Expansion Joints:

How thermal expansion solutions can become big pressure problems

Almost all industrial facilities—whether process, power, manufacturing or research— have at least one and often many expansion joints to provide engineered solutions for issues such as thermal expansion, piping fit-up, equipment nozzle loads and vibration isolation. Sometimes they are a last resort. Other times, they are widely accepted as an extra means of safety or protection from problems like those listed above. There is an issue across industry concerning a lack of understanding about how expansion joints work and, more importantly, how they are affected by pressure.

The author has encountered some extremely experienced people who have not fully grasped how pressure thrust can affect expansion joints—from engineers and scientists at national laboratories to NASA staff to plant managers. One of the worst examples of an expansion joint-caused incident was an industrial accident in 1974 that killed 28 people. Most of the accident analysis in that case focused on management of change; however, if engineers on the plant floor up through management are not aware of the issue, how can proper management of change expect to catch it or resolve it?

This white paper will examine the basic design principle of pressure thrust and how expansion joints affect it, look at examples of improper expansion joint use, and detail the advantages and disadvantages of different types of expansion joints. The paper will conclude with three takeaways that will grow your understanding of expansion joints and when and how to use them safely.

Pressure Thrust Design Principle

Normally, pressure piping is in tension from the internal pressure. The longitudinal stress (SL) associated with pressure can conservatively be estimated as SL=PD/4t. It does not matter whether the piping is in a refinery, power plant or any other facility, nor does it matter what fluid or gas is in the piping, the pipe will be in tension from any positive pressure unless we add an expansion joint.

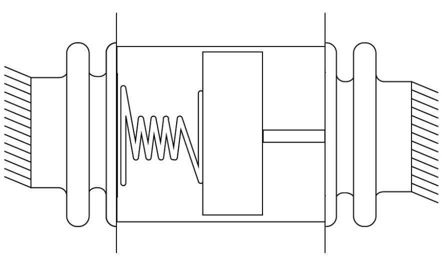
P = Design or pressure being evaluated
D = OD (Outside diameter of the pipe, which is a conservative assumption)
t = Wall thickness available

Once an expansion joint is put into the system, the pipe wall is no longer available to take this longitudinal stress, and the piping and restraints are now exposed to a pressure thrust equal to the design pressure (or pressure being evaluated) times the effective thrust area of the expansion joint. This may be conservatively estimated as PD^2. For a 20-inch pipe at 150 per square inch gauge, this thrust becomes 60,000 pounds trying to blow the ends of the pipe apart. The piping is also no longer in tension, but somewhat in compression and, therefore, column buckling is also a concern. Figure 1 from the Pathway Expansion Joint Catalog shows how you must look at an expansion joint. You should keep in mind that the expansion joint was added to take care of thermal expansion or some kind of displacement and has a significant effect on the pressure design of the piping system.

This concept is difficult for some people to grasp as they try to figure out where the thrust is coming from (see figure 2). Some of it is occurring right at the joint. It is the internal pressure pushing on the metal area of the pipe and on the wall of the expansion joint. The rest of the internal pressure is much harder to identify. It is acting on the internal area of the pipe, which is calculated by πr^2. As you look at the pipe, there is nothing along the axis of it for the pressure to act on, so it goes down the line in both directions until if finds something to act on. This area will be an elbow, tee or maybe a piece of equipment, but it will be there and the pressure will try to push the affected area away from the expansion joint.

FIgure 1 - Pressure Thrust for SIngle Bellows: For the purpose of understanding pressure thrust, a single bellows designed for pure axial motion can be modeled as hydraulic cylinder with a spring inside. Force on equipment or adjacent piping anchors:

F+ (the effective area of the bellows) x (the working pressure) + (the spring rate of the bellows) x (the stroke of the bellows)
The spring represents the axial spring rate of the bellows. The hydraulic piston represents the effect of the pressure thrust which the expansion joint can exert on the piping anchors or pressure thrust restraints (hinges, gimbals, tie rods) which may be part of the expansion joint assemply.



Working pressure acting on the effective area of the bellows

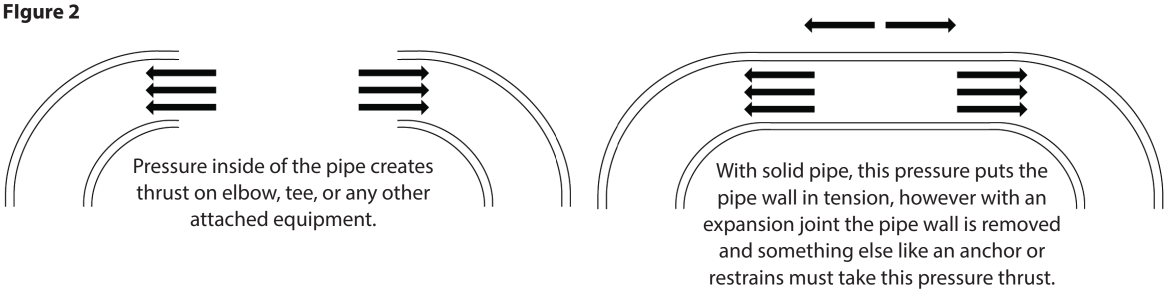
The are of the hydraulic cylinder would be the effective area of the bellows. For a 20", 150 psig catalog standard expansion joint with 20 convoltions, the spring force for 1" of axial stroke would be:

(the axial motion) x (the spring rate of the bellows)
or 1inch x 1521lbs/inch=1521lbs.

The pressure thrust force would equal:

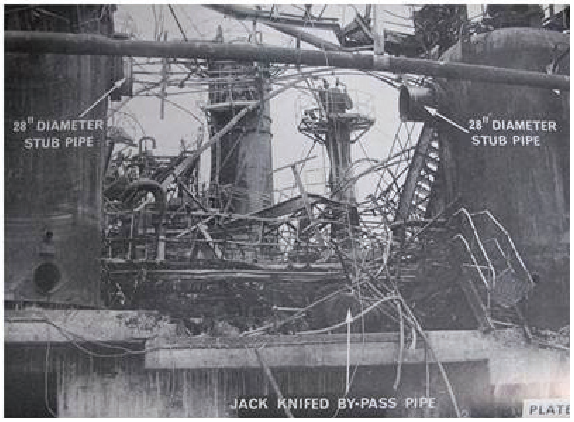
(the working pressure) x (the bellows effective area)
or (150 lbs./inch^2) x (359 inch ^2) = 53,850 lbs.

FIgure 2



How Lack of Pressure Thrust Understanding Can Cause Issues

FIgure 3



Reproduced with permission from the U.K. National Archives

The following examples show how, either in design or maintenance activities, the concept of pressure thrust has not been understood and unfortunately has resulted in significant loss of life.

The worst example came when the author was just starting his engineering career in 1974, working on a sister plant to the one that was destroyed in Flixborough, United Kingdom (see figure 3). A series of six reactors were designed and built with expansion joints between each. Site staff installed a temporary 20-inch piping spool piece (see figure 4) to remove one of the six reactors for repairs. Twenty-eight people were killed and many more injured in the explosion that followed. Many of the accident reports blame lack of change control; however, it is the author's opinion that the culprit was misunderstood pressure thrust. Pressure thrust was always present, but the difference was that the reactors were stable and could take the pressure down to the foundation. The spool piece was not stable and, therefore, buckled either out or up (see figure 5).

FIgure 4: Arrangement of 20" pipe scaffodling (as deduced from the evidence)

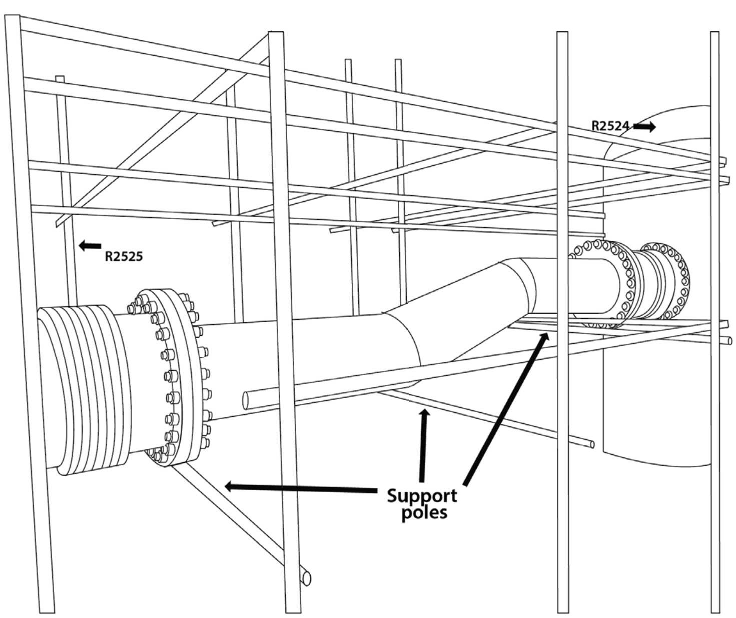
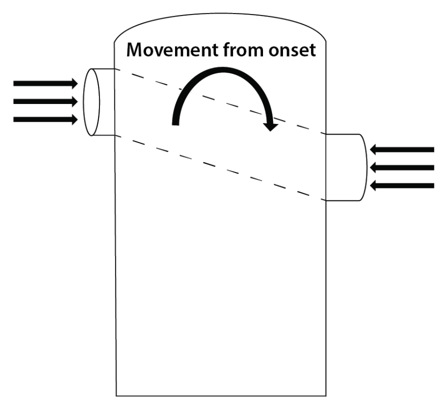


FIgure 5



Pressure thrust on reactor at Flixborough created a moment which was easily carried by the foundation of the reaction, however when it was replaced by the spool shown dotted, the moment created by the offset load made the spool kick up off the scaffolding

Figure 6

Figure 7

Figure 8

Figures 6 and 7 show another example of pressure joint failure from a different facility. Figure 6 shows how pressure thrust deformed the bellows above the platform. Figure 7, taken just below the platform, shows the support—which was supposed to be strong enough to hold the weight of the piping—and the pressure thrust from the joint. As this example shows, the pressure thrust was stronger than support design. The author does not know the exact design conditions, but the following approximation shows how quickly pressure thrust can develop loads much greater than just the piping weight:

- Section modulus W4x13 = 5.5 in3
- Moment arm = 36”
- 35,000 lbs. yield

Load of approximately 5,000 lbs. would fail this support structure. With a pressure thrust area of 360 in2, the pressure would be about 15 lbs. per square inch. The pressure in this pipe and vessel were obviously much higher.
Note the support failure caused by pressure thrust in figure 7. The support steel is very small compared to the size and pressure of the bellows.

Finally, figure 8 shows a relativistic heavy ion collider at Brookhaven National Lab in New York. Pressure thrust here caused 4-inch piping with an expansion joint to become unstable and buckle. This instance was very similar to the failure at Flixborough, except the piping was limited by other internals, which prevented a rupture in the liquid helium line. This buckling occurred at seven different locations around the collider.

Unfortunately, there are many more examples of where expansion created pressure thrust havoc. While change management is important to any facility modification, it is clear that to limit expansion joint accidents, the industry needs a further commitment to good, relevant technical training.

Selecting the Right Expansion Joint and Using it Properly

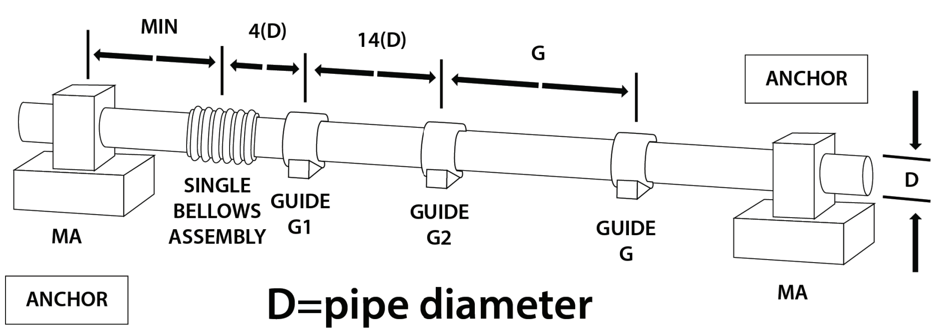
Once you understand the design principles behind pressure thrust and how expansion joints affect it, you will be in a better position to select and incorporate an expansion joint when it is needed. The following table lists the advantages and disadvantages of available expansion joint options:

Type of Expansion Joint	Advantages	Disadvantages
Bellows **EJMA – Expansion Joint Manufacturers Association**	• No packing leaks • Inexpensive • Custom fabrications can be done quickly • High Temperatures • Many Control Options	• Pressure Thrust • Cannot Take Torsion • Limited Pressure to generally below 300 psig
Slip or Packed	• High Pressure • Allows Torsion • Limited Stop on Movement Slightly Less Pressure Thrust	• Expensive • Alignment is critical • Packing Can Leak
Ball	• High Pressure • No Pressure Thrust • Allow Torsion	• No Axial Movement • No Lateral Movement • Expensive • Packing Can Leak
Fabric	• Flexible • Inexpensive • Square or Round • Large Sizes	• Low Pressure < 1 psig • Temperature Limits • Not Applicable to Pressure Piping (15 psig)
Flanged and Flued (usually limited to Heat Exchangers)	• High Pressure	• Very Stiff

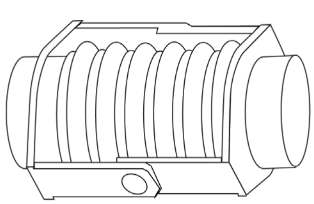
LOUIS PERRY GROUP
A CDM SMITH COMPANY
CDM Smith

Rubber	• Abrasion Resistance • Vibration Isolation	• Temperature Limits • Some Code Limits for Non-Metals like Flammable Fluids.
Teflon	• Flexible • Vibration Isolation	• Temperature Limits • Some Code Limits for Non-Metals like Flammable Fluids.
Victaulic Couplings	• Inexpensive • Easy to Assemble	• Seals Can Leak • Limited Movement • Limited Temperature

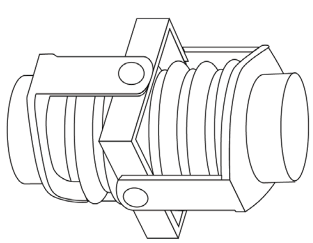
Here's an example of a simple design that incorporates an expansion joint and is engineered to properly handle pressure thrust. A benefit of this basic design is that is does not require piping analysis software to analyze loads.



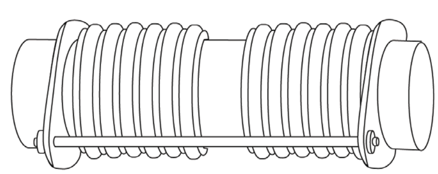
Incorporating the right hardware is key. Once hardware is used, expansion joints can no longer take axial movements. Here are some examples of safe hardware configurations.



Hinged Expansion Joint

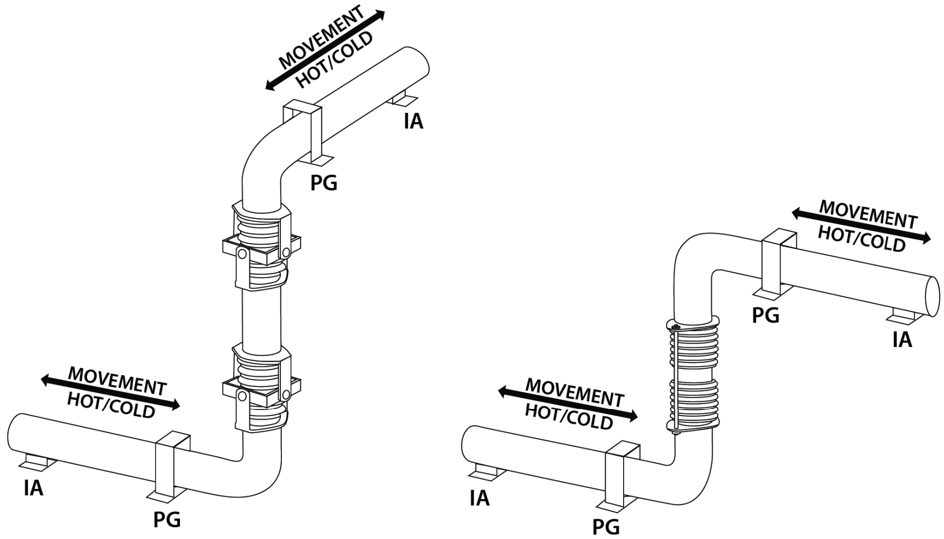


Gimbaled Expansion Joint



Tie Rods or Universal Expansion Joint

Typical piping arrangements for Expansion Joint with Pressure Control Hardware.



Summary

In summation, here are three key takeaways from this white paper:

1. Calculate your pressure thrust. The minute you add an expansion joint to your system, you need to do the math to limit any potential issues.
2. Confirm the reason you are using a joint. What problems are you trying to solve? If you are thinking about an expansion joint, you should likely be thinking about loads on equipment, vibration or piping fit-up.
3. Know your layout options. It is key to have your layout plan conceived well in advance, ensuring that pressure thrust and thermal expansion can be handled properly.

Jim E. Meyer, PE, *is a principal engineer at the Louis Perry Group, a CDM Smith Company. He has more than 40 years of experience in refining petrochemical, chemical, power generation and industrial facilities. Jim is an expert in American Society of Mechanical Engineers (ASME) piping and pressure vessel codes, stress analysis and field troubleshooting piping system support, vibration and expansion problems. Jim is also experienced in project management, pressure equipment, piping design, analysis, specifications, support design, mechanical system and documentation requirements. He has been a member of ASME for more than 35 years and chairs the ASME B31.3 Process Piping Section Committee and ASME B31 Pressure Piping Standards Committee.*