## DESIGN OF BELLOWS

The bellows is the flexible element of an expansion joint consisting of one or more convolutions and the end tangents. This element is designed to absorb thermal movements that result from a change in temperature in a piping system. A bellows may also be designed to absorb mechanical movements. The number of convolutions in a bellows is a direct relationship to the amount of thermal or mechanical movement in the piping system, and/or the force necessary to achieve this deflection.

The bellows is a very unique component of a piping system. It must be designed strong enough to accommodate the system design pressure, as well as, flexible enough to accept the design deflections for a calculated number of occurrences, with a minimum resistive force.

The system pressure and deflection create the major stresses in a bellows. Typically the deflection stresses are higher than the pressure stresses and are meridional or longitudinal in direction. These stresses are calculated and evaluated in the Standards of the Expansion Joint Manufacturers Association, Inc. or EJMA.

The pressure stresses include circumferential (hoop) stress in the bellows tangent as well as the convolutions. EJMA defines the bellows tangent membrane stress due to pressure as $S_1$. The bellows circumferential membrane stress due to pressure is designated as $S_2$ in the EJMA calculations. The tangent stress ($S_1$) and circumferential bellows stress ($S_2$) must not exceed the maximum allowable stress, which is set by code or the customer's specification.

There are also meridional pressure stresses that are evaluated in the design of a bellows. The bellows meridional membrane stress due to pressure is designated as $S_3$ in the EJMA calculations. The other meridional stress that is evaluated in EJMA is the bellows meridional bending stress due to pressure, or S4. If these meridional stresses are exceeded, the convolution sidewall will be overstressed and this will lead to bellows failure.

EJMA uses a "Combined Stresses" technique to evaluate the approximate cycle life of a bellows. The stresses involved are recorded in EJMA as $S_5$, $S_6$ & $S_t$. A cycle is defined as one complete movement, at pressure and temperature, from the initial position of the bellows, to the operating position, and back to the initial position. Factors that affect the fatigue life of a bellows are, operating pressure, operating temperature, bellows material, movement per convolution, bellows thickness, convolution pitch, convolution height and shape, and bellows heat treatment. Based on the evaluation techniques in EJMA, it is possible to predict the cycle life of a bellows rather than cycling to failure.

Utilizing the above stresses and evaluation techniques, it is possible for the bellows designer to provide the optimum bellows design that will handle the system pressure, remain stable, and provide a satisfactory service life.

## BELLOWS SQUIRM

A bellows that is subjected to increasing internal pressure will reach a critical pressure at which the bellows becomes unstable or *squirms*. This condition is very detrimental to the bellows function and can in some cases lead to catastrophic failure. It is the bellows designer's duty to design a bellows that will remain stable under design conditions as well as test conditions. An expansion joint can be pressure tested to assure that the unit will not squirm in service. The standard pressure test is performed at one and a half times the operating pressure. This pressure test is not mandatory per EJMA, therefore, the customer must specify if this test is required. There are two types of squirm, *column squirm* and *in-plane squirm*. It is the responsibility of the piping system designer to provide adequate anchoring, supporting, and guiding of the system in accordance with EJMA standards and good engineering practice. This will assure stability of the piping system including the bellows.

*Column squirm* is the condition in which a bellows exhibits an arch or curvature in its centerline. This condition is mainly associated with bellows that have a relatively large length-to-diameter ratio. This condition can also be exaggerated by a bellows that is subjected to lateral offset or angulation. This type of squirm is somewhat similar to the buckling of a loaded column. The EJMA calculation for squirm is based on the ends of the pipe run being rigidly anchored and the piping being properly guided per EJMA.

*In-plane squirm* is the condition that occurs when one or more individual convolutions of a bellows shift or rotate out of the plane perpendicular to the bellows longitudinal axis. This condition may seem like a tilting or warping of one or more convolutions. This squirm condition is mainly associated with high meridional bending stresses.

## BELLOWS PRESSURE THRUST

Pressure thrust is an often misunderstood characteristic of applying a bellows to a piping system. The pressure thrust force is the result of the internal system pressure multiplied by the bellows effective area. This catalog provides the effective area for each bellows design. The system designer must account for the pressure thrust force, and in the case where an expansion joint is to be installed in the piping system, this pressure thrust force warrants special consideration. The main concern is the fact that the bellows is a flexible component of the system. Because of this flexibility, the bellows has a tendency to elongate as the pressure is increased, unless the piping is anchored and guided properly. If the ends of the expansion joint are not restrained, this force is only resisted by the bellows spring rate. In most applications, the bellows spring force is considerably less than the thrust force. This can be visualized by capping the ends of the bellows and pressurizing the inside. In order to restrain the bellows from extending due to the internal pressure, the piping system must be anchored at the ends or if there is a change of direction, at the elbow. This analogy applies to a simple straight pipe run with a Single Expansion Joint. In the case of more complicated piping layouts where it is not practical to separate the piping into simple straight runs, the expansion joint can be designed with restraint hardware such as tie rods, hinges, or gimbal rings. These hardware items restrain the pressure thrust force. Unless an In-Line Pressure Balanced Expansion Joint is used, this hardware will also restrict the bellows from accepting axial movement. In the case of an expansion joint that is specified with tie rods and axial compression, this pressure thrust force must be overcome before the bellows will compress, and as the bellows compresses the unit is no longer tied or restrained.

## PRESSURE THRUST RESTRAINT DEVICES

### ANCHORS

In order to properly restrain the pressure thrust loads of a piping system with an expansion joint installed, a number of devices may be used. The most basic is the main anchor of the piping system. The pipe anchor is used to divide a pipe line into individual expanding sections. These pipe anchors limit and control the amount of movement that an expansion joint must absorb. Major equipment such as turbines, pumps, compressors, heat exchangers, and reactors may function as anchors, but the equipment design must consider all loading. Other pipe anchors are typically located at valves, changes in direction of the pipe, blind ends of the pipe, and at major branch connections. In some cases, a directional anchor may be used in a pipe run to restrain the piping in a particular direction, but allow the pipe to deflect in another direction.

### HARDWARE

Another method of restraining pressure thrust is to add hardware to the expansion joint. This can be done with a number of different devices, the most common being Tie Rods or Limit Rods. Tie rods and Limit Rods are designed to restrain pressure thrust forces in Single, as well as, Universal Expansion Joints. They are also used in special cases such as Pressure Balanced Expansion Joints. Other restraint devices include Hinge and Gimbal hardware. All these hardware items can be used in a variety of different applications and each has its own limitations. Please review **"Expansion Joint Types",** on pages 6 thru 8 for further discussion on these devices and how they are applied to an expansion joint.

## PIPE GUIDES

Proper alignment of the adjoining pipe is of essential importance to the correct functioning of an expansion joint. In order for the expansion joint to provide the expected service, the pipe line must have the recommended number of guides and should be anchored and supported in accordance with good engineering practice. Pipe guides are required to insure proper application of movement to the expansion joint and to prevent buckling of the line. Planar pipe guides may be used in situations where the pipe should be allowed to deflect in a particular direction but the thermal growth should still be directed into the expansion joint. The first two pipe alignment guides adjacent to the expansion joint should be circumferential to the pipe.

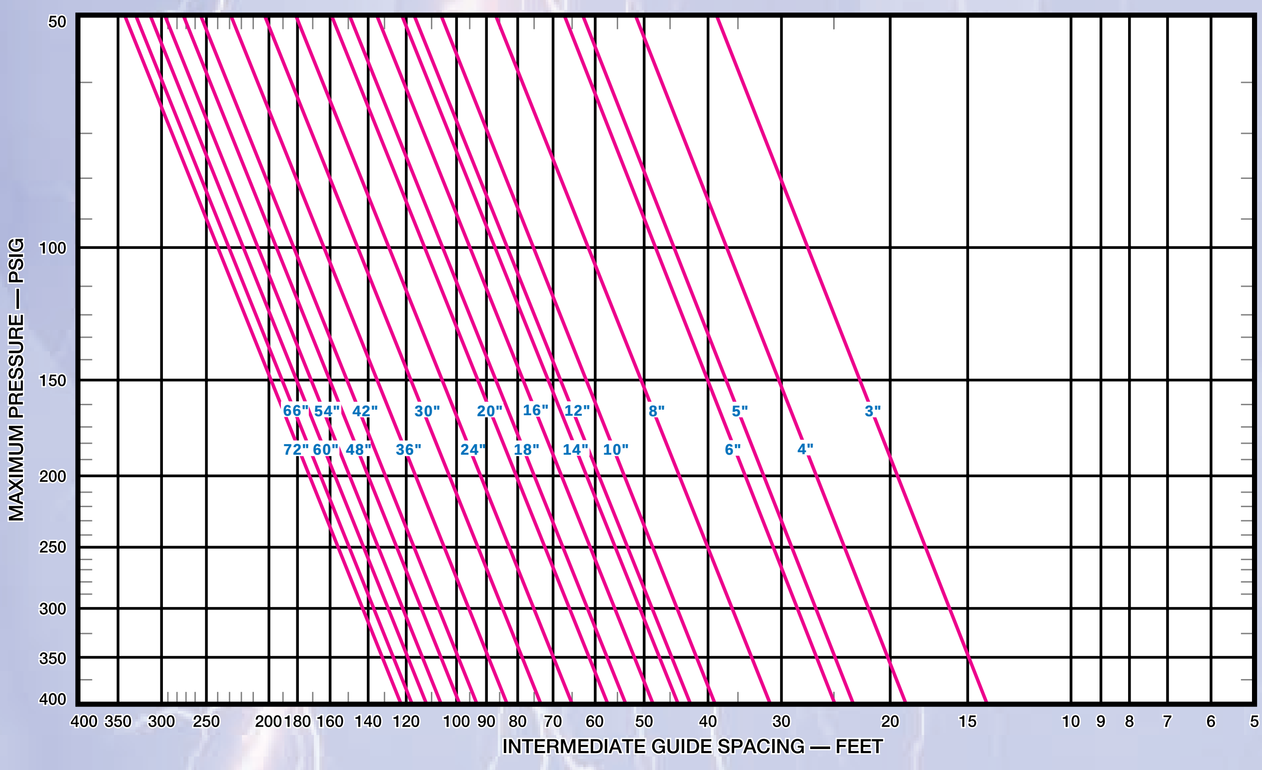
For applications involving axial movement only, it is typically recommended that the expansion joint be located close to the anchor and that the first pipe guide be located a maximum distance of four (4) pipe diameters from the end of the bellows. The second pipe guide must be located a maximum of fourteen (14) pipe diameters from the first pipe guide. The recommended maximum spacing of intermediate pipe guides along the balance of a standard weight, carbon steel pipe line, can be determined by the chart below.

Maximum intermediate guide spacing for any pipe material or thickness can be calculated using the following formula:

$$L = 0.131 \sqrt{\frac{EI}{PA \pm xR}} \quad \text{(ft)}$$

L = Maximum intermediate guide spacing (ft).
E = Modulus of elasticity of pipe material (psi).
I = Moment of inertia of pipe ($In^4$).
P = Design pressure (psig).
A = Bellows Effective Area ($In^2$).
x = Axial movement of Expansion Joint (in).
R = Axial Spring Rate of Bellows (lb/in).

Note: When a bellows is compressed in operation use (+) x R; when extended, use (-) x R.



## BELLOWS DEFLECTIONS

The bellows, as stated previously, is a flexible element designed to absorb deflections in piping systems. These deflections may be a result of thermal expansion, or movements and vibrations of equipment and structures. With the proper placement of anchors and supports in a piping system, the application of expansion joints can be evaluated, and the types of deflections specified to the manufacturer.

### AXIAL

This is the most common type of bellows deflection and is simply the dimensional change of the bellows along its longitudinal axis. This axial movement is typically a shortening of the bellows or *COMPRESSION*. This compression of the bellows would occur as the piping heats up and expands. Another type of axial movement in a bellows is the elongation of the bellows or *EXTENSION*. Extension would occur for example in a cryogenic system in which the piping would contract as the temperature drops.

### LATERAL

This type of bellows deflection is the relative displacement of the bellows ends perpendicular to its longitudinal axis. This type of displacement occurs with the bellows ends remaining parallel to each other and can occur in more than one plane. If lateral deflection does occur in more than one plane, a resultant is calculated and used in the bellows evaluation. This movement in multiple planes should be evaluated with respect to cycle life and hardware orientation. *PARALLEL OFFSET* and *TRANSVERSE* are other common terms for lateral deflection.

### ANGULAR

This type of bellows deflection is the displacement of the longitudinal axis of the bellows into a circular arc about its center and at its midpoint. This deflection may also occur in a number of planes and should be properly evaluated with respect to cycle life and hardware orientation. *ROTATIONAL MOVEMENT* is another term for angular deflection or rotation. This is not to be confused with torsional rotation.

### TORSION

This type of bellows deflection is the twisting of one end of the bellows with respect to the other end, about the bellows centerline. Due to the extremely high shear stresses produced by this type of deflection, it is usually advisable to provide the piping system or expansion joint with restraints or hardware that will relieve the bellows of this torsional load.

### CONCURRENT

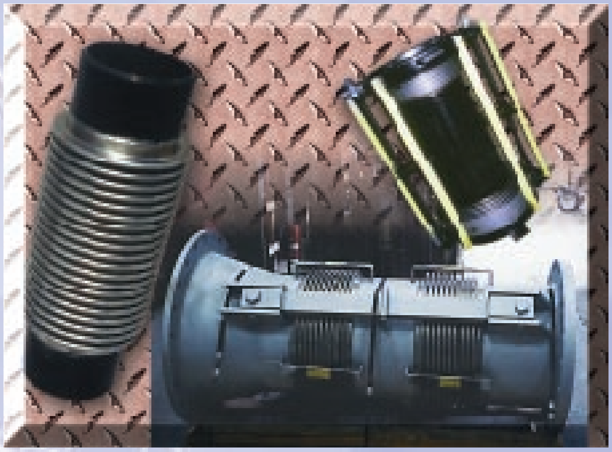
The movements shown in this catalog are based on any one type of movement occurring alone. This movement condition is known as non-concurrent or rated movements. In most expansion joint applications there can be a combination of movements that occur simultaneously or concurrently. This could be an expansion joint that is subjected to axial movement in combination with a lateral offset. In this case, the selection of the proper expansion joint can be best determined by the bellows designer who can evaluate the effect of these movements and provide the optimum bellows design.

### VIBRATION

Metallic bellows can be designed to accommodate system vibration as a result of pumps, fans, or other rotating equipment. If the rotational speeds or frequencies of the equipment are specified, the bellows designer can evaluate the bellows and assure that it does not have a resonant or harmonic frequency that is in a range that will cause premature bellows failure.

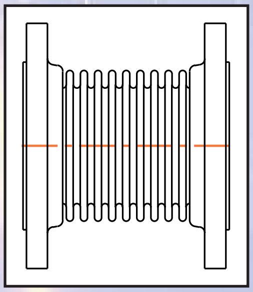
### INSTALLATION MISALIGNMENT

Expansion Joints can be designed with an installation misalignment included. This type of movement is typically a one-time occurrence at installation of the unit and can be a combination of any of the previous types. If a misalignment is not included in the expansion joint design or evaluated by the manufacturer, the expansion joint should not be used to make up for imperfections in the piping and equipment locations. All expansion joints are shipped with rigid restraints for shipping and installation purposes. If the expansion joint is required and specified to accept some installation misalignment, devices such as limit rods can be installed to allow adjustment. A unit can also be preset at the factory to accommodate a specified misalignment.



## EXPANSION JOINT TYPES

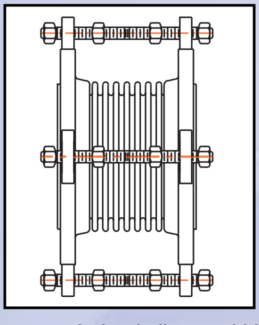
### SINGLE UNRESTRAINED EXPANSION JOINT



This is the simplest expansion joint available and consists of a single bellows element and end connections. This expansion joint will deflect in any mode listed under **Bellows Deflections,** and is usually the first considered in system design. The Single Unrestrained Expansion Joint will require the most control of the adjacent piping with respect to anchors and guiding. The Single Unrestrained Expansion Joint will not control the movement of the piping in any direction. Proper anchoring and guiding must be used to control the piping and restrict the movement to only that specified for the expansion joint design. This expansion joint will not resist deflections with any force other than the spring force of the bellows. This expansion joint will not resist the pressure thrust force along the axis of the bellows. This force must be handled by the use of main and directional anchors.

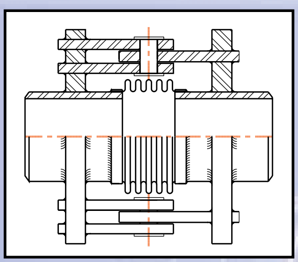
# EXPANSION JOINT TYPES (cont.)

## SINGLE TIED EXPANSION JOINT



This expansion joint type has the same characteristics of the Single Unrestrained Expansion Joint except the tie rod hardware has been added. The tie rods are designed to restrain the system pressure thrust and prevent the bellows from over-extending. This expansion joint is not usually designed to allow axial movement. In the case of a tied unit with axial movement, the rods function as limit rods with the stops set to allow axial movement of the bellows within a specified limit. The Single Tied Expansion Joint can be designed to accept lateral movement in any plane, as well as, angular in a single plane. The angular deflection can be accommodated with a two tie rod design.

## HINGED EXPANSION JOINT

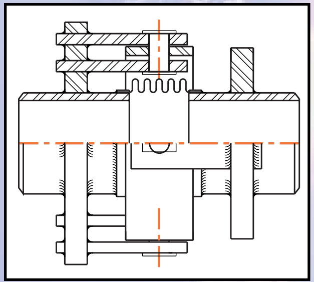


This expansion joint contains a single bellows element and is designed to permit angular rotation in one plane only, by utilizing a pair of pins through hinge plates that are attached to the expansion joint ends. The hinge hardware is designed to restrain the pressure thrust load, as well as, any additional customer specified external loads. The hinge hardware is rigid in the axial direction, therefore, the expansion joint is not able to accept axial movement. In a piping system application, the Hinged Expansion Joint is typically used in pairs or threes, or in combination with the Gimbal Expansion Joint. With the hardware restraining the pressure thrust loads, the anchor and support requirements are greatly reduced from the requirements for the Single Unrestrained Expansion Joint.

## SLOTTED HINGED EXPANSION JOINT

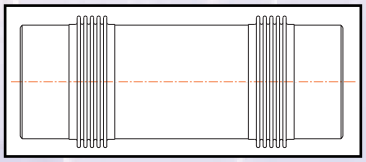
This expansion joint is identical to the Hinged Expansion Joint except that it is designed to allow a specified amount of axial travel. This axial movement is accommodated by a slotted hole in the hinge plate, which allows a limited amount of compression and or extension of the bellows. The Slotted Hinged Expansion Joint, of course, does not restrain the pressure thrust forces while it is allowed to move axially. Only after the pin has reached its maximum and bottomed out will the pressure thrust be restrained, therefore, the system must be properly anchored and supported.

## GIMBAL EXPANSION JOINT



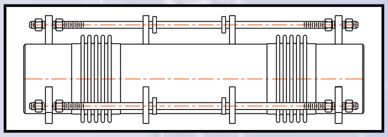
This expansion joint contains a single bellows element and is designed to permit angular rotation in any plane, by utilizing two pairs of hinges connected to a common central floating ring or box. The Gimbal Expansion Joint provides the same restraint to axial deflection and pressure thrust as the Hinged Expansion Joint. This expansion joint functions in much the same fashion as the drive shaft universal joint on most automobiles. The Gimbal Expansion Joint is typically used in pairs or threes, or in combination with the Hinged Expansion Joint.

## UNIVERSAL EXPANSION JOINT



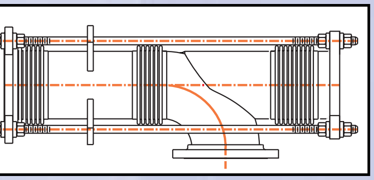
This expansion joint contains two bellows elements separated by a center pipe section or spool. This type of arrangement provides a design that can accommodate large amounts of lateral deflection. The amount of lateral deflection is dependent on the amount of angulation each element can absorb and the distance between the bellows. The Universal Expansion Joint can also accept axial and angular movements in addition to the lateral. This expansion joint does not have restraint hardware to resist pressure thrust, and must be treated similar to the Single Expansion Joint and properly anchored and supported. The Universal Expansion Joint design should also consider the thermal movement of the center pipe section.

## TIED UNIVERSAL EXPANSION JOINT



This expansion joint has the same characteristics of the Universal Expansion Joint except the tie rod hardware has been added. With the addition of the tie rods to restrain pressure thrust, the expansion joint will not accept external axial movement without overcoming this pressure thrust force. However, the thermal expansion between the tie rods (within the expansion joint) shall be accommodated by the bellows elements. If more than two tie rods are used to restrain pressure thrust, the unit will not accept angular rotation. If only two tie rods are used at 180 degrees apart, the unit can deflect angularly as well as laterally. In many cases, the Tied Universal Expansion Joint is installed between two elbows in a piping system. In order to minimize the effect of deflection of the elbows, the tie rods are often installed on the elbow centerlines.

## PRESSURE BALANCED (ELBOW) EXPANSION JOINT



This expansion joint is a unique design that not only restrains the pressure thrust, but also balances this thrust force so that main anchoring of the pipe and adjacent equipment is not necessary. The result is that the forces and moments on the nozzle connections of delicate equipment such as pumps and turbines are kept below the allowable loads. This expansion joint is used in cases where a Tied Expansion Joint is required to accept axial movement while restraining pressure thrust. The Pressure Balanced Expansion Joint can be designed as a single, or a universal if large amounts of lateral movement are required. The Pressure Balanced Expansion Joint is normally used at a change of direction in the piping, and the elbow is mounted between the line or flow bellows and the balancing bellows. The line bellows and balancing bellows have the same cross-sectional area and are connected by tie rods that restrain the pressure thrust. As the line bellows compresses, the tie rods force the balancing bellows to extend an equal amount and the elbow between the two is free to move axially with only the resistance of the spring rates of the bellows. The axial spring rate of the expansion joint is the sum of the spring rate of the line bellows and the balancing bellows. However, the lateral deflection and spring force of the expansion joint is only a function of the line bellows, whether it is a single or universal, and the balancing bellows is not subject to the lateral deflection.