Types of joints

There are two basic categories of tube-to-header joints: welded-only and rolled, including rolled and welded. Rolled-only joints are of two basic types: full-strength and full-penetration. Full-strength welds typically are characterized by a bevel and fillet weld. For the last 10 years, most HRSG designs have relied on welded-only tube-to-header joints. Rolled and rolled-and-welded joints still are used today for packaged HRSGs and waste-heat systems with integral steam drums.

Here are the specific types of joints you should be familiar with:

- **Full-strength welds**
  - Stick-through with standard “J” bevel
  - Stick-through with contoured weld groove

- **Full-penetration welds**
  - Set-on
  - Set-on with header spot-face (also called spot-face set-on)
  - Extruded header butt weld

- **Mechanical joints**
  - Rolled
  - Rolled and welded

### Review basics of tube-to-header joints before writing specs

By Mike McGuire, Chanute Manufacturing Co

Over the past 20 years, boiler manufacturers have relied on a variety of tube-to-header joint designs in their heat-recovery steam generators (HRSGs). Since most owners of gas-turbine-based cogeneration and combined-cycle plants are inclined to buy HRSGs and related services from one or two, possibly three, OEMs (original equipment manufacturers), you may not have been exposed to all nine of the joint configurations typically used in North America.

At some point you may be asked to help develop the specification for a new HRSG, or for replacement harps or repairs for an existing unit. A significant part of any such specification probably will involve tube-to-header joints. The first thing you must become familiar with before putting pen to paper is the nomenclature for each type of joint. Things work more smoothly when you and your fabricator are speaking the same language. Remember, the more defined you write the spec, the better the result for your particular application.

You also should be aware of the production costs associated with each of the joint options. Cost always is important to buyers.

The “catalog” of joint configurations that follows provides the foregoing information and offers a solid foundation for the preparation of your specifications. Note that the engineering merits of the various joints are not discussed because they are designed to satisfy the form and function intended by the OEMs. All joints meet the requirements of the ASME Boiler & Pressure Vessel Code (shortened to Code throughout this article).

Further, Chanute Manufacturing Co, Chanute, Kan, has successfully produced all of these joints and not found one more reliable than the others. The company’s experience base includes the fabrication of more than 1600 HRSG pressure-part modules for nearly all of the major OEMs over a wide range of unit sizes and operating conditions.

### Comparing the costs of welded tube-to-header joints

Here’s a comparison of the various cost components for the welded tube-to-header joints. The stick-through with standard “J” bevel is used as a baseline with a factor of 1 for its cost components. All other joints are assigned cost factors compared to this joint.

<table>
<thead>
<tr>
<th>Tube-hole prep</th>
<th>Harp fit-up</th>
<th>Joint weld</th>
<th>Skill level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stick-through with standard “J” bevel</td>
<td>1x</td>
<td>1y</td>
<td>1z</td>
</tr>
<tr>
<td>Stick-through with contoured weld groove</td>
<td>2.1x</td>
<td>1y</td>
<td>1.1z</td>
</tr>
<tr>
<td>Socket seat</td>
<td>2x</td>
<td>1.8y</td>
<td>1z</td>
</tr>
<tr>
<td>Side-hill stick-through</td>
<td>2.3x</td>
<td>1y</td>
<td>1.3z</td>
</tr>
<tr>
<td>Set-on</td>
<td>0.8x</td>
<td>2y</td>
<td>0.8z</td>
</tr>
<tr>
<td>Spot-face set-on</td>
<td>2x</td>
<td>1.8y</td>
<td>1.8z</td>
</tr>
<tr>
<td>Extruded header</td>
<td>4x</td>
<td>1.8y</td>
<td>0.8z</td>
</tr>
</tbody>
</table>

Where, x is the cost to bore the tube hole and machine the weld groove, y is the cost to trim (if required), fit, and tack a tube into an upper and lower harp header, z is the cost to weld out a tube-to-header joint, and d is the degree of difficulty to make a quality weld.
Code applicability:  
Section I

Most tube-to-header weld joints are designed according to the sketches presented in Figs 1 and 2. These appear in Section I of the Code as Figs PW-16.1 (a) and PW-16.1 (z), respectively. The Code is careful to state that these are only some of the acceptable types, but in most cases, the weld-only joints for HRSG harps are related to either Fig 1 for full-penetration welds or Fig 2 for full-strength welds. Note in the figures that \( t_n \) is the thickness of the tube wall and \( t_c \) is a dimension that may not be less than the smaller of \( \frac{1}{4} \) in. or \( 0.7t_n \).

More specifically, Fig 1 depicts a standard set-on joint. A common variation of this joint is the spot-face set-on, described in detail in the catalog of joints that follows. Fig 2 is applicable to the stick-through types of joints. A socket-seat joint is shown, even though it is less common in the US than joints with a through-hole size equal to the outside diameter of the tube, which eliminates the seat. The Code permits the seat-less configuration as detailed in “Section I, Interpretations Volume 35” (refer to Interpretation I-92-95).

The Code allows the dimensional depth of the weld groove to be measured from the vertical top—or high side—of the header pipe as shown in Fig 2, Section 1-1. There is no governing requirement on the low side. In application, some combinations of small-diameter pipes and tubes larger than 2 in. diameter result in little or no weld groove on the low side of the tube hole. In such situations, it is common to specify a low-side requirement, such as a minimum chamfer, in addition to the Code.

**FULL-STRENGTH WELD**

**Stick-through with standard “J” bevel**

This is the most common tube-to-header joint configuration. It is favored because it meets the HRSG designer’s performance requirement and it is the least expensive weld joint for harps. Fig 3 shows the tube hole with “J” bevel prep. As noted in the introduction, bevel depth is measured from the top, or high side, of the header. The resulting weld, shown in Fig 4 is uniform, matching the contour of the tube and header intersection. Fig 5 is a cross section of the weld after chemical etching.

From a manufacturing perspective, one benefit of this joint is the relative ease of machining the hole and weld prep with a simple two-axis machine. Experienced fabricators can machine both the hole and weld prep in a single operation. When a computerized numerical control (CNC) boring machine is used, an entire tube field can be produced very efficiently; no tooling change is required.

Other manufacturing advantages pertain to harp fabrication. It is common for finned tubes to vary in length by some small tolerance. This is easily absorbed by stick-through joints during fit-up because minor tube-length variations typically are allowed to run out in the bottom header. This eliminates the need to trim-to-fit every tube, as is the case with some of the other joint configurations.

Finally, the stick-through weld joint is a fillet weld and does not require the higher level of skill that an open-root weld requires. Thus you can expect the level of quality for these joints to be more consistent than for other types.
**FULL-STRENGTH WELD**

**Stick-through with contoured weld groove**

This joint (Fig 6) is very similar to the standard “J” bevel design, but it goes beyond the requirements of the Code sketch shown in Fig 2 by articulating the “J” bevel around the contour of the hole. Result is a weld groove of constant depth at both the high and low sides of the header tube hole.

With regard to fit-up and welder skill requirements, this joint has the same shop benefits as the standard “J” bevel joint. However, it is a more expensive weld prep because it typically is performed in two separate operations: the first to bore the hole and then a second operation to three-axis machine the contoured bevel.

It also can require more filler metal than the standard “J” around the low side of the joint, depending on weld technique, but the additional welding generally is negligible.

**FULL-STRENGTH WELD**

**Socket seat**

The socket-seat stick-through configuration (Fig 7) is the purest translation of the Code sketch in Fig 2. This joint is particularly useful in upper headers because it can facilitate draining. Note, however, that there are simple methods to facilitate upper-header draining with other joint configurations as well.

To fabricate this tube-hole configuration, a two-step process of boring and machining typically is required.

Thus this hole is more expensive than the standard “J,” but less than the contoured bevel prep.

Fit-up and welding must guard against cracking of the weld caused by shrinkage-induced mechanical stress inside the joint. This can occur when the tube is fit-up flush in the socket seat throughout the weld process and the consequent weld shrinkage draws the tube hard against the seat. The resulting stress can be sufficient to fracture the weld. Experienced shops account for this situation in their fit-up and welding techniques.

If a socket-seat joint is specified for the upper header only, the tubes usually are not trimmed to fit because minor length variations can be run out into the lower header. If both upper and lower headers are specified with this joint, additional trim-to-fit labor normally is required.

**FULL-STRENGTH WELD**

**Side-hill stick-through**

The stick-through tube-to-header joints described previously are installed on header radial lines, meaning that the tube centerline intersects the header centerline. Alternatively, some HRSG designs use offset centerlines, thereby resulting in a so-called side-hill configuration. Machining of the tube hole and weld groove is a two-step process on a three-axis machine; the groove must be milled around the circumference of the hole. This joint is the most expensive of the stick-through configurations because a side-hill hole has a longer circumference than a radial hole. For the same reason, this joint also requires the most filler metal.

**FULL-PENETRATION WELD**

**Set-on**

The set-on tube-to-header configuration (Fig 9) uses a tube-hole diameter equal to or smaller than the tube ID. On small-diameter headers, the tube end typically is coped (so-called “fish-mouthed”) to match pipe contour. This joint requires an open-root weld and the back side is inaccessible; therefore, it demands a higher degree of skill from the welder than is required for most other joint configurations.

When making a complete harp assembly with these joints, additional labor is required for trimming the tubes to a precise length and fish-mouthing the ends. Drilling the tube hole is a simple one-step operation, making this the least expensive hole prep of all the welded joints.
**Spot-face set-on**

This joint, similar to the set-on, eliminates the need to fish-mouth the tube end by spot-facing the header. It also is an open-root weld, but the recess can make for more difficult access to the root. As Figs 10 and 11 show, this configuration requires significantly more welding labor than the simple set-on joint. With the proper equipment, the spot-face weld prep and the tube hole can be machined in a single step, but two steps normally are used. Additional tube trimming to fit between headers is still required when fabricating complete harps.

**Extruded header**

Extruded tube holes enable butt-welding of tubes to the header (Figs 12 and 13). This joint is marketed as a lower-stress connection than the other welded joints because the transition legs of the extrusion have a radius and because a butt weld is used in place of a fillet weld. The weld also can be radiographed.

While the extruded header has its advantages, the tube field on an extruded header is significantly more expensive to produce compared to the other joints with machined tube holes. When fabricating a harp with extruded headers on both ends, additional trimming of the tubes typically is required during fit-up. This can be eliminated only if the upper header is extruded and the lower header has stick-through joints. Lastly, this joint uses an open-root butt weld, calling for greater skill on the part of the welder than some of the other joints shown.

**Rolled, rolled and welded**

In HRSGs with integral steam drums you may see a mechanically expanded—or rolled—joint (Fig 14). Here, the inside of the tube is mechanically pressed against the sides of the tube hole to form the pressure seal—capable to more than 1500 psig without a seal weld. In the shop, the tube wall is squeezed to the point that it thins out by 6% to 14%. The optional seal weld is implied by Code Section I, PWT-11, to be a tube retention weld; some engineers believe it also serves as a pressure weld. This joint is not included in the cost-comparison table because it rarely is used in electric generating facilities.