The Fillet-Welded Staybolt – An Aspect of Modern Locomotive Boiler Construction

Matt Jansen, Foreman, Wasatch Railroad Contractors, ESC Member
Dave Griner, CMO, Wasatch Railroad Contractors, ESC Member

March, 2006 – Revised October, 2006

From World-War II on, the fillet-welded staybolt has provided a safe, economical, and most effective means for staybolt attachment in the locomotive boiler. The economy is gained through the elimination of machining processes to apply threads to the staybolt hole and staybolt. Safety is improved by the fact that a positive attachment of the staybolt to the boiler is provided by a weld, where threading loosens over time due egging-out of the holes from expansion and contraction of the firebox sheets and shrinkage of the firebox. The attachment is most effective because it eliminates staybolt "weeping" while providing the least heat-affected weld zone at the minimum of labor expense. This technology is one aspect of a greater objective which is to obtain a boiler design that affords a minimum of maintenance while achieving greater steam pressures and heat-transfer rates at a reduced cost compared to traditional designs.

"Nobody knows what they don't know until they know it." – L.D. Porta

The design of steam locomotive boiler in America is the product of empirical calculations that have been derived through almost two century's experience. The results of this experience have yielded design practices that are conservative, and on occasion, wrong. An example of this is the theory of the relationship of the boiler and firebox over the life of the sheets. While expansion and contractions do play a major role in the life of staybolts, it is the overwhelming shrinkage of the firebox that usually results in the breakage of staybolts. Evidence to prove this occurrence is given by the characteristic breaks at the bottom of the bolt on the fireside and top on the boilerside. This misalignment of the staybolts leads to plastic bending and caustic embrittlement of the staybolt shaft and water intrusion and consequent corrosion of the threads of the threaded staybolt.

Bending of the staybolts is so closely calculated and measured by Tross because it is bending and not tension stresses which lead to staybolt breakage. Tension breakage of all the Tross bolts is the same.[1] In order for the locomotive boiler to achieve higher pressures while reducing maintenance, other factors need to be considered.

While the fillet-welded staybolt alone does not effectively combat expansion and contraction of the sheets, other technologies that were developed in Germany soon after the fillet-weld design do. It is accepted that staybolt breakage generally occurs in the areas of the bolt closest to the sheets. This is due to the edge of the sheets creating a fulcrum for the bending of the staybolt. The design of the profile of the staybolt can be changed where at the optimum condition it exhibits a smooth s-shaped bend. A practical

[1] Tross, Arnold, Dr. Ing. "The Results of Measurements of Stretch with the Different Types of Staybolts," Glasers Annalen April 1953 p. 76.

compromise is reached with the “BTH”[2] which is easy to machine in its straight-taper design while affording the best-distributed bend over the length of the staybolt due to its application-calculated cone length.

Though staybolt design and attachment is a fundamental component of the modern locomotive boiler, other improvements contribute to superior design and operational longevity. These include the manipulation of sheet thickness, pre-arching the sheets, lowering the fire grates, redesigning the fire arch, washing techniques, and welding techniques (all to minimize stress and deformation.) Additionally, improvements to combustion (coal or oil) to reduce erosion and improve heat distribution have been made. Also, modern water treatment (to eliminate corrosion & caustic embitterment) greatly contributes to the locomotive boiler’s longevity by allowing thinner sheets to be used which allow for localized elastic bending rather than general arching and distortion of the boiler.

Modern Locomotive Construction depends on a thorough, quantitative understanding of the prediction of hardware and the phenomena associated with it. Much work has been done by Tross, Chapelon, and Porta, but there is still much more to do.

“It is not as yet possible to design on the basis of (low cycle) fatigue stresses because the actual strains are not more than vaguely (if not wrongly!) known. Tross’ work showed that many past opinions and assumptions were FALSE, and that a vast amount of phenomena were not ever suspected.”[3]

The acceptance by American boiler-code entities of modern locomotive boiler design and construction techniques such as the application of the fillet-welded staybolt will be the first step to designing new, advanced steam locomotives in America for specialized purposes and applying advanced principles to existing locomotive rebuilding thereby enhancing the safety and utility of one of the best inventions of modern society.

---

[2] Tross, Arnold, Dr. Ing. “New Knowledge and Constuction Directions in the Area of the Rear Boiler” Glaseeers Annalen, April 1953, p. 16.

[3] Porta, L.D., “The Thermo-Mechanical Design of the Steam Locomotive Firebox – an Overall View,” 1984 Original transcript, unpublished, p. 5.