Flange disassembly – An underrated source of safety incidents

While much has been written about the importance of correctly assembling flanged joints to ensure the reliability and safety of the joint, there has been relatively little published about the potential for incidents during disassembly of these joints.

Despite ASME PCC-1 offering a warning and guidance on the disassembly of thick flanges and general good practices in various training documents avoidable incidents still occur.

This paper presents formal studies and case histories that can be used to formalize and strengthen procedures and technician training. The paper will include scenarios of flange disassembly both with and without internal pressure and will highlight the potential for incidents that could arise from them. Finite element analysis and case histories will be used where applicable to support or illustrate the results.

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Introduction

Flanged joints are widely used in pressure piping, pressure vessels, and heat exchangers in petro-chemical industries. The need for joint integrity while a plant is running has resulted in lots of research and many papers being written about the importance of correctly assembling a flanged joint. However when it comes to disassembly of these joints there is relatively little information available about the potential for safety incidents.

In this paper the current perceived received wisdom will be reviewed and compared with results from finite element modelling. The effects of flange thickness will be considered as well as the bolt removal sequence, the bolt removal sequences compared are the cross pattern from ASME PCC-1 2013 and rotational order. The potential for safety incidents will be highlighted using case histories.

The results appear to contradict the current perceived wisdom and highlight the need for more focus to be placed on flange disassembly.

Current Information

Currently there is very little information available about the disassembly of flanged joints.

Paragraph 15 in ASME PCC-1 2013 provides some advice on flange disassembly. First it highlights the importance of ensuring the system is completely pressure free prior to the joint being opened. While this is written in most procedures, incidents still occur due to joints being disassembled with pressure behind them.
Elastic recovery of the clamped components is considered particularly when loosening bolts in a rotational order, stating that this “can result in excessive loads on the relatively few remaining bolts”. It points out the potential for galling between the nut and potential and subsequent potential for torsional overload. To mitigate this ASME PCC-I 2013 recommends loosening the bolts in a cross pattern. According to ASME PCC-I 2013 the reported incidents of disassembly difficulties have typically involved

a) Flanges larger than DN 600 (NPS24)
b) Flange thicknesses greater than 125mm (5in.)
c) Bolt diameters M45 (1¾in.) and larger.

It suggests that a disassembly procedure meeting the criteria of ASME PCC-I 2013 paragraph 15.1 may be desirable for such joints.

A paper presented at the 2002 ASME Pressure Vessels and Piping Conference titled Finite Element Simulation of the Disassembly Process of Pipe Flange Connections\(^2\) provides information about the mechanical behavior of flanged connections during disassembly. The key parameters assessed in the paper are flange size, flange rating and bolt removal sequence.

The analysis found that the maximum bolt load seen during flange disassembly increases with increasing flange size and rating class. This is consistent with the information provided in ASME PCC-I 2013.

Both the cross pattern recommended in ASME PCC-I 2013 and rotational order were modelled as bolt removal sequences in the paper. It was found that the bolt loads generated by the star pattern are significantly higher than the bolt loads generated by removing the bolts in rotational order. This was validated with experimental results. This result is inconsistent with the information presented in ASME PCC-I 2013. Another important finding of the analysis was that maximum bolt loads are significantly reduced when the bolts are removed in two or more passes.

**Finite Element Analysis**

After a near miss at Methanex New Zealand Ltd. where a nut rapidly dislodged while disassembling a 42" blind flange, Matrix Applied Computing Ltd. were contracted to model the flange to provide greater understanding of the bolt loads in the flange during disassembly. This initial investigation included two flange thickness dimensions, the bolt removal sequence was the cross pattern recommended by ASME PCC-I 2013. It confirmed that the load on the remaining bolts increases as bolts are removed, as found in the 2002 finite element simulation. The increase in bolt loads is caused by elastic recovery of the flange, there was no internal pressure or pipe stresses included in the model. The magnitude of the bolt loads seen in the simulation also reinforced the need for care and consideration when disassembling large diameter flanges.

![Screenshot from thick flange unbolting animation](image-url)

**Figure 1. Screenshot from thick flange unbolting animation**
Unexpectedly, the bolt loads in the thin flange were significantly higher than the bolt loads seen in the thick flange. As can be seen on the stud highlighted with a red circle in Figure 1, the thick flange, the stresses are mostly in the yellow and orange areas of the scale (400MPa-500MPa). While in Figure 2, the thin flange, the stresses are mostly in the red region of the scale (600MPa) and the maximum stress is in the grey area (739MPa+), this is above the yield strength of a standard B7 or B16 stud. This result was counter-intuitive and is anomalous to the current information from ASME PCC-1 2013 that bolt loads during disassembly increase with increasing flange thickness.

The investigation was expanded to try and understand the anomaly from the original results where the bolt loads in the thin flange were higher than the bolt loads in the thick flange. The original 42in. pipe to blind flange model was expanded to include a pipe to pipe joint, and a gasket. An 18in. class 300 flange was also modelled for comparison. As per the 2002 finite element simulation, the results were plotted as a bolt load ratio against the bolt removal sequence, the removal sequence modelled was the cross pattern from ASME PCC-1 2013. The bolt load ratio is the force on the bolt during disassembly versus the initial bolt load prior to disassembly.

All of the scenarios saw the bolt load ratios increase in a similar pattern to that published in the 2002 paper with the loads increasing in steps to a maximum followed by a rapid drop in load for the last few bolts. There were too many variables to draw any valid comparisons between diameters and thicknesses.

The models were adjusted so that one variable could be examined at a time. A 24in. flange which is the largest standard ASME B16.53 flange was modelled instead of the 42in. flange which was not a standard size. To compare diameters a standard ASME B16.5 12in. flange was modelled instead of the 18in. flange. The model includes a gasket of standard ASME B16.204 dimensions, the properties of the gasket are assumed to be the same as carbon steel based on the assumptions that the flange faces will pull up against the outer and inner ring of the gasket and that there is very little relaxation of the spiral wound part of the gasket during flange disassembly. Class 300, 600, 900 and 1500 flanges were modelled.
With the number of variables reduced the results became more consistent. While there was remarkably little difference between the 12 inch and 24 inch flanges, the result that stands out is the 24 inch class 300 flange. This has significantly higher bolt loads than all of the other flanges as is particularly noticeable when compared with the 24 inch class 600 flange that also has 24 bolts. This backs up the findings from the original model of the 42 inch flange that a thinner flange produces higher bolt loads during disassembly. Notably, the peak load ratio is 2.24 times the original bolt load meaning there is a real possibility of yielding the stud.

There are geometrical differences between the class 300 and class 600 flanges other than just the thickness. To focus purely on the thickness the 24 inch class 300 flange was modelled with varying thickness while keep all other dimensions constant. The thicknesses modelled were original thickness (t), 0.5t, 1.5t, and 2.0t. The pipe to blind flange model demonstrated the expected behaviour with the bolt load ratio decreasing with increasing flange thickness.

The same simulation was run for a pipe to pipe flange joint with similar results. The half thickness flange had unexpectedly low bolt ratios, but the remainder of the thicknesses followed the expected pattern. It was noted during the model that the half thickness flange deflected to the point where the two flange faces contacted each other, reducing the energy stored by the flange and explaining the unexpectedly low bolt ratios.
In the 2002 finite element simulation it was identified that removing the studs in rotational order rather than a star pattern resulted in lower bolt load ratios. The 24 inch class 300 flange simulation seen in Figure 5 was run again removing the bolts in rotational order. The results confirmed those of the 2002 study with the maximum bolt load ratio seen only 1.51 compared with 2.24 for the star pattern.

Investigation into the incident identified failing to follow the flange un-bolting procedure as a contributing factor. The procedure requires the flange seal to be broken while there are four studs remaining in the joint. This helps mitigate any unexpected release of energy. In this instance it would not have prevented the leak, but it would have reduced the risk to the craftsmen disassembling the joint.

As was reported at the 2014 Ammonia Safety Symposium workshop, another incident involved a major girth flange sealed with a lip seal gasket that was being disassembled while internal pressure remained. The nature of a lip seal gasket allowed significant unbolting to occur without loss of containment. However the lip seal gasket had distorted to the point where it required replacing which is not a trivial task, making this a significant incident. While the flange was being disassembled the warning signs that internal pressure remained were present to the technicians, but were not recognized. The warning signs reported were the remaining studs becoming progressively harder to remove as the flange was disassembled.

Case History – Near Miss, Methanex New Zealand Ltd
The bottom flange on a vertical heat exchanger was being disassembled on a plant that had been shut down for four years. The nuts were being gas cut as they were seized, while cutting the fourth to last stud the nut rapidly and unexpectedly dislodged and fell to the ground twenty feet below.
This was recorded as a potential major incident due to the dropped object and a Taproot® investigation was carried out. One of the root causes identified in the investigation was the flange joint assembly procedure not specifically addressing the disassembly of large flanges. The procedure states that “large flange sizes require a specific disassembly procedure to avoid overloading studs” but does not include any further guidance of the procedure to be followed.

The finite element analysis presented in this paper was initiated as a corrective action from the incident investigation.

**Flange Disassembly Training**

Methanex New Zealand Ltd currently has in-house flanged joint assembly training that all staff and contract mechanical maintenance technicians complete. This comprises of practical information on the importance of assembling a flange correctly including:

- Flange and stud condition
- Gasket selection
- Flange alignment

Lubrication
- Bolt up sequence

The theoretical training is followed by a practical session on a purpose built flange joint test rig; this allows supervisors to confirm that the technician has understood the training and is capable of applying it in practice.

As a result of this research flange disassembly has also been included in the training. This highlights the potential for incidents due to increasing bolt loads during the disassembly process and the need to be completely certain that the system is pressure free. Another important facet added to the training is the requirement to ensure the seal on the joint is broken with a minimum of four studs remaining; this reduces the impact of any potential incidents due to pressure remaining in the system.

The flange training test rig has been modified to mimic internal pressure using an internal spring and technicians are required to disassemble the flange during the training. This will help give the technician a feel for the telltale sign of inter-
nal pressure remaining in the joint, the increase in bolt loads and consequent increase in torque required to remove the nuts during disassembly.

Conclusions

Current information indicates the potential for safety incidents during disassembly and is backed up by case histories. The current perceived wisdom is that care needs to be taken when disassembling thick large diameter flanges and that a star pattern is the best order to remove the studs, however, recent work has called this recommendation into question.

Further research using finite element modelling confirms the potential for incidents but is contrary to some of the current information. It indicates care should be taken when disassembling all flanges that are large in diameter regardless of thickness and that the bolt loads seen during disassembly actually decrease with increasing flange thickness. The analysis shows that the bolt loads can be reduced by removing the studs in rotational order rather than in a cross pattern. Another method to reduce bolt loads demonstrated is removing the studs in two or more passes instead of in a single pass.

Steps that can be taken to reduce the potential for safety incidents during disassembly of large diameter flanges include:

- Highlighting the risks associated with disassembly of large diameter flanges in procedures and training
- Removing studs from large diameter flanges in rotational order rather than a star pattern, and with multiple passes.
- Use of a flange joint training test rig to mimic a flange being disassembled with pressure behind it
- Highlighting the “at risk” flanges that require care during disassembly on the bolt torque chart

References
