RESEARCH

20” FLANGE CONNECTIONS

Research to the relaxation and range behavior of stud bolts when replaced in a system under pressure

Gasunie Netherlands
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SUMMARY

This report studies the behavior of stud bolts during one by one replacement in a 20” flange connection under pressure of 66 Bar.

The purpose of this research is to determine the required tension force in the to be replaced stud bolt, taking into account the relaxation and range.

To apply this replacing method a special clamp is developed. Since the clamp hasn’t been used within the Gasunie or elsewhere before, it was necessary to test the mechanical strength of the clamp. For this a special elaboration was designed to test the clamp during operation. The clamp has also been tested by calculations of the program Cosmos. This calculation program is based on the restricted elements method. The results of the two test are compared in this research. Both tests conclude that the clamp doesn’t meet the standards set by the Gasunie.

Based on these results the decision was made follow-up this research on the feasibility of replacing the stud bolts one-by-one under pressure without using the Leak Repair Clamp. This research is focused on the following conditions:

- Relaxation behavior
- Range behavior

By a number of test these conditions have been studied. The following principal conclusions have been made:

1. The average relaxation value in flange connections with isolating gasket is appr. 36% (note: in general a value of 30% is applicable). This means that the tension force needs to be increased with 36% of the initial tension force to remain a tension force that corresponds with the desired initial tension force.
2. The course of the relaxation during the 2 tests clearly shows that the relaxation decreases when the connection is tightened step by step.
3. It is not shown that simultaneous tightening of all stud bolts in the flange connection by hydraulic tensioners isn’t accurate at all. During this test a huge inaccuracy of up to 86% with simultaneous tensioning was the result!
4. By removing one stud bolt under pressure of 66,2 bar it is proven that the range remains limited to 3 studs on both sides of the removed stud bolts. The total loss of gasket pressure as a result of removing one stud, is 45% at the removed stud bolt. This is the total of the loss of tension force in the adjacent stud bolts. However, the main loss is set in the direct adjacent stud bolts on both sides of the removed stud. This loss has an average value of 12% - 19%. Despite the total loss of 45% gasket pressure there were no leakages. So the remaining gasket pressure of app. 55% was sufficient to secure zero-leakage.
5. The tests show that the stud bolts in a flange connection under internal pressure can be replaced one-by-one without using the Leak Repair clamp, under the perfect conditions and new materials.
6. The flange deformation of the flanges is mainly caused by the tension force on the stud bolts. The internal pressure has only a small influence on this.
7. All tests are executed with isolating gaskets. These gaskets are more or less equal to the conditions of a flat face gasket. In other words, the above mentioned conclusions are also applicable for flat face gaskets.
8. More conclusions can be found in chapter 4.

RECOMMENDATIONS

Based on the conclusions of the Summary the following proceedings are recommended:

NOTE: The recommendations below are not only related to this research, but also to the internal organization of the Gasunie.

1. To minimize the effect of relaxation in flange connections during hydraulic tensioning, the following aspects should be considered:
   - The know-how of the operators tensioning nuts with a “locking ring” in the head of the hydraulic tensioner
   - To center the stud bolts during assembly of the flange
   - All studs and nuts should be clean, free of damages and well lubricated
   - Control of leakages in the hydraulic system of the tensioning equipment
2. Examine the possibilities of tightening methods with which the desired tension force can be checked and the know-how of the operator isn’t a crucial factor. An example is to apply hydraulic torque tools which are more ergonomic to prevent extra burden to the personnel because of the tensioning equipment.
3. The advice is to tighten the flange connection several times with a hydraulic tensioner, e.g. step-by-step.
4. It is proven that the use of the Leak Repair clamp is not necessary by one-by-one replacement of stud bolts. Both relaxation as range will be minimized because of this method. However, taken security into account a clamp is strongly recommended. In case of (invisible) corrosion of one or more stud bolts, the consequences for personnel, environment and organization can be enormous.
5. The tested Leak Repair clamp is not suitable for application within the Gasunie at a pressure of 66 bar under the current conditions. The design has to be reconsidered and a new modified design has to be tested before any usage within the Gasunie.
6. The results of the test with one-by-one replacement have shown that the maximum loss of gasket pressure varies between 12 – 19%. In general we assume a loss of 20%. In case of a relaxation value of 36% (see 1 at the Chapter Summary), the initial value to compensate the loss should be equal to 56% (20+36%). So, when using the clamp, the stud bolts need to be tightened with a tension force of 56% of the desired tension force.
7. Do NOT tighten the flange connections with unnecessary high tension force. This will lead to more tension and a bigger flange deformation. More flange deformation will lead to leakage of the gasket at the outside of the flange face and then to leakages in the flange connection.
8. Check the hydraulic surface of the tensioning equipment. There are more hydraulic tensioners with different hydraulic surfaces for the same nominal thread diameter depending on brand and type.
9. During all tests the stud bolts were tightened simultaneously. However, in general only half of the studs are tightened simultaneously. It is advisable to simulate the actual situation with a future test.
10. Because the mechanical characteristics of a spiral wounded gasket differs from a isolation gasket, it is wise to do the same test with a spiral wounded gasket to determine relaxation and range.
11. Flange connections with a stud smaller than 1 ¼ “ will be tightened with a torque wrench within the Gasunie. It is advisable to do the same test for this kind of connections.
12. As result of the conclusion in this report the Gasunie needs to modify specification CSW-43-N.

1. INTRODUCTION

The gas piping of the Gasunie is partly provided with flange connections. By environmental influences the studs and nuts are damaged by e.g. corrosion. When a corroded stud bolts or nut isn't replaced in time, this can cause dangerous situations and a safe gas supply cannot be guaranteed. Gas piping, which can be set out of order from a gas transport technical point of view, will be dismantled and provided with new gaskets and fasteners according to CSW-43-N (a technical standard for tightening flange connections within the Gasunie). In the piping network there are also piping lines (so-called RTL and HTL lines) which cannot be switch off, because of their vital function. This can be branches of the transport system to larger industries and energy suppliers. In this situation fasteners can be replaced one-by-one by using a particular designed clamp, the Leak-Repair-Clamp. At this replacement it is of vital importance that the new stud bolts and nuts will be tightened with the applicable tension forces prescribed in CSW-43-N. The used tension force can decrease, direct or after a while, because of relaxation or range during tightening. Because of this the preload can decrease which will lead to a reduction of surface pressure of the gasket and thus leakage of the flange connection can take place. An important question is:

What is the required tension force to tighten the stud bolts and nuts to guarantee zero-leakage, taking into account the influences of relaxation and range in the flange connections?

The influence of range can be eliminated by tensioning all stud bolts and nuts simultaneously. However, the influence of relaxation is much more complicated than the effects of range. There is much written about this, but in real life it is hard to predict. The best way to determine the influence of relaxation is by testing.

To examine the above mentioned a test will be conducted using a 20" flange connection, ANSI 600 (at pressure of 66,2 bar). The inferred relaxation factor will be implemented in specification CSW-43-N.

2. DEFINITION OF THE PROBLEM

At one of the export stations of the Gasunie there exists a problem with a 20" flange connection with isolating gasket at a pressure of 66,2 [bar]. The isolating gasket guarantees a cathode separation between the pipe line and the installation. In this connection the studs and nuts are seriously corroded.

These components need to be replaced. Due to the vital function of this pipe line, it is not possible set the line out of order. The Gasunie has chosen to replace the studs while the transport of gas is still running.

The exchange involves the replacement of studs, nuts, steel washers, isolating washers and isolating tubes. The isolating gasket cannot be replaced.

In August 2005 the Gasunie has tried to replace the studs with the accompanying elements one-by-one using the Leak Repair Clamp. It was the first time the clamp was used for a 20" flange connection. Because doubts arose during assembly, all activities were stopped. Before the clamp is used again, the following questions needs to be answered:

1. Does the clamp meet security requirements with regard to mechanical strength to take over the total tension fore of the flange connection under pressure of 66,2 [bar]?
2. What tension force is required to replace the studs of a flange connection one by one under normal conditions?

3. GENERAL TECHNICAL INFORMATION

The following subjects will be commented in this chapter:

- What is relaxation?
    i. The relaxation to be expected
    ii. How to reduce relaxation?
- What is range?
- The behavior of the flange connection with and without external force
- What are the possibilities to replace stud bolts at vital pipe lines?

3.1 What is relaxation?

Relaxation in a flange connection is the loss of preload in the connection after assembly. A flange connection is composed of multiple components which seal the transported medium from the atmosphere. Relaxation in a flange connection is an extremely complicated issue since many parameters can be the cause of loss in preload. The most common causes:

- Embedded flange face-nut or stud bolt-nut:
  The surfaces of the thread of the fasteners (stud bolt and nut) and those surfaces exposed to preload, washer, etc are never completely smooth. Examined with a microscope the surface appears to be rough. When a rough surface encounters a heavy load for the first time, great tension arises on the top of both surfaces (see fig. 3.1).

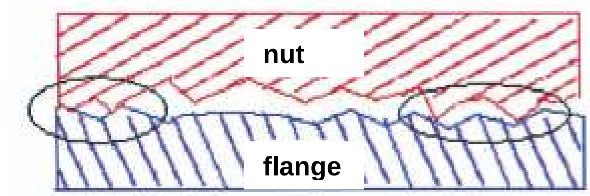

Fig. 3.1 schematic view of surfaces

The joint surfaces are relatively small and cannot handle the load. The top of the surface will experience a plastic transformation until the surface pressure is even with the produced load.

Many of the so-called surface tops disappear in the tightening process by torquing. However, when using hydraulic tensioners there is no pressure at potential relaxation points during tightening. The pressure arises when the hydraulic tensioner is released. This way the embedded relaxation is higher with hydraulic tensioning than with torquing. This last method is used at the test.

Embedded characteristics have greater influence on new components (like studs and nuts) than at used components, because the contact-surfaces are smaller (there has already been relaxation). That is why is it advisable at vital connections to tighten and loosen the fasteners several times to minimize the relaxation.

- Weak contact between thread stud bolt and nut:
  When using undersized studs and nuts it is possible that the contact surface cannot handle the load, with relaxation as a result.

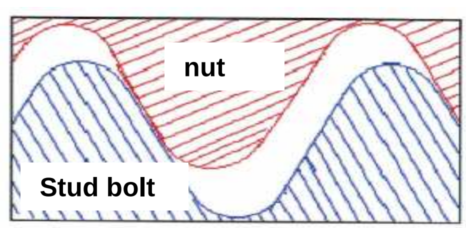

Fig. 3.2 schematic view of thread surfaces

- Clamping length of stud/nut:
  The clamping length of a stud in a nut has to have a minimum value of 0,8 (value depends on the material) x the nominal diameter of the stud. If this length is shorter, the contacting surface of the combination stud-nut is too small. This may lead to sliding and relaxation in the whole connection.

- Soft components:
  When components are softer than the engineer has calculated, e.g. because of a weak heat treatment or of the lacking quality of the materials used. Despite the right measurements and calculations relaxation can occur.

- Inclination of stud bolt:
  When the stud bolt inclines, one side of the stud will experience more tension. Because of this tension more embedding occurs and thus more relaxation. The inclination is the result of flange deformation during tightening of the fasteners.

- Curved nuts:
  The contact surfaces of nuts are never completely straight compared to the base line of the stud bolt or the base line of the hole in the nut. This means that the tension is taken over by a nut surface which is not equal to the complete and calculated nut surface.

- Oversized nuts:
  With oversized nuts there is too little contact surface between nut and surface of the flange. The nut will embed itself, with relaxation as result.

- Speed of tightening:
  Relaxation depends on time. When fasteners are tightened quickly, the studs and nuts do not have the time to set themselves. After a fast tightening process (not step-by-step) the connection is more exposed to relaxation than normally.

- Gasket behavior:
  The behavior of the gasket is rather complex and difficult to predict. The gasket is subjected to relaxation. However this is an observation on long term. Within the guidelines of the RTOD to calculate flanges, which are used by the Gasunie, flange deformation and minimum and maximum surface pressure play an important role.

- Number of components:
  The more components in a flange, the more relaxation can occur, because more surfaces can be subjected to embedding.

3.1.1 The expected relaxation value

In general a relaxation loss of 10 to 30% is taken into account. However, this percentage can only be determined empirically in a combined test with range. Shortly, there has never been a test in which only the relaxation percentage is taken into consideration. With this test the Gasunie wants to set an accurate relaxation value.

3.1.2 Reduction of relaxation value

Relaxation will always occur. To decrease the relaxation value as much as possible the following measures are recommended:

- The thread of the stud bolts and nuts used need to be slab-free, clean, polished and greased in order to decrease the roughness of the surface which will reduce the embedding.
- Carefully centering of the gasket, stud bolts and nuts during assembly.
- Correct alignment of the connection, before you start tensioning
- Tighten the connection step-by-step, not at once.

These solutions are very expensive because more time is needed and are therefore not applied.

3.2 What is range?

The term range implies the link between stud bolts. This will be clarified by the following example.

When a round 16-holes flange connection is pulled together a certain procedure is carried out. First the flanges is fastened by 2 stud bolts which are 180 º opposite each other (see fig. 3.3). This method is also known as the clock method.

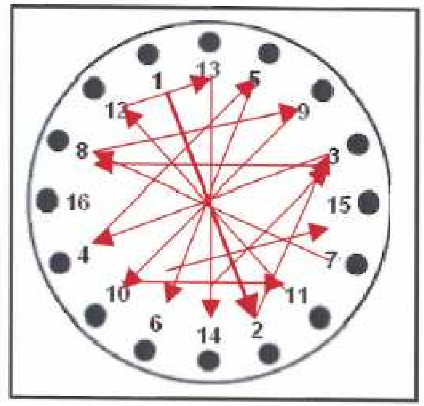

Fig. 3.3 Clock method

At assembly a hydraulic torquing wrench is used to guarantee an equal tension force in each stud bolt. The two studs are tightened simultaneously with an exact tension force of F=10.000N on each stud. This means a total tension force of 20.000N on the flange.

The next studs to be tightened are nr 3 & 4 on angle of 90 º of studs 1 & 2. The tension force is 10.000N on each stud, which should imply a total force of 40.000N on the flange. However, in practice this tension force will not be achieved. The tension force of studs 1 & 2 are reduced by placing tension force to studs 3 & 4. This is called the interaction effect.

When the assembly process continues by tightening studs 5 & 6 until nr 16, the tension forces in the tightened studs will decrease each time another stud is fastened. The results is different values in the 16 studs at simultaneous tightening of 2 studs at the time

3.3 The behavior of the flange connection

When there are no external factors influencing the connection, the flange can be reflected as shown in fig. 3.4. In this diagram the rigidity of the stud is compared with the rigidity of the connection including packing. To illustrate the average tension the following diagram is applicable:

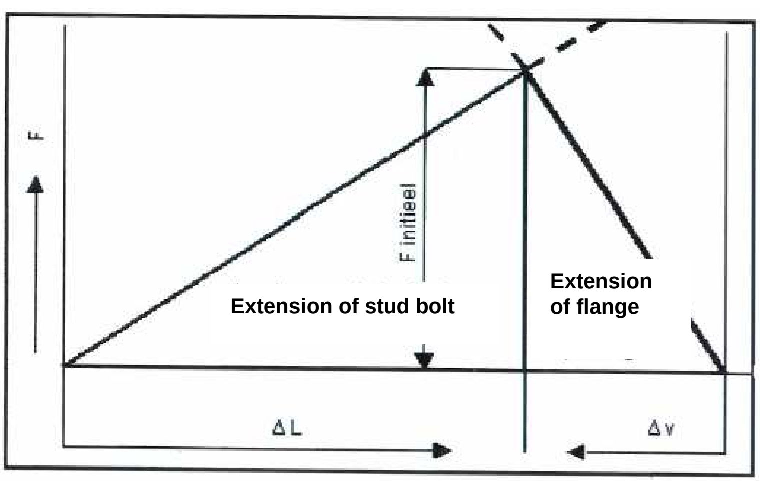

Fig. 3.4 Extension tension of studs and nuts

F = tension [N]
ΔL = extension in stud
Δv = extension in flange
F initial = tension force of the connection after tightening

Besides the great amount of insecurities that could influence the flange, even if it is out of order, there are numerous uncertainties originating from the process in which the flange is active. Some examples:

- Vibration
- Variance in temperature
- Transported medium (can be acidic)
- Corrosion
- External forces

Below you find some insecurities that could influence the connection and will change the preload:

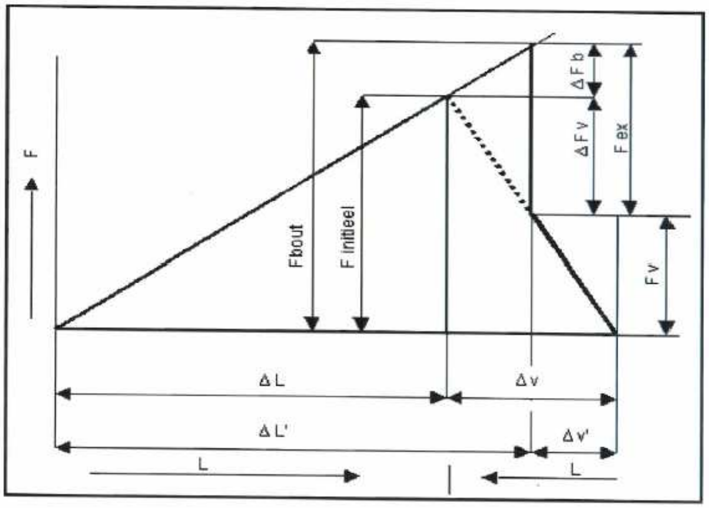

Fig. 3.5 Extension force with external influences

F = tension in [N]
F initial = initial tension force in the connection
F bout = tension force in stud when external force is executed on the flange
ΔFb = difference in tension force between F initial and F bout. This is an external force in the stud
ΔFv = loss in tension force in the flange by external force
F ex = external force
ΔL = extension difference by initial tension force
ΔL'= extension difference by initial and external tension force
Δv = extension difference in flange by initial tension force
Δv'= extension difference in flange by initial and external tension force

Because of the external forces on the flange, the tension force will increase and with that the clamping force of the connection will decrease. This is the main reason why we are so interested in the exact amount of preload in the connection during assembly.

3.4 Replacing stud bolts in vital piping

There are several pipelines within the Gasunie which cannot be set out of order. For those pipelines there are 2 possibilities to replace the studs:

- By using the Leak Repair Clamp. The clamp is placed on the flange. By giving the clamp that amount of tension force corresponding to the tension force of the studs and nuts, the clamp will take over the connecting function of the fasteners in the flange. This way the stud bolts can be replaced one-by-one. This method is used on the RTL transport network up to 40 [bar].
- By tapping a by-pass can be made in the gas transporting line without putting it out of order. However, this is a very expensive method and is only used when the Leak Repair clamp cannot be used.

4. TESTS & CONCLUSIONS

4.1 Determination of relaxation value

There is a special procedure to determine the relaxation value of a 20” flange connection with isolating gaskets. To get a clear view of the course of the calculation it is required to execute at least 3 tests. Take into account that the maximum pressure on the connection cannot be exceeded. The following pictures give an impression of the test elaboration:

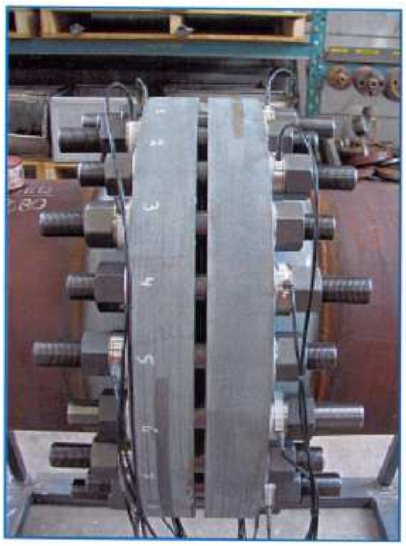

Fig. 4.1 Flange with bolt sensors

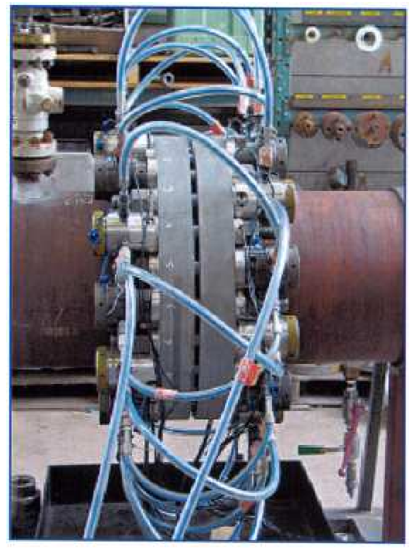

Fig. 4.2 Flange with bolt tensioners

4.1.1. Results

The test is executed in 3 phases. The result are shown in the figures below:

<u>Test 2.1</u>
Tighten the connection with a required tension force of 157 [kN] according to CSW-43-N. This corresponds with a hydraulic pressure for the bolt tensioners of 4450 [PSI].

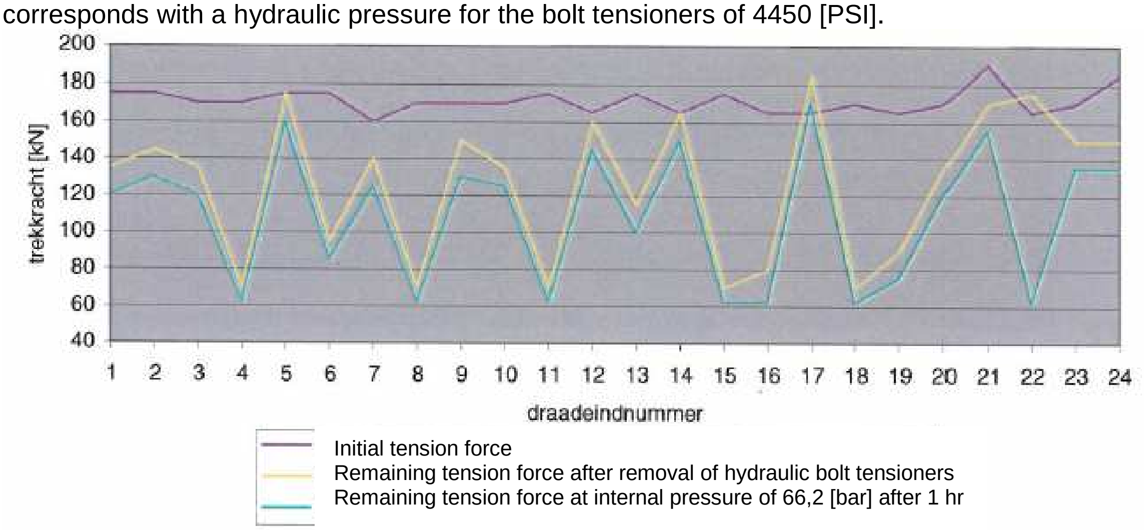

Fig. 4.3 Measured tension force in studs of 1st test

Test 2.2
Extra tightening with 157 [kN] plus the relaxation value of 62 [kN] of test 2.1. A total tension force of 233 [kN]. This corresponds with a hydraulic pressure for the bolt tensioners of 6600 [PSI].

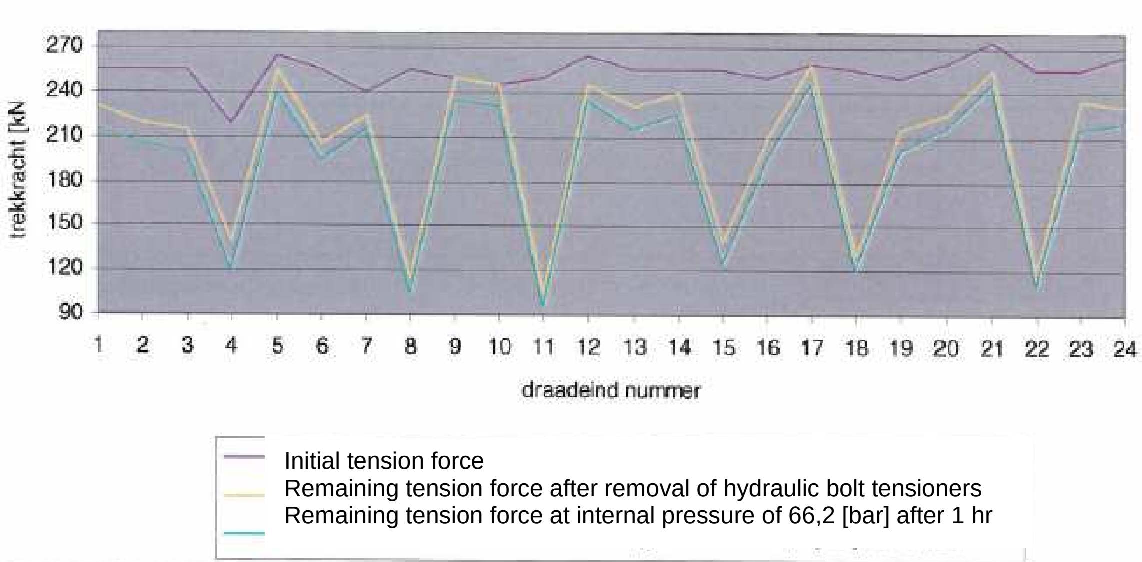

Fig. 4.4 Measured tension force in studs of 2nd test

Test 2.3
Extra tightening of 233 [kN] plus the relaxation value of 62 [kN] of test 2.2. A total tension force of 316 [kN]. This corresponds with a hydraulic pressure for the bolt tensioners of 9000 [PSI].

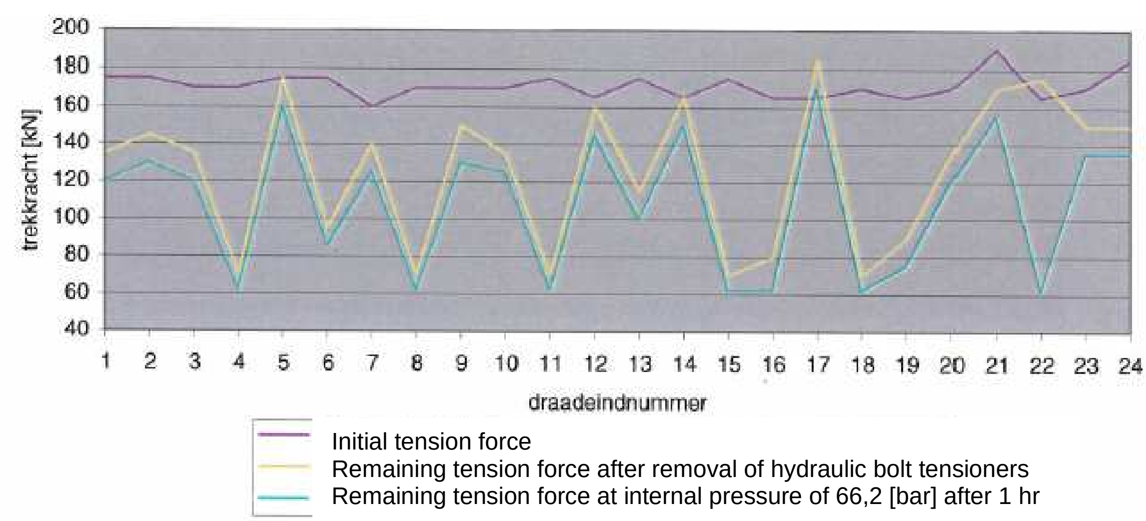

Fig. 4.5 Measured tension force in studs of 3rd test

During the execution of the 3 tests to determine the relaxation value, we have also measured the distance between the two flanges. The results are shown in the schemes 4.6 -4.8

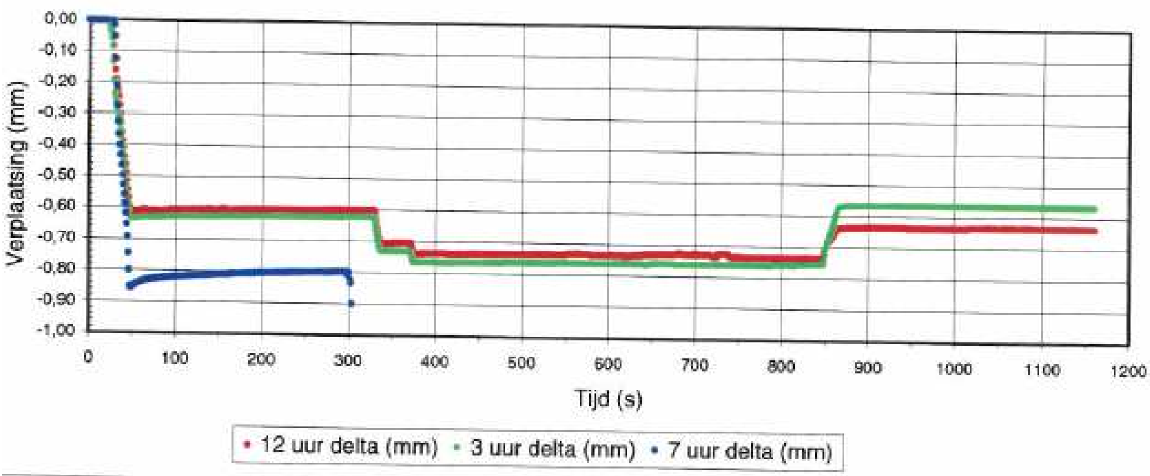

Fig. 4.6 Isolating gasket at 4450 PSI (test 2.1)

* 0-320 seconds	connection is tightened with hydraulic bolt tensioners
* 320-380 seconds	extra tightening with hydraulic bolt tensioners
* 380-850 seconds	elaboration is filled with water
* 850-870 seconds	all pressure is released from bolt tensioners
* 870-1150 seconds	no movements of the flanges. After 1150 seconds the pressure is set to 66,2 [bar]. This is not shown in the diagram.

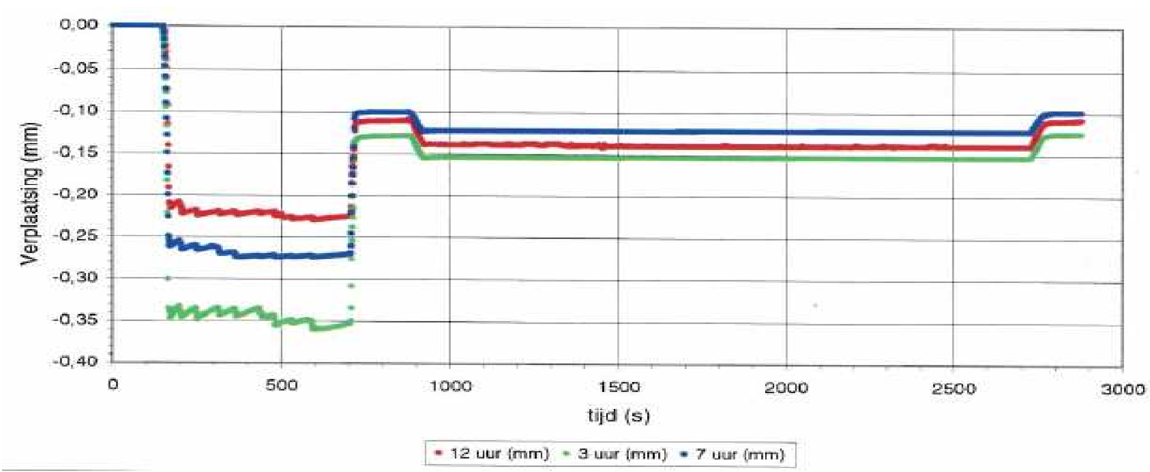

Fig. 4.7 Isolating gasket at 6600 PSI (test 2.2)

* 0-150 seconds	connection is tightened with hydraulic bolt tensioners
* 150-700 seconds	check connection on right tightening of studs
* 700-720 seconds	all pressure is released from bolt tensioners
* 800-900 seconds	pressure is fixed to 66,2 [bar]
* 900-2700 seconds	stabilizing system
* 2700-2800 seconds	all pressure is released

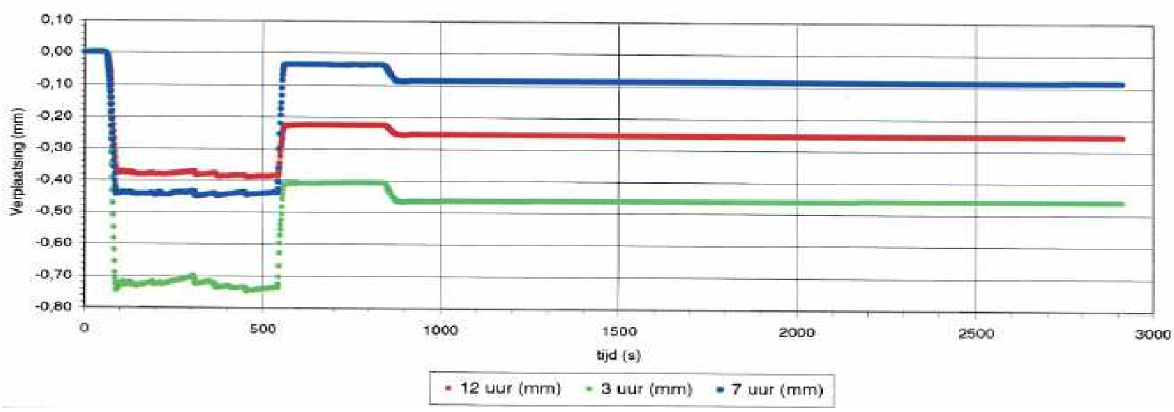

Fig. 4.8 Isolating gasket at 9000 PSI (test 2.3)

In figure 4.8 the following is shown:

* 0-550 seconds	connection is tightened with hydraulic bolt tensioners
* 550-570 seconds	all pressure is released from bolt tensioners
* 800-850 seconds	pressure is fixed to 66,2 [bar]
* 850-2800 seconds	no movements of the flanges.

General

Please note that some bolt sensors indicate a value of 0 [kN]. This is the case when the measured value is below the range of the bolt sensors (75-775 kN). When calculating the average tension force it is assumed that all 0 values are equal to 70 [kN], just below the minimum of 75. This assumption influences both the average calculated relaxation value as the observed range.

4.1.2. Conclusions

1. In the first test the tension force was equal to the required value according to CSW-43-N. The next tests are only executed to determine the course of relaxation when the studs are tightened step-by-step. The average relaxation value of 36% during the first test can be seen as a representative value for application in the field.
2. The course of relaxation during the three tests clearly show a decrease in relaxation when the connection is tightened in multiple steps.
3. It was assumed that the range would be zero when all studs are simultaneously tightened by hydraulic bolt tensioners. However, the test proved that there is a great amount of range. This cannot be compensated by increasing the initial tension force with a adjustment factor. The range remains in the connection unless the cause of it can be eliminated as much as possible.
4. The know-how of the personnel is of great importance. Stud bolts are being fastened manually under hydraulic pressure. This is done by feel. Therefore nuts can be fastened at different forces. This may lead to great differences in the tension force of the stud bolts, which can cause an increase of relaxation and range.
5. Because of damages on the thread nuts cannot be tightened completely against the flange face. This way the stud bolt cannot take all the tension force, which means an increase of relaxation and range.
6. Oil leakages can take place
7. The main cause of flange deformation is tension force on stud bolts. The influences of internal pressure are only small. Internal pressure causes some radial tension in the connection (0,5 x internal pressure = 0,5 x 6,62 = 3,31 [N/mm2]), so this can be neglected in further calculations. The force F2 causes axial tension. The tension is equal to the internal pressure x surface between internal diameter of the flange and the diameter of the gasket.
   Extra tension force on the studs is not preferred, because this may lead to more flange deformation, which may cause leakage on the outside of the gasket and eventually to leakage in the flange.
8. When bolt sensors aren't used it's very hard to control the required tension force.

4.2 Determination of range value

When a stud bolt is removed, range arises in the remaining stud bolts. To determine the course of the range it is required to execute at least 3 tests. The test elaboration needs to be modified in order to place the length gauges at the to be removed stud bolts.

4.2.1 Results

The test is executed in 3 phases. The result are shown in the figures below:

Test 3.1
Tighten the connection with a required tension force of 157 [kN] according to CSW-43-N. This corresponds with a hydraulic pressure for the bolt tensioners of 4450 [PSI]. The elaboration has an internal pressure of 66,2 [bar]. Stud nr 22 is removed under pressure. The results are shown in fig. 4.9.

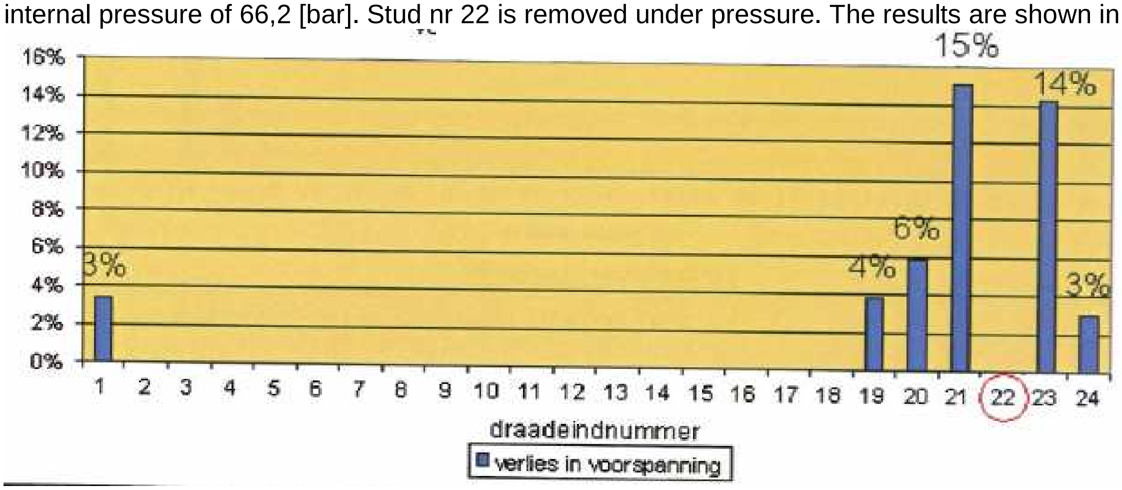

Fig. 4.9 Removal of stud nr. 22 – Loss in percentage per stud at 4450 [PSI]

Test 3.2
Stud nr 22 is replaced with the original tension force of 157[kN]. The connection is tightened with a tension force equal to 157 [kN] + the relaxation value of 62 [kN] from test 2.1. The total tension force 233 [kN] corresponds with a hydraulic pressure for the bolt tensioners of 6600 [PSI]. The elaboration has an internal pressure of 66,2 [bar]. Stud nr 8 is removed under pressure. The results are shown in fig. 4.10.

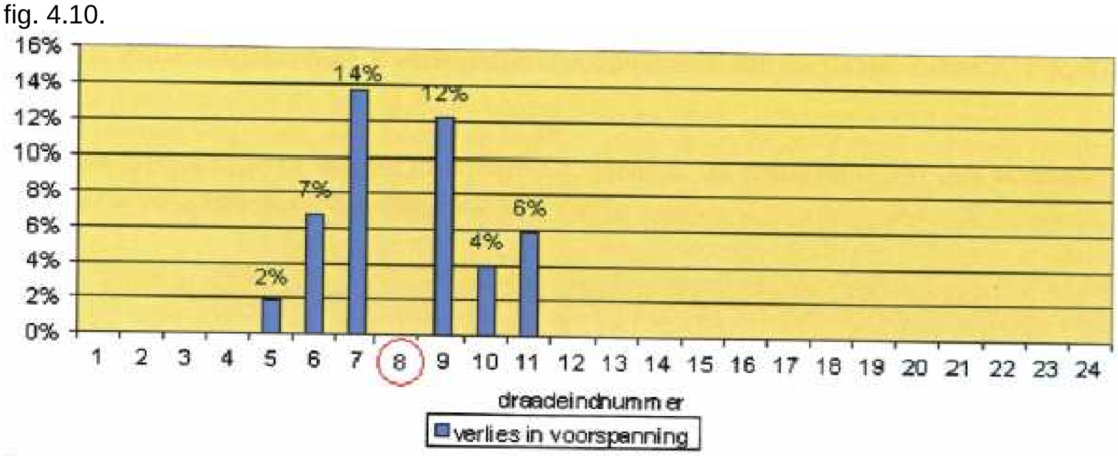

Fig. 4.10 Removal of stud nr. 8 – Loss in percentage per stud at 6600 [PSI]

Test 3.3
Stud nr 8 is replaced with a tension force of 233 [kN]. The connection is tightened with a tension force equal to 233 [kN] + the relaxation value of 62 [kN] from test 2.2. The total tension force 316 [kN] corresponds with a hydraulic pressure for the bolt tensioners of 9000 [PSI]. The elaboration has an internal pressure of 66,2 [bar]. Stud nr 2 is removed under pressure. The results are shown in fig. 4.11.

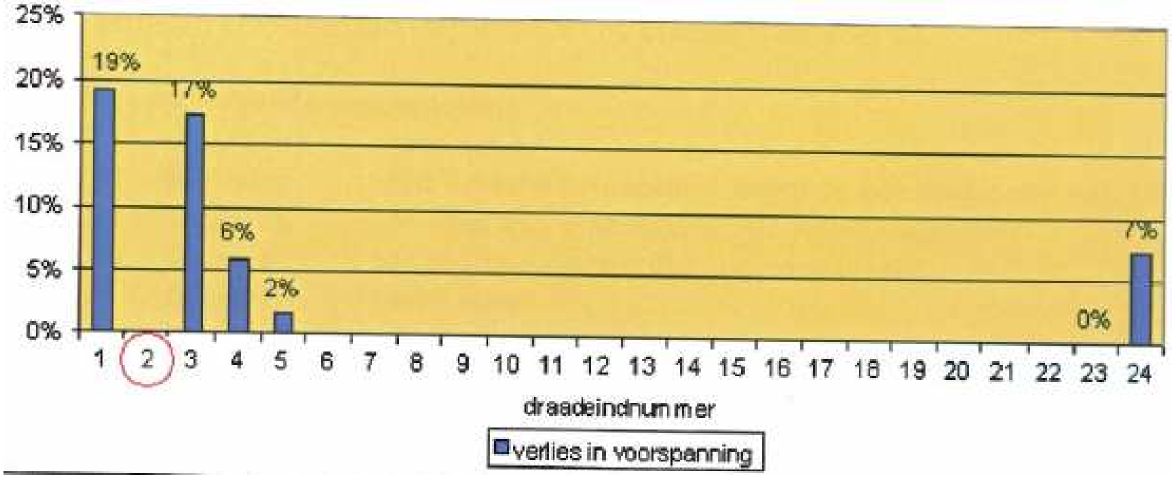

Fig. 4.11 Removal of stud nr. 2 – Loss in percentage per stud at 9000 [PSI]

During the execution of the 3 tests to determine the range value, we have also measured the distance between the two flanges with 3 length gauges. These are placed on the left, right and opposite the stud to be removed. The results are shown in the schemes 4.12 -4.14

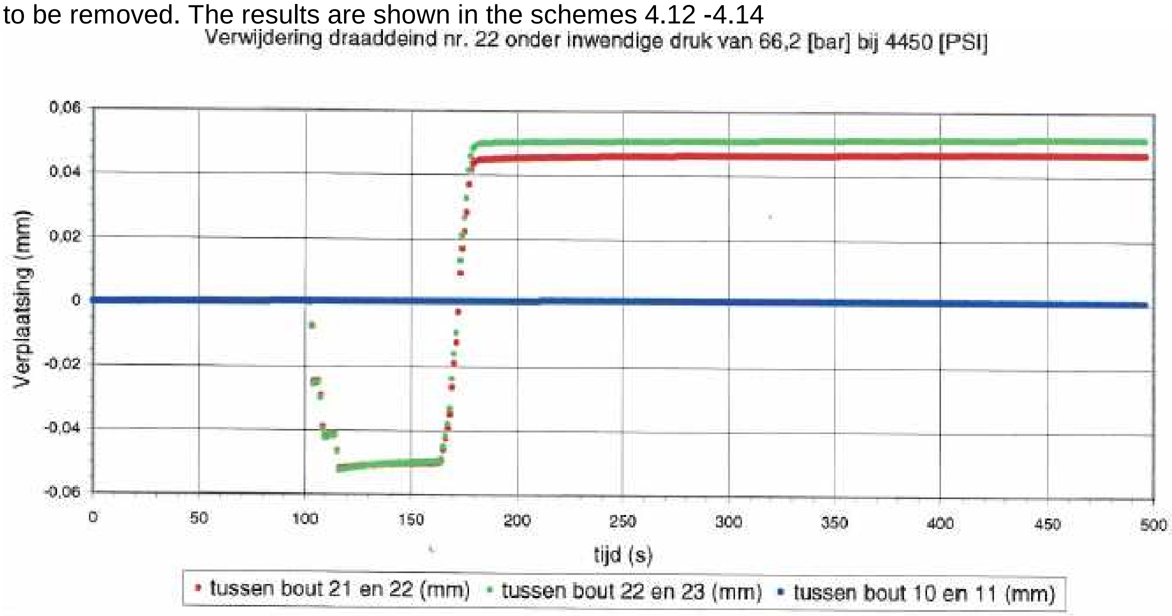

Fig. 4.12 Measurements during removal of stud 22

In figure 4.12 the following is shown:

* 0-100 seconds	no action
* 100-120 seconds	hydraulic bolt tensioner is set to 4450 [PSI]
* 120-170 seconds	nut of stud nr 22 is loosened
* 170-180 seconds	all pressure is released from the bolt sensor
* > 180 seconds	no action

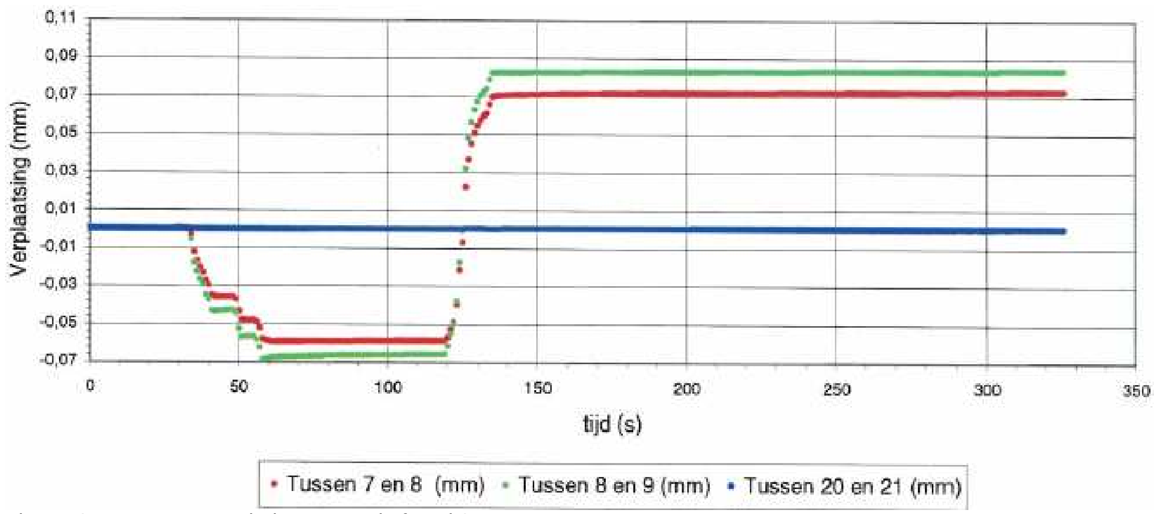

Fig. 4.13 Measurements during removal of stud 8

In figure 4.13 the following is shown:

* 0-60 seconds	no action
* 60-70 seconds	hydraulic bolt tensioner is set to 4450 [PSI]
* 70-120 seconds	nut of stud nr 22 is loosened
* 120-140 seconds	all pressure is released from the bolt sensor
* > 140 seconds	no action

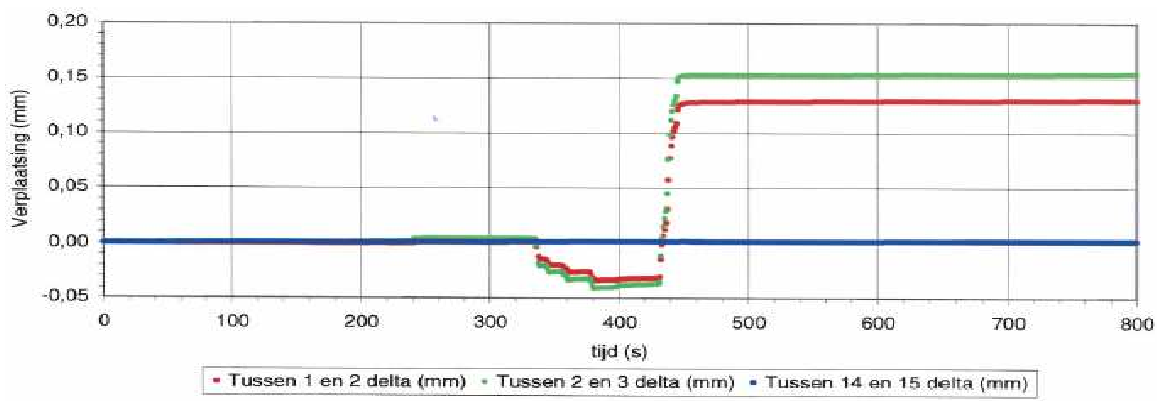

Fig. 4.14 Measurements during removal of stud 2

In figure 4.14 the following is shown:

* 0-320 seconds	no action
* 320-380 seconds	hydraulic bolt tensioner is set to 4450 [PSI]
* 380-415 seconds	nut of stud nr 22 is loosened
* 415-420 seconds	all pressure is released from the bolt sensor
* > 420 seconds	no action

4.2.2. Conclusions

1. The tests show that the flange connection as a whole is not subjected to range. The three studs on both sides of the removed stud are only subjected to range.
2. The total loss of gasket pressure at the removed stud is equal to the sum of all loss in the adjacent studs. This is app. 45% of the tension force. As there was no leakage, the remaining flange pressure (55% of the original tension force) is sufficient to guarantee a leak-free gasket.
3. During execution of the test there was no leakage. This proofs that stud bolts can be replaced under pressure of 66,2 [bar] without using the Leak Repair Clamp.