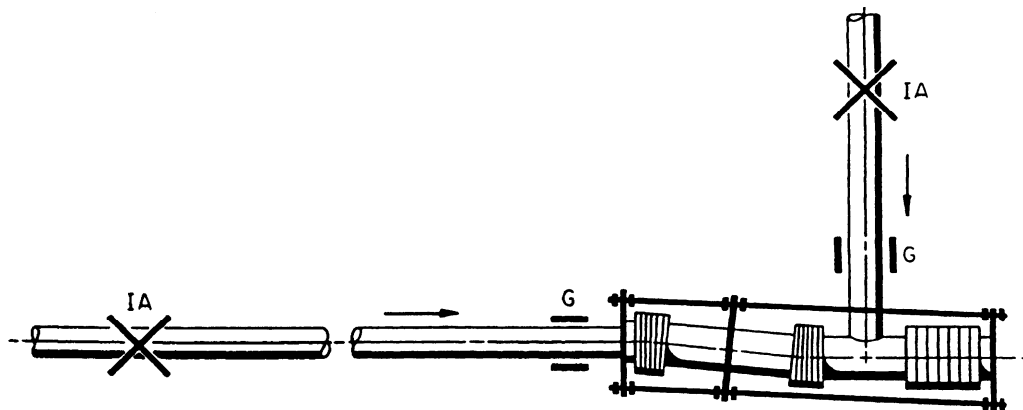


FIGURE 2.21

Where large amounts of lateral deflection are involved, a pressure balanced universal Expansion Joint must be used. In this design, two bellows are used in the flow end of the Expansion Joint and a single bellows in the balancing end. Normally, as shown in Figure 2.21, the balancing

bellows will be subjected only to axial movement if the tie rods are properly designed to rotate or pivot at their attachment points.

In order for a pressure balanced Expansion Joint to function properly, the pressure thrust restrained by the tie rods must exceed the axial movement forces of the Expansion Joint. In a large diameter, low pressure application, it may be impossible to utilize the pressure balanced Expansion Joint to eliminate the pressure loading or, at best, the effect may be uncertain. In such cases, some other Expansion Joint design must be considered. Pressure balanced Expansion Joints are not recommended for use in services where the pressure equalizing connection between the flow bellows and the balancing bellows may become plugged or blocked by the flowing medium or by contaminants. Where flow considerations permit, this problem may be overcome by the use of a tee as a center fitting of the Expansion Joint, rather than an elbow. In some cases, the pressure for the balancing end of the Expansion Joint has been introduced from a separate pressure source, but this is considered somewhat hazardous. A control failure or even a slow control response might result in partial or full pressure loading being imposed upon the piping or equipment, thus overcoming the initial reason for using the pressure balanced Expansion Joint.

The pressure balanced Expansion Joint is used to relieve loads on equipment such as pumps, compressors and turbines. In many cases, the cost of the pressure balanced Expansion Joint will be negligible when compared to the cost of additional equipment, piping and building space which would be necessary for safe functioning of the equipment without the Expansion Joint.

2.7 APPLICATIONS USING HINGED EXPANSION JOINTS

Hinged Expansion Joints are usually used in sets of two or three, to absorb lateral deflection in one or more directions in a single plane piping system. Each individual Expansion Joint in such a system is restricted to pure angular rotation by its hinges. Each pair of hinged Expansion Joints, separated by a segment of piping, will act in unison to absorb lateral deflection in much the same manner as a swing or universal Expansion Joint in a single plane application. For a given angular rotation of the individual Expansion Joints, the amount of lateral deflection which a pair of hinged Expansion Joints can absorb is directly proportional to the distance between their hinge pins. In order to utilize the Expansion Joints most efficiently, this distance should be made as large as possible.

Expansion Joint hinges are normally designed to absorb the full pressure thrust of the Expansion Joint and may be designed to support the weight of piping and equipment, wind loads or similar externally applied forces. Where such external forces are anticipated, their direction and magnitude must be indicated to the Expansion Joint manufacturer so that the hinges can be adequately designed to withstand these forces.

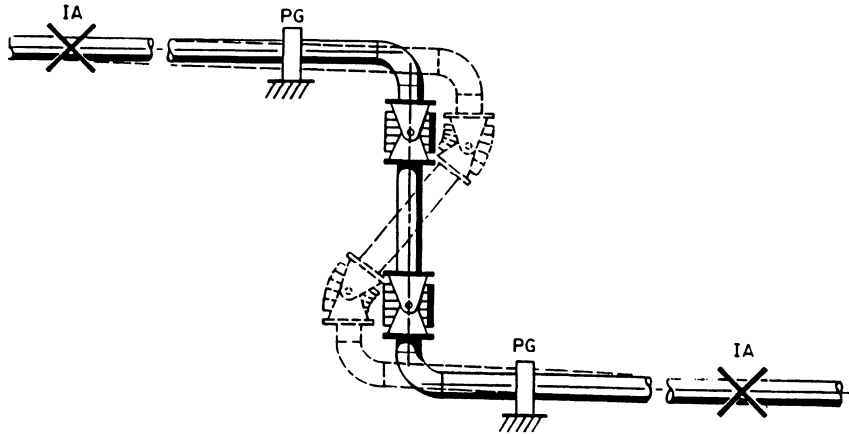


FIGURE 2.22

Figure 2.22 illustrates the use of a two-hinge system to absorb the major thermal expansions in a single-plane "Z" bend. Since the pressure thrust is absorbed by the hinges on the Expansion Joints, only intermediate anchors are required at each end of the piping system. The thermal expansion of the offset section containing the Expansion Joints must be absorbed by bending of the piping legs perpendicular to that segment, since the Expansion Joints are restricted to pure angular rotation by their hinges and cannot extend or compress. The amount of bending deflection imposed on each of the two long piping legs may be controlled by proper design of guides and supports. Where one long leg is sufficiently flexible to absorb the full thermal growth of the offset leg, the other long leg may be controlled to permit longitudinal movement only. The planar guides shown at the ends of the long piping runs near the elbows are intended to maintain the plane of the piping system only and must allow for the bending deflections of the long piping legs. In calculating guide clearances, consideration shall be given to the fact that the thermal expansion of the offset piping leg containing the Expansion Joints will be partially offset by the reduction in length resulting from the displacement of the center pipe section. The latter effect may be neglected only where the distance between hinge pins is very large and the lateral displacement small. This effect can be minimized by cold springing the Expansion Joints 50% of the full rated deflection.

Because of the ability of the hinges to transmit loads, support of a hinged piping system can frequently be simplified. Assuming that Figure 2.22 is an elevation view and that the upper piping leg is sufficiently flexible to absorb the total expansion of the vertical leg, it would be possible to use sliding supports on the lower horizontal run to support its weight and restrict it to longitudinal movement only. By utilizing the rigidity of the hinges, a substantial portion of the weight of the upper horizontal leg may also be carried on these lower supports. It should be noted that the sliding supports nearest the vertical leg must be designed to resist the force required to deflect the piping. Spring supports must be used throughout the length of the upper horizontal leg where bending occurs. Beyond that point, sliding supports may be used.

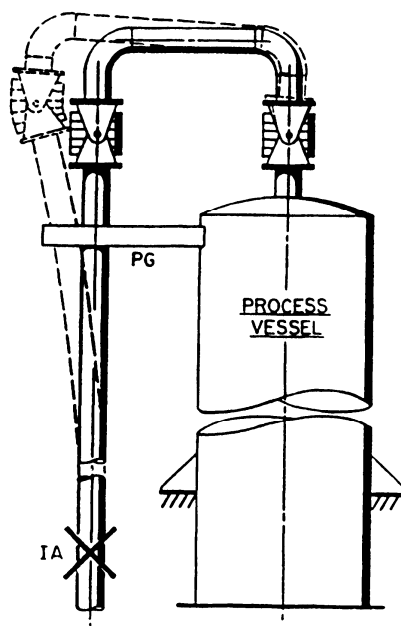


FIGURE 2.23

In locating hinged Expansion Joints for more efficient use, it should be noted that the hinges need not be co-linear in order to function properly. Figure 2.23 illustrates a two-hinge Expansion Joint system similar to the pressure balanced Expansion Joint application of Figure 2.20. In this case, the Expansion Joints will absorb only the differential vertical growth between the vessel and pipe riser. Any horizontal movement due to piping expansion, vibration and wind loads will be absorbed by bending of the vertical pipe leg. A planar guide may be installed near the top of the vessel to protect the hinged Expansion Joints from wind loads at right angles to the plane of the piping.

The anchor shown at the bottom of the riser is an intermediate anchor only, since the pressure load is absorbed by the Expansion Joint hinges. This anchor must be capable of withstanding the forces created by bending of the riser. Depending upon the dimensions and weight of the piping system, complete support may be obtained from the process vessel and from the intermediate anchor. If additional supports are required, spring type supports should be used. The vertical piping may be cold sprung to reduce bending stresses, utilizing the hinges to withstand the cold spring force.

Where the piping in a single plane system is not sufficiently flexible to absorb the bending deflections involved in a two hinge system, or where the loads resulting from such bending exceed the allowable limits for connected equipment, a system of three hinged Expansion Joints may be used. Figure 2.24 illustrates a system of three hinged Expansion Joints in a single plane "Z" bend. The thermal expansion of the offset piping section is absorbed by the action of Expansion Joints B and C. It is therefore evident that Expansion Joint B must be capable of absorbing the total of the rotations of Expansion Joints A and C.

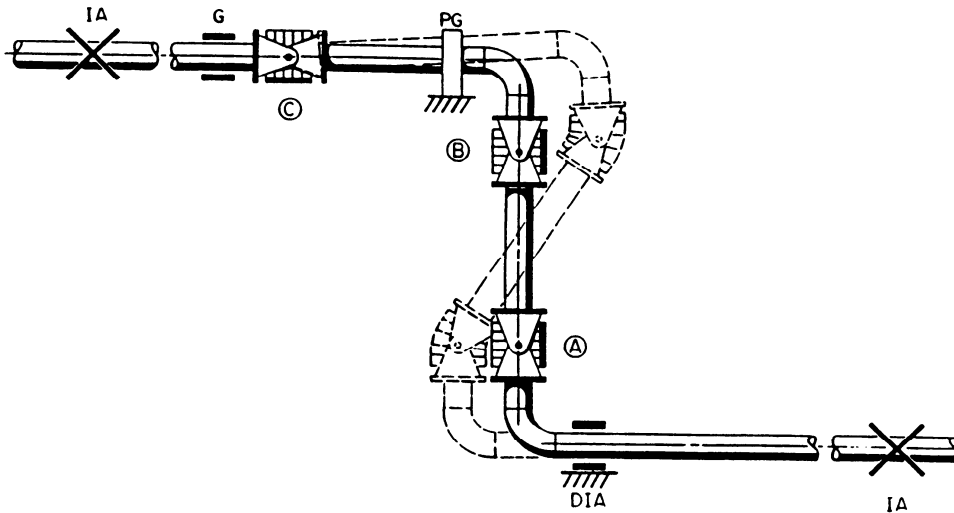


FIGURE 2.24

As in the previous cases, the anchors at the ends of the piping system are intermediate anchors only. In this case, all deflection is absorbed by the Expansion Joints and negligible pipe bending loads will be imposed upon these anchors. Where the distance between the anchor at the left and the first hinged Expansion Joint C is large, a pipe guide should be installed adjacent to the Expansion Joint, as shown in Figure 2.24. This pipe guide will minimize bending of the pipe section between Expansion Joint C and the left hand anchor which might otherwise result from the moment required to rotate the Expansion Joint. One or more additional guides may be used to maintain the plane of the piping system and relieve the hinges of bending forces which may be created by external loads. Support of the piping system may be accomplished in various ways, utilizing available supporting structures with greatest efficiency. It is essential that spring supports be used to permit free movement of the piping between the Expansion Joints.

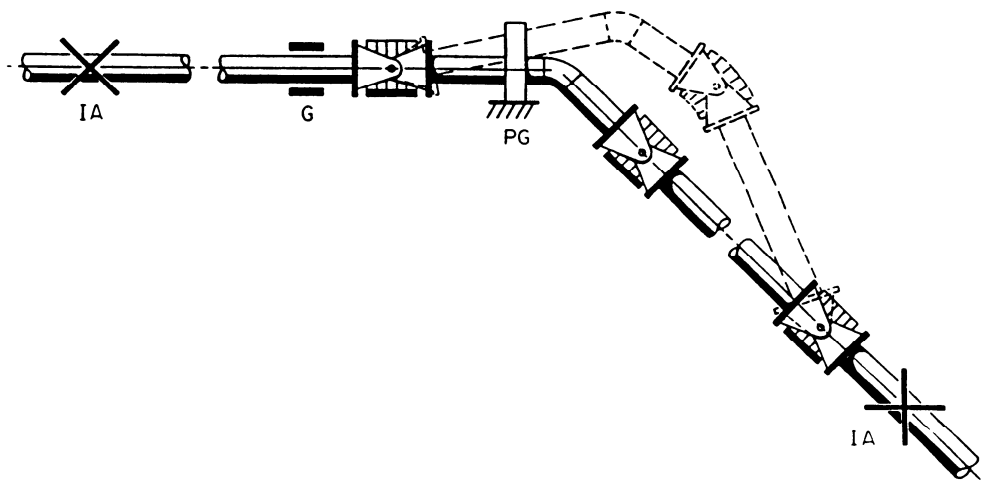


FIGURE 2.25

Figure 2.25 illustrates the principle that systems of hinged Expansion Joints may be used in other than 90° bends. Only intermediate anchors and planar guides are required.

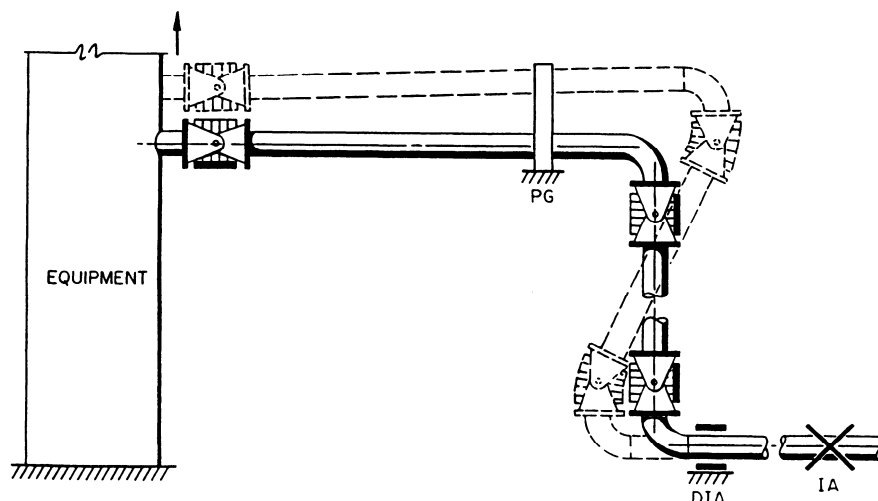


FIGURE 2.26

A hinged Expansion Joint system may be used effectively in applications involving movement other than the pure thermal growth of piping. Figure 2.26 illustrates an application combining the thermal expansion of a piping system with the single plane movements of a piece of connected equipment. So long as all movements are restricted to a single plane, the behavior of the Expansion Joint system is quite similar to that of the system shown in Figure 2.24. An intermediate anchor is required at one end of the piping, while the equipment serves as an intermediate anchor at the opposite end. The displacements of the equipment are added to those of the piping to evaluate the movements of the Expansion Joints. Planar guide clearances in the plane of the piping must be adequate to allow for the equipment movement as well as the piping rotations.

Some advantages of hinged Expansion Joints are compact size and structural rigidity. By the use of these individual units, it is frequently possible to compensate for the thermal expansion of irregular and complex piping configurations which might preclude the use of other types of Expansion Joints. Because of the ability of the hinge structure to transmit loads, piping systems containing hinged Expansion Joints impose minimum forces on the pipe anchors. Such systems may be supported at virtually any point which does not interfere with the free movement of the system.

2.8. CALCULATION OF ANGULAR ROTATION IN A 3 HINGE PIPING SYSTEM

The application of a 3 hinge piping system is described in Section 2.7. This section provides a standard method to calculate the angular movements in each of the three hinge joints. Refer to Appendix J for a sample problem to illustrate the calculations.

Diagram the piping system as shown below. All lengths of pipe outside of points A and C should be added algebraically to compute the thermal growth from $A - A^1$ and $C - C^1$.

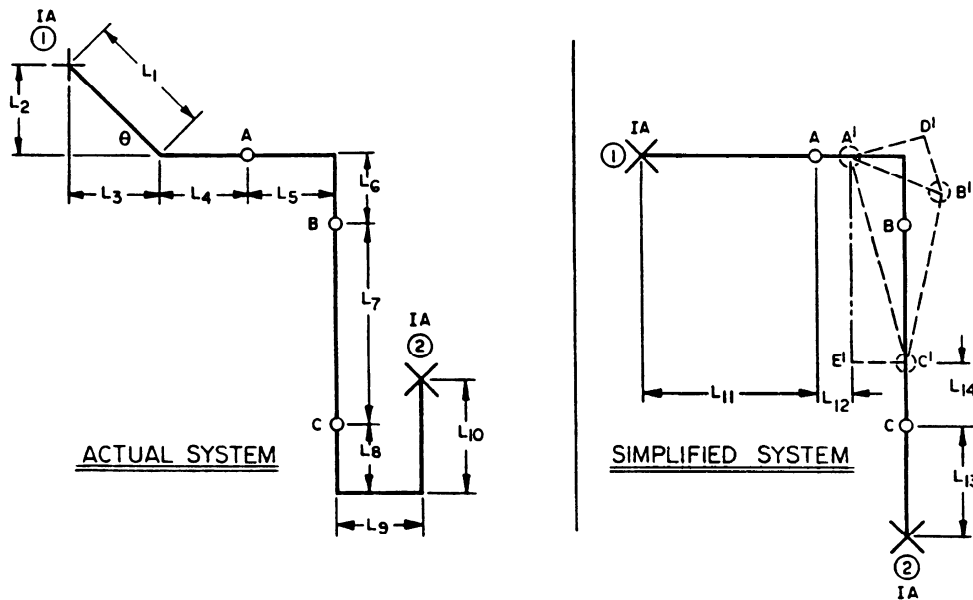


FIGURE 2.27

GIVEN

$$L_1 = \underline{\hspace{2cm}} \text{ in. (mm)} \quad L_6 = \underline{\hspace{2cm}} \text{ in. (mm)} \quad \delta = \underline{\hspace{2cm}} \text{ in. (mm)/in. (mm)}$$

$$\theta = \underline{\hspace{2cm}} \text{ deg.} \quad L_7 = \underline{\hspace{2cm}} \text{ in. (mm)}$$

$$L_8 = \underline{\hspace{2cm}} \text{ in. (mm)} = \frac{\text{Tabulated values from Table I}}{1200}$$

$$L_4 = \underline{\hspace{2cm}} \text{ in. (mm)} \quad L_9 = \underline{\hspace{2cm}} \text{ in. (mm)}$$

$$L_5 = \underline{\hspace{2cm}} \text{ in. (mm)} \quad L_{10} = \underline{\hspace{2cm}} \text{ in. (mm)}$$

MOVEMENT CALCULATIONS

$$L_2 = (L_1)(\sin \theta) = \underline{\hspace{2cm}} \text{ in. (mm)} \quad L_3 = (L_1)(\cos \theta) = \underline{\hspace{2cm}} \text{ in. (mm)}$$

$$L_{13} = (L_2) + (L_8) - (L_{10}) = \underline{\hspace{2cm}} \text{ in. (mm)} \quad L_{11} = (L_3) + (L_4) + (L_9) = \underline{\hspace{2cm}} \text{ in. (mm)}$$

$$L_{14} = (L_{13})(\delta) = \underline{\hspace{2cm}} \text{ in. (mm)} \quad L_{12} = (L_{11})(\delta) = \underline{\hspace{2cm}} \text{ in. (mm)}$$

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$$A^1E^1 = L_6 + L_7 - L_{14} = \underline{\hspace{2cm}} \text{ in. (mm)}$$

$$E^1C^1 = L_5 - L_{12} = \underline{\hspace{2cm}} \text{ in. (mm)}$$

$$A^1C^1 = \left[(A^1E^1)^2 + (E^1C^1)^2 \right]^{1/2} = \underline{\hspace{2cm}} \text{ in. (mm)}$$

$$A^1 = TAN^{-1} \left[\frac{(E^1 C^1)}{(A^1 E^1)} \right] =$$

$$C^1 = 90^\circ - A^1 =$$

$$A^1 D^1 = (L_5)(1 + \delta) = \underline{\hspace{2cm}} \text{ in. (mm)}$$

$$D^1B^1 = (L_6)(1 + \delta) = \underline{\hspace{2cm}} \text{ in. (mm)}$$

$$A^1B^1 = \left[(A^1D^1)^2 + (D^1B^1)^2 \right]^{1/2} = \underline{\hspace{2cm}} \text{ in. (mm)}$$

$$A^1 = TAN^{-1} \left[\frac{(D^1 B^1)}{(A^1 D^1)} \right] =$$

$$B^1 = 90^\circ - A^1 =$$

$$B^1C^1 = (L_7)(1 + \delta) = \underline{\hspace{2cm}} \text{ in. (mm)}$$

$$B^1 = \cos^{-1} \left[\frac{(A^1 B^1)^2 + (B^1 C^1)^2 - (A^1 C^1)^2}{(2)(A^1 B^1)(B^1 C^1)} \right] =$$

$$C^1 = \cos^{-1} \left[\frac{(A^1 C^1)^2 + (B^1 C^1)^2 - (A^1 B^1)^2}{(2)(A^1 C^1)(B^1 C^1)} \right] =$$

$$A^1 = 180^\circ - B^1 - C^1 =$$

$$\Sigma =$$

[illegible]

CALCULATED ANGULAR MOVEMENTS

$$\Delta A = \sum A^i - 90^\circ = \underline{\hspace{2cm}} \text{ deg.}$$

$$\Delta B = 180^\circ - \sum B^1 \quad = \quad \text{deg.}$$

$$\Delta C = \sum C^1 - 90^\circ = \quad \text{deg.}$$

$$\Delta B = \Delta A + \Delta C \text{ (Check)} = \text{deg.}$$

Refer to Appendix J Example 7 for a sample calculation.

2.9 APPLICATIONS USING GIMBAL EXPANSION JOINTS

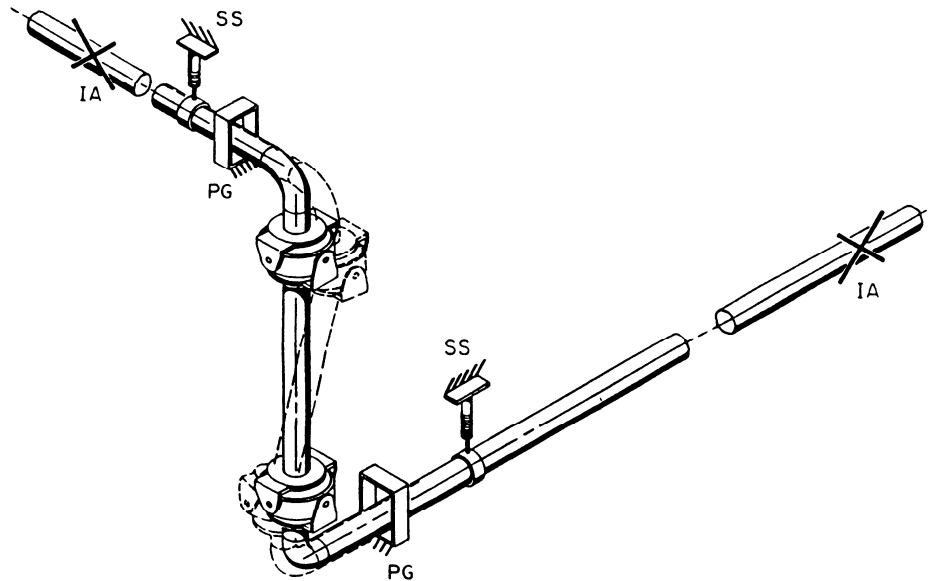


FIGURE 2.28

Just as hinged Expansion Joints may offer great advantages in single plane applications, gimbal Expansion Joints are designed to offer similar advantages in multi-plane systems. The ability of the gimbal Expansion Joint to absorb angular rotation in any plane is most frequently applied by utilizing two such units to absorb lateral deflection. An application of this type is shown in Figure 2.28. Since the pressure loading is absorbed by the gimbal structure, intermediate anchors only are required. Planar guides are provided to restrict the movement of each piping leg. As in the case of hinged Expansion Joints, the location of pipe supports is simplified by the load carrying ability of the gimbal structure. Since, in a two gimbal system, the growth of the vertical pipe leg will be absorbed by bending of the long legs, spring supports (SS) may be required on either or both of these. Guides must be designed to allow for the thermal expansion of the leg containing the Expansion Joints and for the shortening of this leg due to deflection.

Where it is impossible or undesirable for the piping to absorb the growth of the offset leg, a system consisting of two gimbal and one hinged Expansion Joint may be used as shown in Figure 2.29. The gimbal Expansion Joints function in unison to absorb the combined movements of the upper and lower legs, while the hinged Expansion Joint and the upper gimbal Expansion Joint act in combination to absorb deflection of the offset leg. Since the expansion of the offset leg takes place in one plane only, the use of the simpler hinged Expansion Joint is justified.

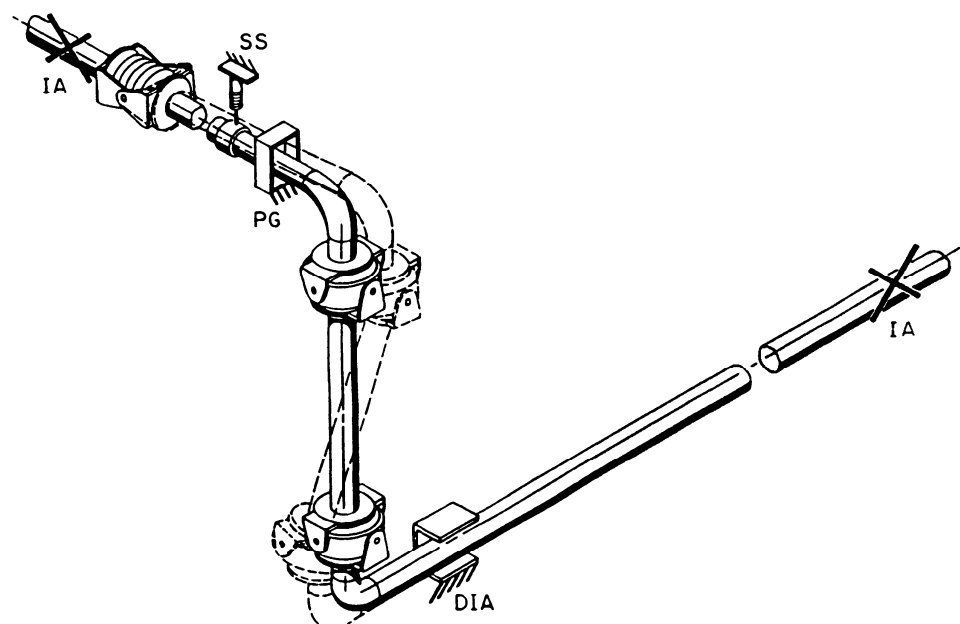


FIGURE 2.29

The advantages of using gimbal Expansion Joint systems are similar to those previously mentioned for systems containing hinged Expansion Joints. Greater flexibility of usage is possible since gimbal Expansion Joints are not restricted to single plane systems.

2.10 ANCHOR, GUIDE, AND SUPPORT REQUIREMENTS

2.10.1 PIPE ANCHORS

It is the purpose of any pipe anchor to divide a pipe line into individual expanding sections. Since thermal growth cannot be restrained, it then becomes the function of pipe anchors to limit and control the amount of movement which Expansion Joints, located between these anchors, must absorb.

Major pieces of connected equipment such as turbines, pumps, compressors, heat exchangers, and reactors may function as anchors. The design of such equipment must anticipate this loading. Additional pipe anchors are usually located at valves, at changes in the direction of the pipe, at blind ends of pipe, and at major branch connections. Expansion Joints must be provided in each of the individual pipe sections to provide adequate flexibility. See Section 2.2 and 2.3 for typical Expansion Joint applications.

DO NOT INSTALL MORE THAN ONE "SINGLE" EXPANSION JOINT BETWEEN THE TWO ADJACENT ANCHORS IN ANY STRAIGHT PIPE SECTION. Where expansion loops are used in the same line with an Expansion Joint, the section of pipe containing the loop must be isolated from the section containing the Expansion Joint by means of anchors.

Pipe anchors, their attachment, and the structures to which they are attached must be designed to withstand the forces acting upon them. Methods are given in the following paragraphs for determining the major forces to which anchors are subjected, and it is on the basis of these major forces that anchors are classified as intermediate or main anchors. The system designer must realize that additional indeterminate forces can be imposed on both intermediate and main anchors. All components of the anchor should be designed to a conservative stress level.

Determination of the magnitude of the major forces acting on anchors as set forth in the following paragraphs are forces acting axially. Consideration should also be given to possible lateral forces in arriving at a suitable anchor design.

The difference in cost of an adequately and inadequately designed anchor is nominal at installation. Anchor failure can cause damage which is far more costly than that of the more conservative design.

2.10.1.1 INTERMEDIATE PIPE ANCHORS

An intermediate pipe anchor must be designed to withstand the forces and moments imposed upon it by each of the pipe sections to which it is attached. These consist of the forces and/or moments required to deflect the Expansion Joint or Joints the full rated movement and the frictional forces due to pipe alignment guides, directional anchors and supports. Note that an intermediate anchor is not intended to withstand the pressure thrust. This force is absorbed by other anchors, by devices on the Expansion Joints such as tie rods, swing bars, hinges, gimbals, and other hardware, or, as in the case of a double Expansion Joint, is balanced by an equal pressure force acting in the opposite direction.

In certain applications, it may be necessary to consider the weight of the pipe, fittings, insulation and flowing medium, as well as various other forces and moments such as those resulting from wind loading or bending of one or more pipe sections. The net loading on the anchor can be calculated by a summation of the moments about the anchor point and by the vector addition of all forces acting upon it.

2.10.1.1.1 CALCULATION OF INTERMEDIATE ANCHOR LOADS FOR APPLICATIONS INVOLVING STRAIGHT PIPE SECTIONS ONLY (See Figure 2.2)

The force F_m required to extend or compress the Expansion Joint its full rated movement is a function of each manufacturer's design and is affected by the material, shape, depth and thickness of the bellows convolutions. This value should be obtained from the manufacturer of the Expansion Joint under consideration.

The frictional force F_g due to pipe alignment guides is a function of the design and number of alignment guides used in each pipe section and should be obtained from the manufacturer of the pipe alignment guides under consideration.

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Assuming that the weight of the pipe line and its contents is carried by supports, the total force acting on the intermediate anchor is then given by the formula:

$$F_{ia} = F_{m1} + F_{g1} + F_{m2} + F_{g2} \quad (2-1)$$

Where:

- F_{m1} = The force required to extend or compress the Expansion Joint located immediately to the right of the intermediate anchor in Figure 2.2, lbf (N)
- F_{g1} = The frictional force in the pipe alignment guides installed on the pipe section to the right of the intermediate anchor in Figure 2.2, lbf (N)
- F_{m2} = The force required to extend or compress the Expansion Joint located immediately to the left of the intermediate anchor in Figure 2.2, lbf (N)
- F_{g2} = The frictional force in the pipe alignment guides installed on the pipe section to the left of the intermediate anchor in Figure 2.2, lbf (N)

If the pipe is the same diameter on both sides of the intermediate anchor, and if the guides on both pipe sections are similar in number and design, F_{m2} and F_{g2} will be equal to F_{m1} and F_{g1} respectively, but opposite in sign. Thus, F_{ia} will be equal to zero. However, it is possible that the pipe line may heat up gradually from one end, thereby causing one of the pipe sections to expand before the other. It is, therefore, considered good practice to design the intermediate anchor to resist the forces exerted by one of the two pipe sections

$$(F_{ia} = F_{m1} + F_{g1}).$$

2.10.1.1.2 CALCULATION OF INTERMEDIATE ANCHOR LOADS FOR APPLICATIONS INVOLVING LATERAL DEFLECTION AND ANGULAR ROTATION

When lateral deflection and angular rotation are present, the loads imposed on an intermediate anchor will vary with each individual application, since they are dependent upon the piping configuration, the number and type of supports, the lengths of the various pipe legs, the types of Expansion Joints used, the weight of the pipe, fittings, insulation and flowing medium, and the magnitude of extraneous forces imposed by wind loading, bending of the piping, etc. Because of the large number of variables involved, it is not practical to establish formulas for calculating the loading of these anchors. Section 4.6 describes the methods used in calculating the forces and moments required to move Expansion Joints in lateral deflection or angular rotation and Section 2.2.1 gives a general description of the forces and moments which will be imposed on the anchors for certain typical Expansion Joint applications. Using this information as a guide, one can calculate the various forces and moments acting on any piping system, regardless of its complexity. The net load on the anchor can then be calculated by a summation of the moments about the anchor point and by the vector addition of all forces acting upon it.

2.10.1.2 MAIN PIPE ANCHORS

A main anchor is one which is installed at any of the following locations in a piping system containing one or more unrestrained Expansion Joints: (a) at a change in direction of flow, (b) between two Expansion Joints of different size installed in the same straight run, (c) at the entrance of a side branch containing an unrestrained Expansion Joint into the main line, (d) where a shut-off or pressure reducing valve is installed in a pipe run between two Expansion Joints, and (e) at a blind end of pipe.

A main pipe anchor must be designed to withstand the forces and moments imposed upon it by each of the pipe sections to which it is attached. In the case of a pipe section containing one or more Expansion Joints, these will consist of the full line thrust due to pressure and flow, the forces and/or moments required to deflect the Expansion Joint or Joints the full rated movement, and the frictional forces due to pipe alignment guides, directional anchors and supports. In certain applications, it may be necessary to consider the weight of the pipe, fittings, insulation and flowing medium, as well as various other forces and moments resulting from wind loading, bending of one or more pipe sections, etc. The net loading on the anchor can be calculated by a summation of the moments about the anchor point and by the vector addition of all forces acting upon it.

2.10.1.2.1 CALCULATION OF MAIN ANCHOR LOADS FOR APPLICATIONS INVOLVING STRAIGHT PIPE SECTIONS CONTAINING A BRANCH LINE (See center anchor in Figure 2.3)

$$F_s = A_e P_d \quad (2-2)$$

where:

F_s = The static thrust due to pressure in the Expansion Joint, lbf (N)

The forces F_m and F_{pg} may be calculated as outlined before for an intermediate anchor. Then, assuming that the weight of the pipe line and its contents is carried by supports; the total force imposed on the main anchor F_{ma} by any one pipe section will be:

$$F_{ma} = F_s + F_m + F_{pg} = A_e P_d + F_m + F_{pg} \quad (2-3)$$

To determine the net load on the anchor, it is necessary to add vectorially the forces imposed upon it by each of the three pipe sections to which it is attached.

2.10.1.2.2 CALCULATION OF MAIN ANCHOR LOADS FOR APPLICATIONS INVOLVING STRAIGHT PIPE SECTIONS CONTAINING EXPANSION JOINTS OF DIFFERENT DIAMETERS (See center anchor in Figure 2.4)

$$F_{s1} = (A_{e1} - A_{e2}) P_d \quad (2-4)$$

where:

A_{e1} = Bellows effective area of large pipe section, in.² (mm²)

A_{e2} = Bellows effective area of small pipe section, in.² (mm²)