Expansion Joints for Fluid Catalytic Cracking Units
Expansion joints used in FCCU service are some of the most critical and complex types of expansion joints manufactured. For this reason, the choice of manufacturer should be carefully considered. These expansion joints are exposed to high temperatures (1400°F), high pressures, large movement conditions, and aggressive media. Great attention and expertise is required in designing the bellows and hardware to ensure that the units perform well in service. Failure of FCCU expansion joints during operation can be extremely hazardous to personnel and very expensive to the user.

Today’s predominant specification for FCCU joints is the UOP Specification. This specification provides the basis for the bellows and related expansion joint hardware design. In addition to the UOP specification, EJS has experience with many other FCCU expansion joint specifications created by engineering companies and refiners worldwide. This technical guide relates mainly to the UOP specification. Please contact EJS for information about other FCC specifications that we also work with.

There are various types of expansion joints used in FCCU applications: Tied Universals, Hinge, Gimbal and Pressure Balanced. All of these fall into one of three major categories: Cold Wall, Hot Wall, and Unlined FCCU joints that will be discussed later in more detail. The bellows membrane design for all three categories is basically the same; although the bellows membrane can be single ply, multi-ply, redundant ply or reinforced.

The Bellows Membrane

Today the material of choice for most FCCU applications is Inconel 625LCF (low cycle fatigue). Almost identical to the original Inconel 625, this special bellows grade of Inconel 625 that was introduced in 1990, provides tighter controls over the carbon, silicon and nitrogen contents. This produces a microstructure that enhances low-cycle fatigue.
Bellows are subject to high bending stress well into the plastic range to achieve the movements required by the thermal expansion of the system. The finished bellows should be uniform in shape and pitch with no forming scratches or heavy tooling marks.

Various performance analysis calculations are used to determine the theoretical life expectancy for a given design. EJMA (Expansion Joint Manufactures Association) is the predominant standard used. The expansion joint manufacturers who make up EJMA are today’s leading authorities on expansion joint design.

The bellows forming process introduces work hardening into the bellows that for the majority of applications is acceptable. This work hardening increases the bellows’ ability to withstand pressure however; it reduces the cycle life of the bellows. (EJMA cycle life formula is based on as formed bellows). If the bellows is annealed after forming, the reduced pressure capability needs to be taken into account. FCCU bellows are often designed to work at elevated temperatures well into the creep fatigue range of the material. To reduce the creep fatigue effect, some specifications call for the bellows to be annealed, or solution annealed, after forming. As most FCCU bellows are designed to absorb large movements, beginning with a completely annealed bellows is usually advantageous.

Types of FCCU Expansion Joint

There are three major types of FCCU expansion joints: hot wall, cold wall, and unlined.

- **Hot Wall**

These joints usually have some form of abrasion resistant lining, comprised of hex-mesh and castable material. Resco AA-22® is a common abrasion resistant material. The lining is designed to withstand the abrasion from the catalyst flowing through the unit in service. The lining requires a thermal dry out after installation.

The lining is not intended to be used as a thermal barrier; therefore the shell temperatures of the expansion joint rise above the allowable temperatures for normal carbon steels. The joint shells are normally manufactured from various Chrome-moly alloys and stainless steels. Due to
their trademark conical sections near the bellows area, hot wall expansion joints are easily visible. The oversize bellows allows for a smooth flow across the bellows area using a straight through liner arrangement.

Cold wall joints as their name suggests are refractory lined to ensure the shell wall temperatures does not exceed 650°F. The lining consists of stainless steel anchors and a high-density vibrocast refractory material. Depending on service condition, the thickness ranges from 4” to 8”. Again, the final process involves a thermal dry out before operational service.

The photograph above shows the stainless steel anchors prior to vibrocasting the refractory. The internal surface will be blasted to near white and casting forms fitted internally to hold the wet refractory in place until it cures. The finished unit is shown here. This expansion joint has been thermally dried and the lining process is now complete. After the unit is installed the remaining refractory will be added onsite.

Cold Wall
• **Unlined**

Unlined FCCU expansion joints normally do not carry catalyst in the media, although the temperatures can be extremely high. Unlined joints are used for inlet air, outlet air, and transferring gases from the reactor, etc. These joints are still required to accept large movements and are designed with the same hardware as lined expansion joints.

Unlined joints are manufactured from various shell materials dependent upon the service temperature and media conditions. Lower temperature and less severe service applications utilize the higher-grade carbon steels. In more severe conditions, stainless steel, and occasionally, high nickel alloys are used. The unit shown above is a 66" diameter unlined tied universal incorporating equalizing hinges for the high lateral movement. The shell material is A516-70 fabricated to ASTM specification 672.

**Design Considerations and Explanations**

• **Packed and Purged Bellows**

When the expansion joint is carrying catalyst, the fines and dust can collect under the bellows. The catalyst can solidify and destroy the bellows membrane or inhibit the joint movement capability. The problem exists irrespective of installation position, however the more the joint moves towards a vertical flow up position, the easier it is for the catalyst to fill the void between the bellows and liner (bellows annulus). There have been various methods used to stop catalyst ingress into the annulus. The two predominant methods used today are:

- Packed bellows
- Purged bellows

By far the most common is the packed bellows. A packed design incorporates a ceramic insulation pillow filling the annulus and a catalyst seal between the liner faces.

It is very difficult to see the liner seal after assembly of the unit.
The drawing below is a typical liner seal arrangement. Usually the type and placement of the seal is indicated on the individual specification for the expansion joint.

Packing the annulus of the bellows creates various design considerations to be examined carefully. The section of the drawing above shows that the liner is connected to the shell wall by a conical section. The thermal gradient between the hot liner and cooler shell would cause severe thermal stress if the liner were attached with a simple ring. For this same reason, the downstream liner is not welded directly to the shell.

The gap between the shell and liner end ring allows the end ring to grow thermally. The growth is absorbed along the liner seal tube. The opposite end of the liner seal tube is connected to the shell with a smaller ring that is protected from the full media temperature. The joint is internally packed with ceramic insulation to protect the shell from becoming hot where refractory cannot be installed due to the liner arrangement.

The surface of the liner has an abrasion resistant lining. The hex mesh is transformed into full refractory by suspending the hex-mesh from bars that are attached to the shell wall. The seal itself is usually made in two parts, both stainless steel. The outer cover is braided hose that is filled with wire mesh rope. The seal is attached to the liner with stainless clips that are secured into the seal itself. Because the liner gap changes during lateral and angular movement, the diameter of the seal has to be calculated in order to maintain a seal when the liner gap opens and closes in service.

When a packed design is used, the inner insulation pillow can reduce the bellows temperature below the media’s dew point. If the media contains chlorides, acids or other elements that will attack the bellows membrane as they condense, it is important to maintain a minimum bellows temperature during operation. The outer pillow is used to ensure a minimum bellows temperature above the media’s dew point. It is also important to maintain a minimum annulus temperature because the microscopic particles of the catalyst that collect in the inner pillow will cake and solidify if moisture is present in the bellows annulus. This type of packing has been very successful and has proven to be an efficient design in many applications.
• **Purged bellows**

Purged bellows are not as commonly used today, but they are still installed successfully on some FCCU units and EJS is occasionally called to rebuild them as well as produce new units.

The purge is applied to the bellows annulus in the form of air or steam. The continuous flow under the bellows introduces a high-pressure area and a flow going back into the gas stream. The purges stop the catalyst from entering the bellows annulus. Caution has to be taken so that the media used to purge the bellows is compatible the process conditions and does not cause corrosion problems within the bellows element.

Typically numerous nozzles are used to introduce the purge equally around the annulus. The nozzles are connected to a circular pipe manifold that surrounds the bellows on the outside of the joint.

• **Self Equalized and Non-Equalized bellows**

As previously mentioned FCCU bellows are subject to large movement deflections in the axial and lateral planes. Due to these large movements, the individual convolutions absorb high deflections. To prevent the convolutions from contacting each other, self-equalizing rings are commonly used. The individual convolution deflection is determined by the resultant total deflection for the sum of the movements divided by the number of convolutions in the bellows. If a 10 convolution bellows is compressed 2" the individual convolution movement is 0.2". Theoretically each convolution will share equally in the total movement. This is true in reality if several important conditions are achieved:

- The convolutions are uniform
- The induced work hardening is uniform
- The material grain structure is uniform

When one of the above is not achieved the result is non-uniform movement in the individual convolutions. If one or two of the convolutions in the bellows are geometrically different to the rest of the convolutions, this will result in a non-uniform movement distribution over the convolutions making up the bellows. The non-uniform convolutions will absorb more movement than others. This may result in the convolutions touching (bottoming out) and rubbing in service consequently leading to premature failure. Increasing the movement for this bellows to 4” will distribute 0.4” of movement to each individual convolution. This allows for a much smaller error.
Utilizing self-equalizing rings ensures that non-uniformity does occur even if the convolutions move slightly differently. Obviously, self-equalizing rings have no effect on extension movements. The drawback of using self-equalizing rings is that the root ring in each convolution that supports the equalizing ring reduces the amount of movement each convolution can absorb as the bending stress caused by the deflection is increased. Equalizing rings will also add cost to the bellows portion of the expansion joint. Most FCCU applications do not need self-equalizing rings. Only in cases when the movement conditions cause severe compression should they be considered. (Seek the advice of EJS before specifying equalizing rings.) All EJS bellows are manufactured within tolerances that will ensure the convolutions move uniformly. Annealing the bellows after forming will ensure the metallurgical uniformity of the bellows material. EJS would only recommend equalizing rings in rare situations.

Bellows Monitoring

The use of multi-ply bellows on FCCU expansion joints is widespread today. Various reasons exist for the use of multi-ply bellows, ranging from redundant ply design to simple monitoring for early warning of failure.

Multi-ply Bellows

Multi-ply bellows in themselves allow the bellows designer to design for higher movements combined with high pressure and still achieve good cycle life. In laymen’s terms the thicker the bellows wall thickness the lower the cycle life for a given movement. By using 2 plies of a thinner material the cycle life will increase for the same movement without a dramatic drop in pressure capability. A simple 2 ply bellows is designed to use the strength of both plies to ensure pressure capability. Redundant ply bellows are designed so that each ply is strong enough to withstand the operating conditions even after one ply fails. These types of multi-ply designs are usually monitored to alert the user when one ply fails.

- Normal 2 ply monitoring

Monitoring a normal 2-ply design still offers great advantages for the operator. A very small leak through the inner ply will normally not cause a catastrophic failure. The indicator will show the leak and the unit can be shut down for repairs without a total failure of the unit.
• **Redundant Ply**
Redundant ply designs offer safety and outage scheduling benefits. The intent is to enable the unit to continue to operate until the next scheduled outage even after one ply has failed. The inner ply typically fails before the outer ply. The operators can see the failure and plan for changing the unit at the next scheduled outage.

**Monitor Types**
Various monitoring devices can be used from connecting a simple pressure gauge to electronic sensing devices.

This is a typical Monitoring port as it Protrudes through the cover. This unit was electronically monitored by the control in the refinery.

EJS can provide a visual indicator that will indicate a ply failure that connects directly to the port and is installed before shipment.

• **Passive monitor**
Passive monitors utilize the line pressure to indicate an inner ply failure. When the inner ply fails the line pressure between the plies will activate the monitoring device. Passive monitors will only sense an inner ply failure.

• **Active monitor**
The active monitor will detect both inner and outer ply failures. A vacuum is pulled between the plies before the monitoring device is installed. If the inner ply fails the pressure between the plies will increase to the line pressure. If the outer ply fails the vacuum will be lost.

**Note**: Redundant ply designs can sometimes cause problems to the bellows designer. On high-pressure systems the designer may need to use multi-ply designs to simply accommodate the line pressure and other design conditions. The redundant ply can then cause excessive spring rates or manufacturing problems. Please consult EJS if in doubt.

**Exterior Hardware**
Many different types of hardware are used to perform various functions on FCCU joints. This Product Information Sheet covers the most widely used items only.

• **Pressure retaining covers**
Pressure retaining covers are typically telescopic and have rings at each end. The intention is that they are designed to retain the pressure in case of bellows failure. The cover can be welded at the end rings and in the middle to seal the bellows. Care needs to be taken if this is performed, as the bellows will no longer absorb any thermal movement.
• Control Rods
Control rods, as their name suggests, are used to control and limit the movement of the bellows. By definition, control rods are not designed to withstand pressure thrust.

• Sampling pipes
Pipes which penetrate the shell wall are used for various reasons and are specified by the end user. The pipes can often interfere with other hardware on the joint. When specifying these pipes, it is important to be flexible with their position.

• Pantographic linkages
Pantographic linkages are devices that equalize the amount of axial compression each bellows absorbs. They ensure that each bellows takes exactly half of the axial movement imposed on the unit.

• Single plane pantographs
Joints that absorb lateral deflection in only one plane can utilize simple pantographic linkages.
- **Gimbal Pantographs**

  Joints that need to absorb lateral deflection in two planes have to be fitted with a gimbal type pantograph. The center gimbal ring allows the joint to offset in the opposite plane to the pantograph without the linkage binding.

  This photograph shows the pantograph center pins connected through the gimbal. The endpins on the gimbal are hinged to allow lateral movement in the opposite plane.

- **Slotted Hinges**

  The slotted hinges can also be seen in the photograph above. The main purpose of the hinges is to fix the center of rotation for the bellows while at the same time ensuring each bellows shares the angulation caused by lateral deflection equally. Slotted hinges are also used to take the dead load of the center spool off the bellows. This is only effective when an expansion joint is close to a horizontal position.

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**EJS and FCCU**

EJS has been specializing in FCCU expansion joints for over 25 years. We have over 200 years cumulative engineering and manufacturing experience.

Along with CAD and 3D Parametric Design, EJS also has in-house finite element analysis and pipe stress capability. You can contact us 24 hours, 7 days a week for any after hour emergencies or questions. Onsite inspection of your system, including thermal imagery and bellows condition analysis is also available upon request and can be a valuable investment.

EJS specialize in the repair and replacement of existing FCCU expansion joints with standard and emergency deliveries. On site maintenance and installation teams are available for field service work.

*3D rendering and actual photo of a 71-1/4" diameter regenerated FCCU expansion joint*
Clamshell Bellows & Cracker Cartridge™ Bellows Replacement Units

Do you have a FCCU expansion joint that needs repair or replacement to its bellows and you are unable to completely remove the unit for a retrofit? Why not consider installing a clamshell bellows or our Cracker Cartridge™ bellows replacement units for your FCCU. Our clamshell bellows and bellows cartridge units offer a quicker and inexpensive solution to this common dilemma.

This is complete turnkey removal and replacement of most expansion joints with a new clamshell bellows or bellows cartridge. Whether it’s during a planned outage or in an emergency situation, EJS can provide site supervision or a complete installation team to support your project.

Contact your local EJS office for more information about our clamshell replacement bellows and our Cracker Cartridge™ Bellows Replacement Unit.

Our Cracker Cartridge™ bellows replacement units are an ideal solution to replace damaged or leaking bellows in the FCC unit.