Joint relaxation behaviour of gasketed bolted flanged pipe joint during assembly

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Abstract: **-** The success of a bolted flanged pipe joint depends upon its proper assembly using proper pre-loading with static mode of load. A dynamic mode is claimed in the gasketed joint, resulting in joint relaxation, fatigue mechanism and ultimately joint failure. This paper presents results of detailed experimental studies for a gasketed joint during assembly, highlighting the importance of proper bolt tightening sequences, bolt pre-loading, bolting and bolt tightening methodology, number of passes to make a joint, gasket quality, gasket physical condition, gasket location and use of different gaskets in the joint, as all these factors can provide joint relaxation. Based on the results and observations, to control and avoid joint relaxation, recommendations are also given.

Key-Words: **-** Gasketed, bolted, flanged, pipe joints, relaxation, gaskets, pre-loading

1 Introduction

Bolted flanged pipe joints are used in industry for the past several hundred years. The success of a bolted flanged pipe joint depends upon its proper assembly using high quality bolts, proper tooling, and proper tightening methodology and so on. A properly pre-loaded joint that assures a leak proof joint requires a static mode, discussed by [1-5,18-19]. Although it is mentioned [2,13,15,19] that dynamic mode rules in the gasketed joints, however, to the authors knowledge a very little attention is given in this area to highlight it experimentally. A short term joint relaxation in gasketed joint assembly is discussed by [8] theoretically. This paper presents results of extensive experimental studies carried out; using different gaskets in the joint to highlight the importance of bolting, bolt sequence, pre-loading, gasket quality and location. Based on phenomenon of relaxation, dynamic mode of load and fatigue mechanism during joint assembly is highlighted. These factors are very important to ensure a leak proof joint, as each of these can be one of the main causes of the joint failure. From results, improper sealing capability of gasketed joints due to joint relaxation, resulting in joint failure is concluded.

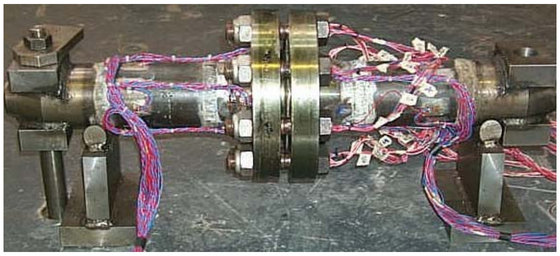
Retightening, to overcome joint relaxation, is not mentioned in any code and is under conflict as is also mentioned in European Sealing Association. [11]. It is concluded that re-tightening provides worst effect in a gasketed joint during operating conditions [3,15], resulting in permanent damage to flange, relaxation of joint and its failure. In addition, due to the inconsistent flange dimensions of different sizes, reason for no proper bolt tightening procedure to be standardized is also discussed.

2 Experimental Program

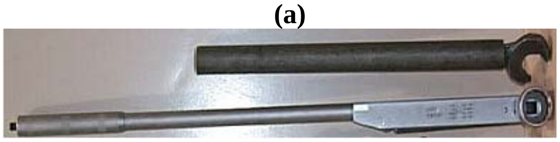
A series of experiments using different gaskets in the gasketed flange joint assembly are performed to examine joint relaxation behaviour during joint assembly.

2.1. Flange Type, Size and Tools

A four inch nominal bore, class 900# gasketed flange joint is selected and suitable test rig is made. For all the tests, same pair of gasketed flanges with four different gaskets of same dimension, same properties and same material is used in assembly to examine variability in supplied gaskets and its effect on joint's relaxation behavior. The gasketed joint assembly and tools used to make the assembly are shown in Fig. 1a and 1b respectively.



(a)



(b)

Figure 1: (a) Gasketed flange joint assembly, (b) Tools

2.2. Bolt Selection

Bolts are considered the most important entity for the proper joint pre-loading and its effect on the joint's failure. In a gasketed joint, pre-load in the bolts should be capable of compressing the gasket as per recommended seating stress values of the gasket suppliers. Preload in bolts is achieved by rotating the nut thus driving it along the helix angle of the thread. In reality, there is no frictionless system; friction exists in the thread, and under the face of the nut, so only a part of the load (10 to 15%) [12], is converted into the useful axial bolt load. This is due to the large variability in the bolt loads for small variations of coefficient of friction even if the applied torque is constant [3].

Bolts are selected as per ES090. [10]. i.e. ASTM A193 GRADE B7 and B7M. The use of lubricants with a lower coefficient of friction than 0.10 could lead to excessive bolt stress applied by torque wrenches, resulting in failure of flanges or bolting. For this reason, Molybdenum Disulphide Greases are not recommended for use. Therefore, Copper-slip lubricant with friction coefficient 0.10 is used on the thread of the bolts, recommended as per ES090 [10].

2.3. Strain Gauging and Instrumentation

Quarter bridge circuits are made with the data-logging system for strain measurements. Four strain gauges of 350Ω at an angle of 90 degree on the shaft of each bolt are placed to observe bolt bending and bolt relaxation behavior. To attach strain gauges a groove of 2-mm is machined on bolt shank to avoid these from damage and all the leads are placed on the hexagonal head of the bolt through a very small hole drilled in the bolt head [Fig. 2].

Figure 2: Bolt strain gauging

2.4. Bolt Calibration, Bolt Tightening Sequence

Using original joint assembly bolts are tightened and calibrated as per sequence mentioned in the document ES090 [10] as to ensure a proper pre-load in a bolted joint, proper bolt tightening sequence is very important. Following two tightening sequences are used [Fig. 3a].

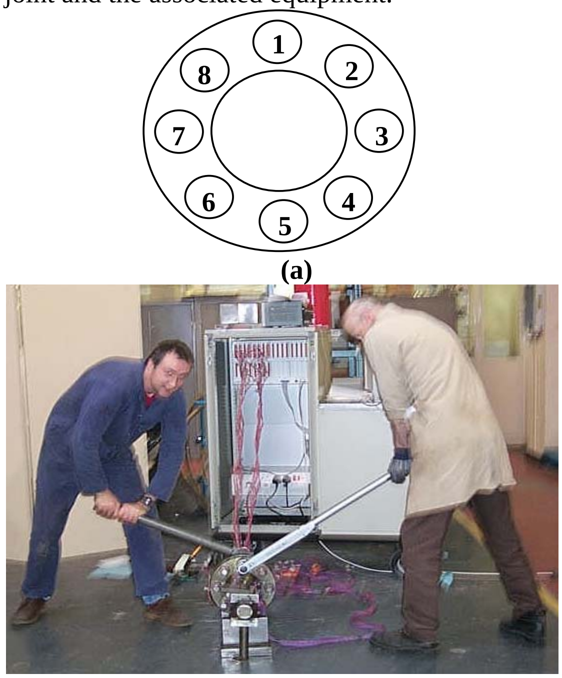
- Sequence-1 1, 5, 3, 7, 2, 6, 4, 8; an industry standard approach [10]
- Sequence-2 1,2,3,4,5,6,7 and 8; as per experimental testing [3]

Each bolt is tightened by increasing torque in four increments i.e. 210, 310, 400 and 505 Nm as per bolt tightening Sequence-1, with copper slip lubricant applied on the threads of all the bolts recommended as per industrial standard [10]. After last torque load application (505 Nm), as per Sequence-1, all the bolts are also tightened as per Sequence-2 to achieve higher pre-load values in the bolts. After tightening each bolt, strain is recorded to observe relaxation effect on other bolts.

2.5. Bolt Pre-loading and limitations in achieving proper pre-loading

The greatest single factor, that can eliminate stress variation in fasteners due to the cyclic loading, is their proper pre-tensioning or pre-loading. The associated ASME [6], BS [9] and EN [17] standards do not specify a magnitude of pre-load for the bolts. These preload values are recommended by the gasket suppliers to control gasket crushing and achieve required gasket seating stress. From initial strain results, it is observed that maximum recommended torque applied could only achieve 30~35% pre-stress of the yield stress of the bolt material [3]. This is concluded very low, resulting in bolt relaxation during bolt up and leakage during operating conditions. Although these preloads avoid gasket crushing, but still provide stresses close to the yield stress of flange material at certain locations around the flange hub fillet due to flange rotation and is one of the main reasons of bolt relaxation due to permanent damage [3,13].

Due to the gasket flexibility and flange rotation providing bending of the bolts, it is difficult to achieve the proper pre-load in the bolts in a gasketed joint. Although in gasketed joints, bigger diameter high strength bolts are used to compress the gasket to the required seating stress, but proper strength of these bolts is not utilized to avoid gasket crushing as discussed above. This results in improper and low pre-load, bolt relaxation and ultimately leakage. In addition, controlled tightening of large diameter bolts using crude methods such as hammering and flogging is difficult, which in turn cause damage to joint and the associated equipment.



(a)

(b)

Figure 3: (a) Bolt tightening sequence, (b) Gasketed Flange Joint Tightening

2.6. Flange Joint Assembly and Tests

Hand-tightening methodology (being the first and the most economical choice of assembly) is adopted using a calibrated torque wrench of capacity 0~810 Nm along-with the other spanners. During joint assembly, using the same bolts, same set-up, same technicians, same lubricant, and calibrated torque wrench even then, stress behavior of each joint is marginally different. In addition, joint assembly is made in a very controlled environment, and such controlled loading cannot be ensured in actual field. As it is difficult to tighten the joint, therefore, two technicians are engaged whilst the assembly is held and fixed in the ground to avoid it from rotation, Fig. 3b. However, it is not the case in field applications as most fitters tighten the bolts as hard as possible to stop the leakage. This may result gasket crushing, flange yielding or bolt broken in actual situations as observed during industrial visits [3,9]. Tests are performed using four different gaskets and condition of each gasket is observed, upon removing from the joint after dismantling the assembly.

3. Results and Discussion

Results during joint assembly are plotted in Fig. 4 to Fig. 9 for the bolt sequence versus average strain with applied torque in each bolt and are discussed below.

3.1. Bolt Relaxation Behaviour

Gasket-1, Sequence-1: Using gasket-1 and sequence-1, joint is made for the very first time with virgin bolts with Nyloc. Two sets of experiments are performed using same gasket. From Fig. 4 and Fig. 5, it is obvious that during each tightening pass, strain in each bolt is almost the same and highest strain is always observed in the last bolt. No visible relaxation is observed in any of the bolt. Bolt-2 showed a high strain at the highest torque value, which is the first bolt after tightening the first four bolts. Joint is re-tightened after one hour and small relaxation in some of the bolts is observed. Using same gasket second time provided better results for bolt strains as compared to first set. For these joint assemblies, due to observed relaxation even after preload of 505 Nm, it is tightened twice using sequence-1 to achieve required torque in bolts. Finally bolts in joint are tightened using sequence-2. A better strain behavior in all bolts observed after the final round applying sequence-2. Under operating conditions, no seepage or leakage is observed from the joint.

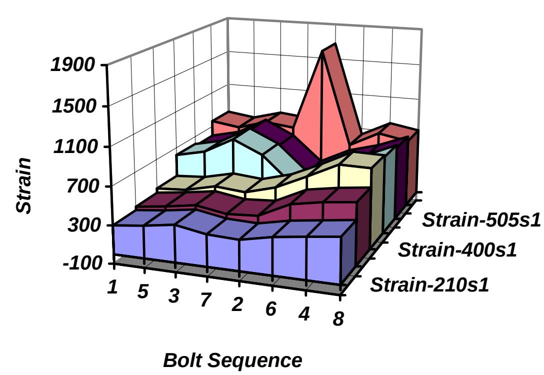


Figure 4: Avg. Bolt Strain Vs Bolt tightening Sequence-1 (15372648) using Gasket 1 (set-1)

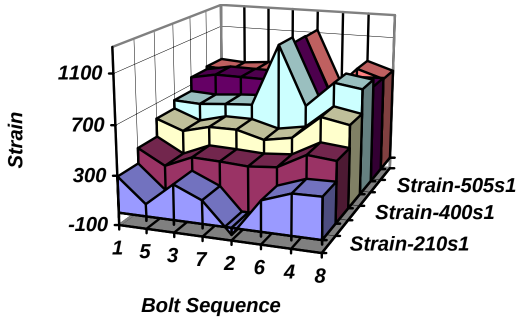


Figure 5: Avg. Bolt Strain Vs Bolt tightening Sequence-1 (15372648) using Gasket 1 (set-2)

Gasket-2, Sequence-1: Two sets of experiments are performed using same gasket. Bolts are observed in good condition, properly lubricated with copper-slip and are used third time. Bolt-5 showed some relaxation and is only controlled at the final round and applying sequence-2. Results are plotted in Fig. 6. Under operating conditions, no seepage or leakage is observed from the joint.

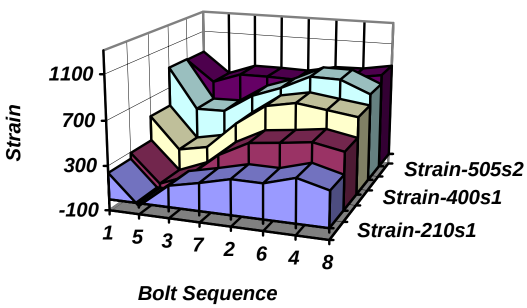


Figure 6: Avg. Bolt Strain Vs Bolt tightening Sequence-2 (15372648) using Gasket 2

Gasket-2, Sequence-2: Using sequence-2, even at the maximum torque of 505 Nm and final round, bolt 3, 4, 5 and 6 are found almost relaxed and it is also felt during tightening. Results are plotted in Fig. 7. No tests for operating conditions are performed after joint assembly. Comparing results of both tightening sequences, difference is obvious for joint relaxation.

Gasket-3, Sequence-1: Bolts are used for the fourth time and their threads are observed in good condition and properly lubricated with copper-slip. Almost same behavior as with gasket 2 is observed with a little bit higher strain in the first bolt. The condition of the gasket is found reasonably well. It is found properly compressed to the required thickness. It is important to note is that a very small seepage is observed from the joint. Results are plotted in Fig. 8.

Gasket-4, Sequence-1: Except at final torque in final round as per sequence-2, bolt 1, 5 and 3 are noted completely relaxed and is also felt during joint tightening. Instead, the gasket is observed in good condition without any damage. Results are plotted in Fig. 9.

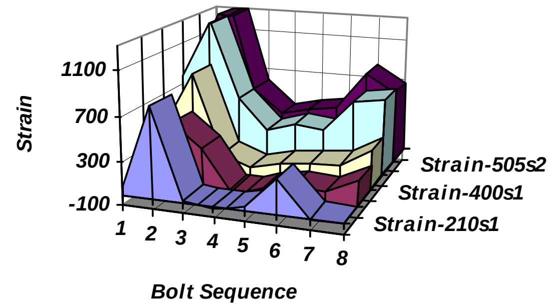


Figure 7: Avg. Bolt Strain Vs Bolt tightening Sequence-2 (12345678) using Gasket 2

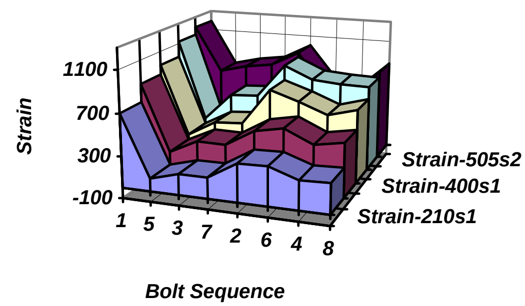


Figure 8: Avg. Bolt Strain Vs Bolt tightening Sequence-1 (15372648) using Gasket 3

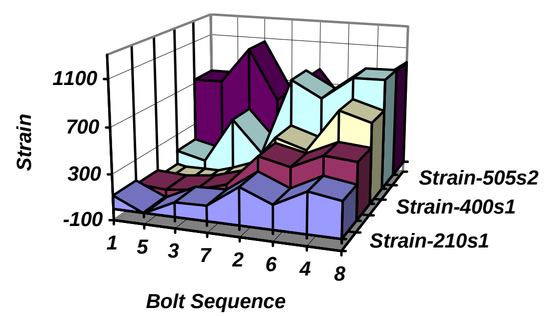


Figure 9: Avg. Bolt Strain Vs Bolt tightening Sequence-1 (15372648) using Gasket 4

3.2. Condition of the gasket before and after joint assembly

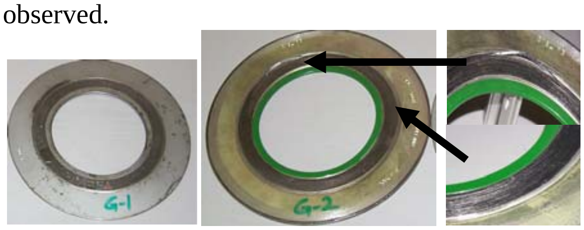
To understand gasketed joint's behavior it is important to observe condition of the gasket before and after joint assembly, as it is one of the most important entity of a joint, due to which relaxation could occur. The outer ring of each gasket received from the supplier is ground to reduce dimension to fit between the bolts. This showed its incompatibility with the flange joint dimensions used. Gasket's dimensional inconsistency is also highlighted by Bibel. [7] and the industrial sector [3,9].

Gasket-1: After performing the experiments for both bolt-up and operating conditions, gasket is taken out and its physical condition is observed. Centering ring is found bent which may be due to the applied bending loading. The spiral wound portion is reasonably compressed; except at one position observed more compressed. The same gasket-1, already compressed used earlier, is used for the second time to make another joint assembly again. After dismantling joint assembly and removing, it is found more compressed, less than the centering ring thickness on one side. Some dents are observed along about 90 degree on one side and centering ring is bent more as shown in Fig. 10a.

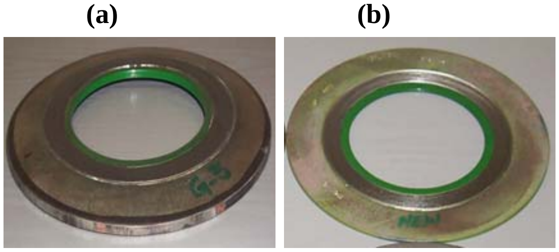
Gasket-2: It is used only for bolt-up, so centering ring is not bent; however its spirals are damaged from one side along with dent at about 180 degree as shown in Fig. 10b.

Gasket-3: Gasket is found reasonably compressed with no damage to the spirals as shown in Fig. 10c, however, seepage is observed from the joint during operating conditions.

Gasket-4: Gasket is found in good condition as shown in Fig. 10d. Instead, the joint relaxation observed is quite high and only after the final round as per sequence-2 a reasonable joint tightness is observed.



(a) (b)



(c) (d)

Figure 10: (a) Gasket-1, No damage, (b) Gasket 2, Damaged Spiral, (c) Gasket-3, bent central ring, (d) Gasket-4, No damage

4. RECOMMENDATIONS TO AVOID JOINT RELAXATION

In the light of above discussion following recommendations are given to avoid joint relaxation;

- Virgin bolts are recommended each time for joint assembly, as reusing the same bolts several times, strain behavior of the bolts changes. The last bolt always showed a considerably higher strain value for each pass, whereas the bolt-5 tightened second in the sequence shows low strain value resulting in the relaxation of bolt and ultimately fatigue and joint failure. In addition, bolt behavior also depends on the gasket behavior used in the joint.
- Bolt quality and its physical conditions such as thread treatment should be ensured. During present study, assembly is made in very controlled and non-corrosive environment, which is not the case in actual working conditions.
- Joint tightening should be performed in at least 5 passes [1,3,11]; It is obvious from the results that as the pre-load increased more even strain distributions are achieved in all the bolts [8].
- Proper joint tightening sequence-1 is most important for a gasketed joint to avoid relaxation. However it is observed that it is important to give a final pass starting from bolt 1 to bolt 8 as per sequence-2 to ensure higher pre-load in the joint.
- Bickford [8] recommend that the first bolts should be tightened to higher pre-load than the last ones. Present author support this only to a certain extent, because it is not the case always. Due to uneven pre-load pattern during the first passes in different bolts it can not be exactly guaranteed and this can result in more uneven pre-load and residual scatter. Present author also does not totally agree with his theory for the pre-load loss after the first pass as regular tooth saw pattern. Similarly, for more than five passes it is very much dependent on different parameters such as fitter, gasket, bolting, tooling and bolt tightening technique (hammering or flogging), it is very difficult to form a mathematical relationship between the torque applied and strain measurements for different joint sizes.
- It is difficult to ensure proper pre-loading and sealing, based on the good condition of the gasket observed after joint assembly, as seepage from one joint assembly is observed. Based on this, it is concluded that bolt behavior is mainly dependent on gasket behavior used in joint.

- For proper gasketed joint assembly, quality of gasket and its proper location between flanges is very important for it to be compresses properly. To get proper gasket seating stress avoiding its crushing, assurance of accurate controlled torque must be applied, which can not be assured in the field. This depends on certain factors such as bolt quality, tooling, methodology adopted; joint size, joint location and fitters. In addition, deformation of flanges during welding with the pipe i.e. parallelism should be controlled, otherwise resulting in gasket damage, no matter how much controlled pre-load is applied. This will provide joint relaxation and ultimately joint failure.
- Relaxation is observed during both the pre-loading and the pressure loading at the room temperature during experiments. However, a decrease in bolt stress can also occur in services at elevated temperatures, because of creep in the bolt, flange or gasket material resulting in leakage and joint failure.

5. CONCLUSIONS

It is concluded that even using same bolts, same set-up, same technician, same lubricant, calibrated torque wrench, controlled bolt tightening methods or environment, the behavior of joint relaxation for a gasketed joint can not be avoided. It varies even for the same joint tightened each time and also for different joints used. Use of sequence-2 followed by sequence-1 is important to get recommended pre-load in the joint and in at least five passes. Using sequence-2 only can never ensure joint tightening. Concluding, joint relaxation behavior in gasketed joint results in dynamic mode, providing fatigue mechanism in the joint, and is the main cause for its failure.

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