TUBE EXPANSION ISSUES AND METHODS

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Tight, durable seating of tubes in tubesheets is one of the critical functions in manufacturing heat exchangers for high pressure steam generators, boilers for conventional power generation, food and pharmaceutical processing systems and condensers. In selecting the best method for expanding the tube within the sheet, producers must examine factors including safety, speed, cost, operator skill requirements, repeatability and overall quality.

With the number of tubes in a sheet ranging from the hundreds to tens of thousands, and the expansion process being done manually one by one, the stakes for achieving the best balance of quality and cost are high.

This article will explore how the four common expansion, or swaging, methods in common use – two hydraulic and two mechanical – meet those key considerations in various applications.

Tube & Tubesheet Issues

As a general rule the smaller the clearance the better, from the expanding point of view, no matter what expanding method is used. What establishes the clearance used by manufacturers is their ability to stuff the tubes through the tubesheets and baffles. This varies with the size of the structure, its configuration and the tube diameter.

From a practical standpoint, the best quality will be obtained by using the TEMA Special Close Fit drilling tolerances and adhering to tubing manufactured in complete conformity with Section II of the ASME code.

To some degree, all tube-to-tubesheet joints leak. While welded expanded joints are the most leak resistant, Hydrogen may pass through welded joints. When welding the tubes to the front face of the tubesheet for tightness or strength, subsequent expanding beginning about 3/8" to 1/2" beyond the weld should be called out to avoid failure of the welds which may result due to cyclical loads from vibration or various loadings to which the tubes are subject. Axial scratches in the hole or tube material will cause leaks in any expanded tube to tubesheet joints, regardless whether expanding by rolling, near contact explosions, compressing a rubber expander, or by hydro-expanding. Therefore, it is recommended that scratched holes be reworked to be free of axial scratches or an optimal groove be cut into the tubesheet.

Tube Expansion Methods

By expanding the tube inside the tubesheet, swaging ensures that the space between the two components is always forced closed. **Hydraulic expansion** is the direct application of high internal pressure within a tube or sleeve in order to form a tight joint between the tube and tube sheet or a tight seal between the sleeve and tube. Two processes are used to accomplish such expansions:

- In **direct hydraulic** expansion, the tube is sealed at its expansion zone ends and fluid pressure is applied directly to the inside surface of the tubular section being expanded.

- **Explosive** expansion involves an explosive charge inside the tubular running the length of the tubular that is sealed on both ends. A charge is detonated and the pressure generated expands the tubular out against the existing casing. The outside is generally sealed to the existing casing with a layer of fiberglass impregnated resin. A mandrel may then be pulled through the expanded liner to complete the expansion process.[5]

In **mechanical rolling**, a set of hardened rolls in a cage rotate around a tapered mandrel. The rolls travel up the mandrel causing an increasing radial force exerted at the contact point between the rolls and the tube. This increasing force moves the tube material outwards until it contacts the ID of the tubesheet hole and continues until supposedly the tubesheet material is just below its yield point.

Two primary methods of mechanical expansion are linear swaging and rotary swaging:

- In **linear swaging**, the tube is either affixed to the existing casing or is suspended on the wire line or tubing string. A mandrel is then forced through the tube to expand it.

- **Rotary swaging** typically utilizes a cone with external rollers to expand the tube. The cone is rotated while it is pulled through the tube, decreasing the axial stresses as compared to linear swaging but increasing the torsional stresses on it. [6]

Application Considerations

Explosive Expansion

Almost all explosive expanding is done on constructions where the primary seal of the tube to the tubesheet is by welding. Explosive expansion has been successfully applied to expand tubes into tubesheets as thin as 1 1/2" and as thick as 33". Most experience with explosive expansion has been with 6" or thicker tubesheets. With explosive expansion, tube materials such as Titanium and austenitic stainless steels frequently must be shot twice. Depending upon the materials, tube diameter, gauge and tubesheet thickness, explosive expanding may be considerably more expensive than hydraulic expansion.

Experience has shown that leakers may occur with only one explosive detonation. There have been instances where explosive expanding caused measurable ligament movement with consequent availing of adjacent tube holes as well as cracked ligaments. It is advisable and customary to install ligament supports in surrounding tubes when setting off another explosive charge to seal a leaking joint.

With explosive expansion, the calculated appropriate explosive charge must be verified experimentally and tube ends must be cleaned after expanding, though a residue remains and there is some discoloration of the tube. Special training and certification is required for technicians who perform explosive expanding.

It is generally unsafe to set off explosives on-site in chemical plants, pharmaceutical plants and oil refineries because of the hazard of igniting volatile materials. The noise level during explosive expanding requires hearing protection for technicians and others within hearing range. Organizations that do explosive expanding must deal with government requirements for purchasing and using explosives. Special permits may be required to transport explosives across state lines.

Mechanical Rolling
When one roller expands tubes into grooved holes, tube metal extrudes into the grooves. But mechanical rolling may cause tube-end fatigue, depending upon the frequency and amplitude of the stresses the rollers apply. The frequency is far more effective in producing fatigue than the amplitude. That is why five or seven roll expanders are used when the tube material is subject to fatigue. By comparison from the fatigue standpoint, hydro-expanding is like having an infinite number of rolls.

The high contact stresses imposed by rolling make it more likely that stress corrosion will cause tube-end failure. When leakers are re-rolled after hydro testing, the tube wall is further reduced. The transition from the reduced wall is a possible trouble source in rolled tubes. Also, ligaments may move enough to start other leaks and even cause ligament damage around the other tubes. This can result in having to chase the leaks completely around the tubesheet.

Mechanical rolling reduces the tube wall by; a) stretching the tube radially, and b) imposing high unit rolling forces that cause the tube to extrude axially. To roll tubes into tubesheets thicker than 2", you must step roll. This is time consuming and requires a tremendous amount of skill. Because mechanical rolling pushes the tube material out the rear of the tubesheet, a very noticeable rear crevice is created often resulting in premature tube failure.

In mechanical rolling, whether using torque setting or apparent percent tube wall reduction, the degree of expansion cannot be directly correlated. Furthermore, torque controllers measure only the power drawn by the rolls which can vary with the condition of the rolls and mandrel, lubrication, operator fatigue and other factors.

Accuracy and quality are heavily dependent on operator “feel” and skill. Over rolling will break the bond between tube and tubesheet, increase leakage and reduce joint strength. An under pressure condition will reduce joint strength and increase tendency to leak.

Hydraulic Expansion
The newest expansion method, hydro-swaging, was developed by request from Westinghouse engineers who were seeking a more effective method than roller expansion for high pressure steam generators. Because expansion pressures are applied uniformly, tube after tube, hydraulic expansion yields consistent joints throughout the tubesheet. The system is easy to operate with minimal training and the method has been applied successfully to expand tubes into tubesheets as thin as ¾” up to as thick as 33”.

Water pressure is applied to the tube ID over the full length of the joint in an accurately prescribed pressure zone, in one step producing clean and consistent joints. With this process stress, crevice corrosion and metallurgical changes are minimized. Because expansion is accomplished using only distilled or purified water, no lubricant is forced into the tube surface and there is no surface flaking or spalling inside the tube. A smooth transition from expanded to unexpanded areas, along with no change in tube material properties, greatly reduces strain hardening, tube fatigue and stress induced corrosion cracking.


HydroSwage® Mandrel in Tube


High Pressure Expansion of Tube


Smooth Transition from Expanded to Unexpanded Areas Groove Penetration is Accurate

When Hydro-expanding tubes into grooved holes, the tube bulges into the groove, providing additional tightness at the contact of the groove edges with the tube. The recommended groove for hydraulic expansion should have a width of 3 times the tube wall thickness and a depth of

0.2 times (20%) of the tube wall thickness. The recommended shape of the groove is rectangular and the edges of the groove need to be clean and square with no interruptions.

Hydro-expanding produces no surface effects on the tube and almost no work-hardening. Bell shaped or hour glass shaped tube ends never occur and the tube-to-wall contact is always uniform.

Hydraulic expanding leaves no residue and does not change the appearance of the tube ends because de-ionized water is used to expand the tubes. Used consistently and successfully on both non-weld and welded joints, it is successful in out-of-round holes and in holes distorted by tube plugging.

As the pressure applied to the joint is controlled accurately hydraulic expansion does not cause ovalling or cracked ligaments and because of its uniformity, it further reduces the probability of axial scratches when re-tubing. Extraction of hydro-expanded tubes is extremely even and uniform, producing cleaner tube holes ready for re-tubing. If a leaker occurs, the exact pressure that will provide a seal without disturbing any of the adjacent holes is known. Because of the fine control hydraulic expansion offers, it is not necessary to insert ligament supports in surrounding tubes when re-expanding.

Tubes may be hydro-expanded to the exact rear face of the tubesheet, thereby reducing the chance of crevice corrosion at the rear. This is accomplished by pressure being applied uniformly to the entire tube length at the same time.

Advanced hydro-swaging systems have a multi-member seal design that allows the operator to perform many expansions without replacing any elements of the sealing package. In addition, touch-screen and PLC technology is being adapted to hydraulic systems to allow storage and download of expansion data.

Hydraulic expansion is quieter than most machines used in heat exchanger factories and in locations that utilize the heat exchangers and it can be done safely anywhere.