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SME Standards & Certification has published a second and much expanded edition of the standard that ensures the integrity and efficiency of bolted joints in pressure vessels and piping. The new document, PCC-1-2010 Guidelines for Pressure Boundary Bolted Joint Assembly had been in preparation for four years and replaces the first edition, issued in 2000.

The original document was unique in the world for addressing issues with the assembly of pressure vessel and piping bolted joints from a standards perspective. Since the initial version, there have been advances in gasket technology, bolting assembly procedures, and calculation methods that enabled the improvement of both the integrity and efficiency of bolted joint assembly. In order to capture these advances, the ASME Post Construction Subcommittee on Flange Joint Assembly (PCC), which developed the standard, was tasked with updating the document beginning in 2006. The revised document was released in March this year and assembles current industry best practice into one easily referenced location. The updates were extensive and have resulted in an increase in the length of the document from 33 pages to 77 pages. This major revision focuses on significant additions to capture proven assembly knowledge, which impacts safety, efficiency, best practice, and cost reduction.

The updates made in PCC-1-2010 are all consistent with the original reasons for the creation of the ASME code, as noted in The Code, An Authorized History of the ASME Boiler and Pressure Vessel Code by Wilbur Cross (ASME, 1990):

“Although safety has popularly been cited in histories relating to the creation of boiler codes as the motivating force for action, there were two other factors that directly prompted ASME to take action. One was the economic benefit that would be derived from the avoidance of waste and unnecessary work trying to join components that had never been designed to match each other. The other influence was professional honor and the reputation for communication and coordination.”

The same driving reasons were employed to define the required additions to the ASME PCC-1 document. As evident from the more than two-fold increase in content, the updates are significant and are primarily in the form of additional information. Much of this new information is leading edge and has never been recorded in any international standard prior to this revision.

SAFETY FROM LESSONS LEARNED

Since the release of the original version of PCC-1 in 2000, there have been a number of incidents of bolted joint leakage, sometimes associated with personnel injury, which could have been avoided with relatively minor changes to assembly procedures. PCC-1-2010 incorporates several new recommendations based on industry experience with failure. In section 13.0 “Joint Pressure and Tightness
Testing,” a caution has been added with regard to the use of temporary gaskets during pressure and tightness testing (gaskets for which the joint was not designed). This caution is based on industry experience where temporary gaskets have blown out during pressure and tightness testing, and caused personnel injury and fatality.

In addition, the revision recommends that gaskets are not reused. This inclusion was made based on field experience with joint leakage or flange facing damage where gaskets, in particular RTJ gaskets, are reused. Most gaskets are designed to plastically deform in order to obtain a seal. This results in a reused gasket being harder than a new gasket, which means that higher assembly bolt loads are required to obtain a seal, the gasket will not seal as effectively, and damage to the flange facing may occur during assembly.

Section 7.0 “Lubrication of Working Surfaces” was updated to include a recommendation that bolts be checked for free-running nuts during the bolt lubrication stage of assembly. This requirement was introduced based on field and laboratory experience which indicated that relatively small imperfections on the bolt or nut thread can have a significant impact on the obtained bolt load when tightening the joint using torque or tension techniques.

An additional lesson learned that was incorporated into the new revision is that excessive paint thickness between the nut and back of the flange may cause joint leakage due to loss of the bolt load caused by the paint degrading during joint operation; therefore a recommendation was added in Section 4.0 that excessive paint be removed prior to assembly of the joint.

FILLING IN THE KNOWLEDGE GAPS

Previous industry guidelines for flange face flatness were based on manufacturing tolerances and often did not reflect what was practical to achieve in the field. The guidelines also did not address acceptable levels of minor local imperfection in the flange facing (pits, gouges, dents, and scratches). In practice, the acceptable imperfections for a flange facing are dependent on the type of gasket being employed, which was never previously considered in industry standards.

The new guidelines in Appendix D: “Guidelines for Allowable Gasket Contact Surface Flatness and Defect Depth” contain flatness limits based on the amount of compression that the gasket is subject to during assembly and different limits are provided for both hard and soft gasket types.

The second set of guidance listed in Appendix D is for acceptable levels of local flange facing imperfections. Once again, the acceptable levels are outlined relative to the gasket material. Harder facing materials (steel, for example) will not conform to the imperfection and will be more sensitive to imperfections than gaskets that have a softer facing material. The limits include assessment of closely spaced imperfections and have acceptable depth tolerances that are dependent on the type of gasket employed and the distance the imperfection extends in the radial direction across the flange seating surface.

The intent is that both of these sets of limits can be employed by an inspector to assess the flange facing condition as part of the standard equipment inspection process and only if the noted damage falls outside of the listed limitations will the joint be flagged for engineering assessment.

The revision of Appendix E: “Flange Joint Alignment Guidelines” also contains a similar departure from typical standard specifications. The additional requirements included in this revision were designed to avoid the pitfalls of present approaches. Previous flanged joint alignment guidelines were primarily obtained from fabrication specifications (such as ASME B31.3, for example) and did not address the fact that the initial alignment was not as critical as the interrelationship between the initial alignment and the force required to bring the joint into perfect alignment (system stiffness).

The alignment guidelines for PCC-1-2010 were completely rewritten to focus on geometry-based limits with associated alignment-force limits. The new limits address the maximum acceptable load to bring the joint into alignment in terms of the specified assembly bolt load. Simple figures illustrating the different types of misalignment have been added to clarify the listed toler-
There are two questions that are often posed for which there was little guidance: “What assembly bolt load should I use?” and “Why did the joint leak?”

Applications for pressure vessels and piping. The specification previously referenced for through-hardened washers prior to PCC-1-2010 was ASTM F436, which is actually a structural washer specification. That specification did not include higher alloy materials, and the washer outer diameters are in excess of common flange spot-face diameters used at the flange-to-nut contact surface. This resulted in the washer bridging the spot face, creating an undesirable bending of the washer during assembly.

The new PCC-1 Appendix M was written with the intent to rectify these two issues and also to provide guidance on the service limits for the different materials listed for washer manufacture. The service limits are based on single use (where softening during operation will be acceptable, since they will not be reused) and also multiple use (where softening is not desirable). The service temperature limits outlined in the appendix are based on metallurgical behavior for multiple usage and service experience for the single-use limits. The four materials listed in the appendix are intended to match commonly applied bolt materials, and significant effort was made to ensure that the washer thickness and material specification resulted in washers that could be easily manufactured.

**IMPROVED INTEGRITY, LESS EFFORT**

The main body of the document has been updated to improve joint assembly productivity by allowing graphite material to remain in the flange surface finish grooves after cleaning of the joint for inspection when using graphite-faced gaskets. This reduces the cost associated with preparing the joint for reassembly and avoids unnecessary work.

An even more significant improvement in productivity is obtained with the alternative tightening procedures now contained in Appendix F: “Alternative Flange Bolt Assembly Patterns.” The original version of PCC-1 contained a bolt assembly pattern and procedure that involved tightening in a pattern pass at three different levels of assembly bolt load, completing a final circular pass, and then an optional additional circular pass four hours afterwards. This method has been retained in the document for continuity and is referred to as the “Legacy method.”

Since the initial release of PCC-1, however, considerable effort in research has gone into proving that faster methods of assembly can be used that will achieve equal or better joint integrity. The theory behind these improvements is based on using an appropriate pattern for the gasket being employed and by increasing the bolt load at a much more rapid rate than the Legacy method. Increasing the bolt load more rapidly can be applied to all gasket types to improve assembly productivity, regardless of the pattern employed.

In addition, pattern passes using multiple tools have been included in the appendix in order to reflect this common industry practice. None of the new pattern passes includes the optional final pass after a four-hour wait, but all include the additional instruction to continue tightening the bolts until they no longer turn for the final pass. There are three new patterns introduced for single-tool application and two patterns for multi-tool. The single-tool patterns include:

- **Modified Legacy pattern:** Similar to the Legacy pattern, but with bolt load increased to the next level after every four bolts tightened, rather than after a full pattern pass. The pattern includes one or two pattern passes (second optional, depending on gasket type) and then a final circular pass until no nut turns.
- **Quadrant pattern:** Similar in configuration to the Modified Legacy, except the bolts do not require numbering as, instead of using a cross-pattern for tightening the bolts, the joint is divided into quadrants and the next bolt in each quadrant is tightened in a circular order. Bolt numbering is not required, as the next loose bolt in the next quadrant is always the bolt that must be tightened. Two patterns are presented, one for flanges with 16 or fewer bolts, where opposite quadrants are tightened successively and one for joints with more than 16 bolts where the next quadrant in a circular order is tightened.
- **Four-bolt pattern:** similar to the Modified Legacy, except only four opposing bolts are tightened in sequence and then a circular pattern is commenced.

The multi-tool patterns are outlined in Appendix F similar to the Modified Legacy pattern and the Four-bolt pattern. In addition, the appendix contains guidelines for suitable measures for assessing the efficacy of other alternative tightening patterns and procedures that are not included in PCC-1.

**ANSWERING AGE-OLD QUESTIONS**

For engineers dealing with pressure vessel and piping bolted joints, there are two questions that are often posed, for which previously there was little guidance and certainly never a standardized method of determining an
answer. These questions were:
“*What assembly bolt load should I use?*”
And
“*Why did the joint leak?*”

A significant effort to answer these two questions has been made in PCC-1-2010. Appendix O: “Assembly Bolt Load Selection” outlines two methods of determining the appropriate assembly bolt load for a given joint. The first method is the use of a standard assembly bolt stress across all joints. It is recognized that the simplicity of that method may assist in its adoption and success on some sites. However, that method may also result in either insufficient or excessive gasket stress or damage to the flange due to excessive bolt load in some cases. Therefore, the second method of determining assembly bolt load involves the calculation of the maximum limits for each component and the determination of the minimum required gasket stress to both seat the gasket during assembly and to seal the gasket during operation.

Once gasket relaxation and hydrostatic end force have been allowed for in the calculation, there is a band within which the assembly bolt load may be selected that will ensure that no joint components will be damaged and that sufficient gasket stress is present during all phases of operation such that no leakage will occur. Using this comprehensive approach allows the end user to be more aware of the reasons as to why the selected bolt load is being applied and therefore to explore opportunities to improve the joint integrity based on the limiting factors for the joint, as determined by the calculation method.

The appendix contains tabulated values of maximum allowable assembly bolt stress to avoid damage to the flange for standard B16.5 and B16.47 “Series A” flanges in sizes from NPS 2 to NPS 48. A worked example for determining the assembly bolt load for an NPS 3, Class 300 flange and an example assembly bolt torque table are also provided.

One of the most important activities that can be undertaken in any leak-free bolted joint program is a diagnosis of the cause of any leaks that occur. The new Appendix P: “Guidance on Troubleshooting Flanged Joint Leakage Incidents” includes guidance on the assessment of the leakage by examining the original joint configuration, assembly history, operating conditions, and condition of the joint and gasket subsequent to joint disassembly.

Appendix P provides guidance and a series of checklists designed to guide the user through an investigation of joint leakage. It contains a sample “Flanged Joint Leak Report” and additional lists of considerations for common flange design issues and some potential resolutions for those issues. It also lists some best practice guidance for basic flanged joint design problems. The diagnostic troubleshooting checklists are written to key from when leakage occurred and to narrow in on conditions and clues as to why the leakage occurred.

**TRAINING AND CERTIFICATION**

The lack of standardized qualifications for bolted joint assemblers has been identified as an issue by many in industry and is a leading cause of joint leakage due to poor assembly practices. Welders are able to train and become certified to industry standards, but bolted joint assemblers have no such system, although they also assemble pressure boundary joints on the same equipment as welders. In an effort to improve the status quo, a significant revision to the existing PCC-1 Appendix A was drafted and is under consideration. The proposed new Appendix A outlines the requirements for a certification entity to create and administer a training and assessment program that provides industry standard certification of bolted joint assemblers.

The proposed appendix also contains requirements for the minimum course content that must be taught in the theoretical portion, requirements for a series of practical demonstrations, a practical assembly exam that must be administered, requirements for maintenance of the certification, and the requirements for the certification entity to establish and maintain its ASME accreditation in order to supply the certified assessment program. The appendix proposes three levels of assembler qualification: Certified Bolting Specialist, Certified Senior Bolting Specialist, and Certified Bolting Specialist Instructor.

ASME PCC-1-2010 represents a step change in the level of detail provided for guidance on bolted joint assembly and will represent a significant body of work for the international improvement of the integrity of bolted flanged joints. The undertaking and commitment by the subcommittee members was significant; however, it is believed that the benefit to industry from this revision will be commensurate.