Bolting Practices for Disaster Prevention

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Prelude

It is 2:15 AM when the unthinkable happens! A phone call rudely awakens John, the Plant Manager from a sound sleep. John is manager for a highly volatile processing plant and the person on the other end of the call informs him that a major explosion has just occurred in the main processing unit. His immediate reaction is to arouse his senses and make sure he is awake, and that he is not having a nightmare!

John then makes a call to the Carl, the Maintenance Manager and summons him to meet at the plant. John jumps into his clothes and proceeds to the plant. On the way to the plant the main thoughts running through John's mind are: Were there any injuries or missing persons resulting from this event? Is there a possibility of a chain reaction from this explosion that could spread and affect the nearby neighborhoods?

In meeting with the Maintenance Manager and the Safety Manager who also arrived, the immediate and primary concerns are addressed. It is determined that all personnel are accounted for and safe. The other concern, "chain reactions at other areas of the plant" is in process of being addressed.

With the two main concerns addressed, they can now move on to begin gathering information that can be used in doing a Root Cause Analysis for this event. With any non-desired event it is especially important to gather information as soon as possible to enhance the accuracy of the information gathered. So, they talk to the plant personnel on duty during this event to get their firsthand information.

Yesterday was the last day of an impromptu maintenance activity that involved disassembly and reassembly of several flanges in some high-pressure piping that contains volatile contents. In doing the analysis some important questions are: Were members of the work crew trained? Was every flange bolted according to a written procedure developed for this activity? Do we have documentation of this? Were all the crew leaders competent in this activity? Were contract employees involved professionally trained in flange bolting? Notes were taken to use for a full Root Cause Analysis to be done after the plant is secured.

Although this is a fictional scenario, in reality, it happens all too often in today's industrial setting. Often the evidence of the cause is destroyed by the event. Hazardous flange leaks in today's industry are a major concern for safety of the workplace and environmental protection. Once this type of event happens the costs can be astronomical in terms of human life and limb, environmental damage, equipment damage and lost production opportunities (LPOs).

Bolt tightening is commonly overlooked in the overall maintenance plan and this is often the cause of defective flange unions that lead to leaking flanges and resultant disasters. How do we engrain prevention of such disasters?

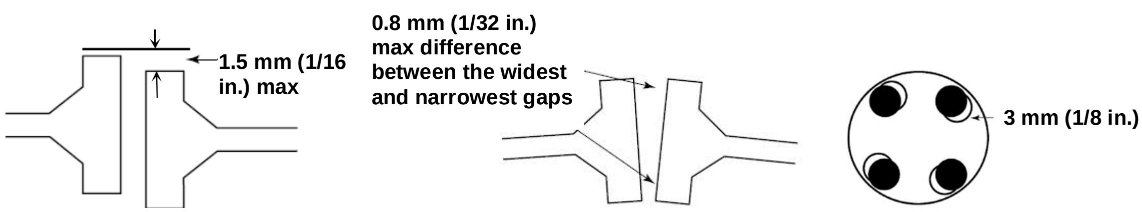
Training

The top priority that should cover all facets of maintenance exercises is to ensure that all members of the work unit are trained for the specific task. In this scenario, bolting mechanisms and how the flange assembly reacts to stress induced by torque or tensioning equipment are subjects that should be addressed. All personnel should be trained and able to follow procedures as outlined below.

Precise Procedures

Individual procedures targeted for each size and class of flange union should be developed by a competent engineer and reviewed/checked by a competent colleague or manager. The procedures should address, at a minimum, the following segments:

- Flange alignment done according to ASME PCC-1, Appendix E with clear limits for out of alignment tolerances. See illustration from Appendix E below. Piping supports should be designed to eliminate pipe strain during operation by using spring supports and expansion loops where necessary.



Centerline Offset | Parallelism | Rotational – Two Hole

- Flange sealing surface inspection and assurance that the surface condition follows the requirements outlined in ASME PCC-1 Appendix D. Identification of repairs needed, and correction of sealing surface defects is vital before assembling the flanges.
- Torque or tension specifications for the bolt or stud used to ensure adequate bolt tension for sealing of the flange union.
  - Remember that torque is not directly related to bolt tension because of inherent error factors. Thread friction caused by surface asperities and dimensional inaccuracies; torque wrench calibration; and surface friction of the nut to the flange or washer surface are all factors that add up to errors of 30% or more.
  - These inherent errors are the reason that when using torque alone the maximum calculated stress should be limited to 60% of the yield stress to avoid overstress caused by these errors. Once a bolt is stretched beyond its yield point it is no longer useful and should be discarded!
  - For the reason mentioned above we never want to use an impact wrench to tighten flange bolts.
  - Bolt tensioning and measurement of bolt stretch should be used when higher accuracy is needed because of flange temperature fluctuations, or other factors that could cause bolt overload.
  - In critical applications, bolt stretch should be the controlling limit of bolt load. Bolt stretch will directly determine the stress of the bolt (in the elastic range) using the

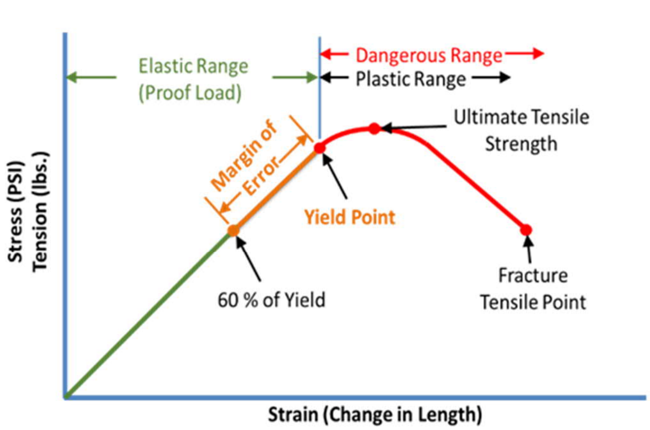
formula F=dl*EA/L; Where F is the bolt tension produced, dl is the stretch of the grip length (part of the bolt that is stretched), E is the modulus of elasticity, A is the stress area of the bolt, L is the original grip length.

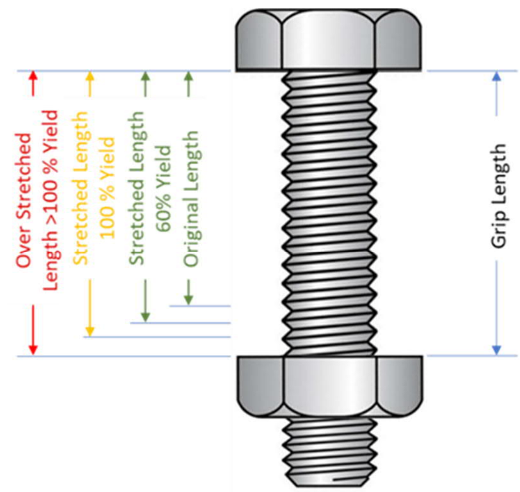
- Bolt and nut size specification for the class of flange and material specifications.
  - Material and size will determine the maximum yield strength of the bolt or stud.
  - Bolt length should allow complete thread engagement with minimum 2-3 threads exposed after final tension of the bolt.
  - Remember that stainless alloy bolting is normally not as strong as B7 carbon alloy steel materials. This can cause problems when steel alloy bolting is substituted with stainless alloy bolting to avoid corrosion issues without taking the reduced strength of the stainless bolting into consideration.
  - Bolt hardware identification is essential and if identification is missing it should not be used.
- Lubricant specification when used.
  - Lubricant is required at all mating surfaces (nut to washer or flange surface and all threads of the stud or bolt). Incomplete lubrication will cause inaccuracies of the bolt torque.
- Type, size, and class of gasket used.
  - Different style gaskets will have unique bolt loads required to seal adequately.
  - With some gaskets the final compression is another indication of flange union integrity. With raised face flanges the gap can be measured using feeler gauge gap readings with bolts snugged/hand tightened compared to final gap readings after the final torque or tension of the bolt. This determines gasket compression.
  - The gap readings should be taken at each bolt location and should be consistent. This check verifies proper flange alignment and adequate clamp force.
- Bolting sequence specification.
  - Using individual torque wrenches or tensioners requires the tensioning process to be done in no less than 3 defined steps in sequential crisscross pattern to achieve the final desired bolt stress.
  - In applications that have special components such as glass or Teflon lined piping more steps may be required depending on the vendor recommendations.
  - There are other varied procedures concerning sequence of bolt tensioning or torqueing depending on the equipment that is used and the piping configuration.
  - Some equipment such as tensioners when used concurrently can simultaneously tension the bolts and this will enable more leveled tensioning of the assembly.
  - The most important point is that all bolts are snugged (less than 10% of final tension or stress) before continuing the exercise. This eliminates the dangerous practice of using bolts to pull an out of alignment flange into alignment with the flange bolts.
- Operational Temperatures and Pressures when applicable.
  - The calculations for thermal changes of the flange and bolt, as well as pressure changes should be done and carefully reviewed in advance.

- This allows for determining the final applied tension to be specified for tightening at atmospheric temperatures and pressures.
- These calculations can be somewhat complex and should be done by engineers experienced in these types of services for flange unions.

Understanding Bolt Mechanics

It is vital that the workforce assigned to flange assembly is aware and understands the mechanics of bolting. The figure below is a pictorial explanation of the stages of bolt stress. In viewing this illustration, we need to stay to the left of the Dangerous Range, the phase where the bolt enters plastic deformation. In this range, the bolt clamping force is no longer proportional to the bolt stretch. The bolt strength is jeopardized and eventually with continued tightening it will lose all clamping force. This range is dangerous because we are now in the blind as far as bolt clamp force and we cannot be assured the clamp force is adequate to seal properly.





Looking at the above figure, we can reduce the margin of error by using tension and bolt change in length instead of torque as a controlling factor. Using bolt tension allows one to increase the bolt load and have assurance that the bolt remains in the elastic range since we are eliminating the sources of error encountered when using torque alone. This enables us to do adequate sealing for applications that have temperature and pressure variations and/or have clamp force requirements to seal that exceed 60% of the yield strength of the bolt. Bolt length is measured with precision UT equipment.

Conclusion

In this article we speak about bolt up of flange unions, however this model can be expanded to cover all bolting applications. Too often in industry precise bolting takes a back seat to the “more glamorous” aspects of maintenance such as turbine rebuilding, etc. Because of this we sometimes put our most inexperienced and untrained personnel to do bolting exercises that are often considered for manual/less skilled labor. This leads to bad and sometimes catastrophic results.

Here we have covered some of the main aspects of implementing a structured bolting process to eliminate disasters caused by not giving the attention that this process requires. In the interest of brevity many details are not covered. The writer's recommendation is to do a review of your bolting processes, identify gaps (areas of risk) and eliminate them one by one. This is an important exercise in defect elimination that will contribute to a safe and efficient workplace in the long haul.

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Bibliography

ASME PCC-1, Guidelines for Pressure Boundary Bolted Flange Joint Assembly, Standard by ASME International, 09/30/2019