Bolt load Measurement Report
Comparing different bolting methods

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1 Introduction

1.1 *BoltSafe the company*

BoltSafe is a Dutch company providing Bolt load Measuring Systems. The main product is a simple designed electronic washer, used in combination with a read-out system. The read out can be done with a handheld reader or by computer to control over 248 washer simultaneously.
The washer is placed under a (regular) nut.

The system is also useful to determine and monitor the bolt load during the assembly process of the flange.

With the BoltSafe measurement system is BoltSafe a party that could do boatload tests for customers.

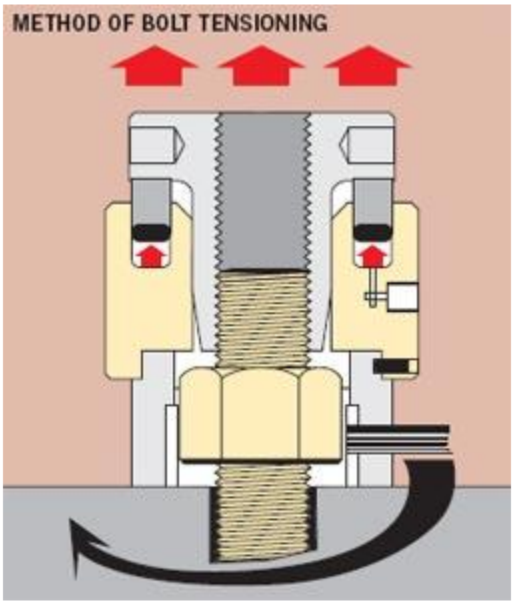
BoltSafe is using calibrated sensors these reports are delivered with the sensors, and could be find on the end of this report. The calibration of the sensors is done with a calibrated press, also these report could be sent on request.

1.2 *Project target*

Saras refinery has asked BoltSafe to engineer a system to compare 3 bolting methods, and to measure the result of independent tests of 3 different bolting methods. The bolting methods that were compared in the test were:

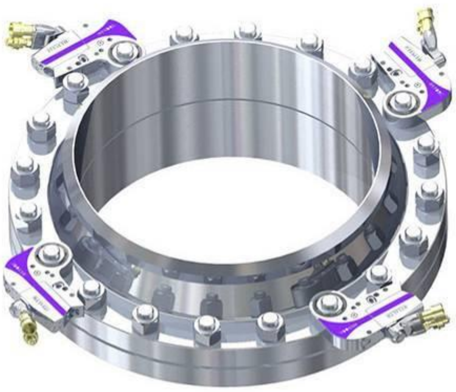
1.2.1 Hydraulic tensioning

With this method the bolts will be stretched in groups by use of hydraulic jacks. By defining the hydraulic pressure, with allowance for the acting relaxation, the bolt force can be applied. After the tightening of the nuts, the oil pressure will be reduced to zero and the nuts will take over the bolt force. In using the bolt tensioning method, the bolts have to be extended at least one diameter of the bolts past the nut, in order to give sufficient thread length for the assembly of tensioning jacks.



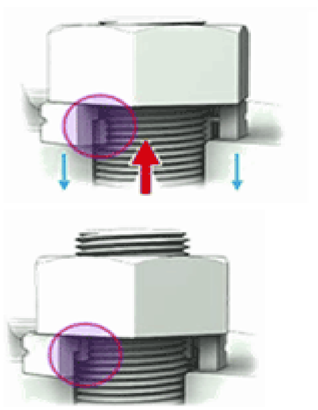
1.2.2 Hydraulic torque

With this method, the bolts will be stretched by means of applying a certain torque to the nut. The nominal torque necessary to obtain the desired bolt load, can be determined from tables or can be calculated. In each pass, all bolts will be tightened in a set pattern, the last pass will be repeated until all nuts are tight. Due to the special design of equipment, bolts which are difficult to access can be tightened or loosened.



1.2.3 The Hytorc washer technology

The HYTORC Washer is a low profile reaction washer with an inner thread segment that is placed underneath a standard heavy hex nut. It provides controlled surface friction that enhances bolt load accuracy. Using this simple washer removes frictional losses due to flange surface condition while it eliminates side loading and bending losses due to external reaction points. The HYTORC tool and driver is equipped with an inner and outer socket. The nut is dry-lubed to reduce the usual frictional scatter.



1.3 Test target

The target of the test is to do an independent research for determine the most accurate bolting method that could be applied on Saras Refinery. In this report are show the results the accuracy of the bolting methods by measuring the bolt load by:

- BoltSafe CMS measurement system
- Ultrasonic elongation measurement

The target load is 646 kN for each bolt in the flange, and the consistent oft the bolt load is very important to get in the practice a leak free flange.

For each bolting methods there were used calibrated equipment and experts who are working every day with bolting methods. So with this we are sure that we could compare only the methods independent of other influences.

During the test another independent company has made elongation measurements this numbers are also showed in this report.

The differences between the two measurements could be caused by different reasons, pending on the principle of both systems. In the next chapters are the both used measurement systems described. Each system have is con's and pro's but we see in the report little differences between both measurements that are in the order of failure of the two systems.

1.3.1 The BoltSafe CMS measuring system

The BoltSafe Sensor is a specially designed sensor to monitor inline the residual tension (often called pre-tension or pre-load) in bolted joints. That is, the force applied from the strain in the bolt will be transferred from the nut through the BoltSafe Sensor onto the surface. In this way we can obtain a direct measurement of the pre-tension in the bolt/nut joint.

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The beauty of this sensor principle is that the basic elements are formed so that the sensor can be produced in an automatic set-up. Through this, the sensor can be produced to low cost, and stable high quality can be obtained through optimized production processes.

The basic sensor elements

The BoltSafe concept and the sensor principle is based on what we call a magneto elastic material. This is a material that has properties that makes it useful in sensor applications. The fact that the materials ability to conduct magnetic field is almost a linear function of the stress in the material is used in the BoltSafe Sensor.

In the particular sensor application, the magneto elastic material has been formed into a ribbon and integrated in the sensor shaped as a washer. Together with a pick-up coil this forms the basic sensing elements. The coil impedance will then be the basic sensor output. Due to the special properties of the magneto elastic ribbon, a change in the load on the sensor can be picked up as a change in the impedance of the coil.

The structural design

Through the assembly process the sensor body will form more or less a solid washer as showed in the figure below. As can be seen, the design is a stiff construction with no spring elements. This means that the structure will not collapse in a way that reduces the pre-tension. The security factor is higher than 1.5*FS. In normal use the bolt will start to deform before the critical load is reached. The very tough material is also chosen to provide ruggedness and stable performance through the lifetime of the application.
The load will be picked up over a continuous area around the circle (**not in single points as for strain gauges**). I.e. integrating the load over the area.

The sensor structure consists of two parts that are forming a washer shaped mechanical body. Before assembly of the two parts, the magneto elastic ribbon and the coil are bonded onto one of the bodies. The sensitive area will then be in the cavity formed between the two parts. Hence, the sensitive area is positioned in the centre of the load bearing area.
The two parts are bonded together by a structural adhesive qualified through an extensive test program. The main function of the adhesive is sealing, and the bonding will in normal use only be exposed to compression.

Armco 17-4 PH is used as material in the load bearing body. This material is well known to have high strength and at the same time excellent corrosion resistance. H1025 condition is used (heat treatment) with a yield stress above 1000 MPa.

Calibration - and what will affect the calibration

Each individual sensor has been calibrated and 100% verified to conform to the specification. The calibration values are stored in the memory cell internally in the sensor, so the valid calibration data will always follow the sensor. The calibration dates can be reviewed by downloading data to BoltSafe Software.

The calibration for the BoltSafe Sensor will be valid throughout the lifetime of the bolt/nut assembly. In other words, there will be no need for re-calibration of the sensor.

The maximum full-scale load is shown in the product data sheet. Loads up to 1,3 x FS (Full-Scale) value will normally not affect the calibration. However, this will not be valid in situations with uneven load. In this case the local load in some areas can exceed the maximum load value. This may change the system accuracy, but it will normally be well within the general specification of ± 5%FS.

BoltSafe Sensor is a specially designed sensor to monitor the residual tension in bolted joints. That means that the product design in general should not be used for other applications or purposes. Through design, manufacturing and calibration processes, the objective is to optimize the product to the requirements from this specific application.

Boundary conditions that can affect the sensor accuracy

Uneven surfaces

The flange is often manufactured from standard machining steel, which is typically rather soft steel. The flanges are easily marked at the landing area of the nut/washer. An uneven or irregular surface with deformations from earlier use of nut etc. will affect the accuracy of the sensor. This will also be the case with painted surfaces.

The stated system accuracy of better than 5% FS will still be valid in most cases.

Uneven Nut surfaces

The picture underneath shows an extreme example of a galvanized nut. A lump of sink material has been left at the landing area of the nut. This point load will affect the sensor. If this nut were used in combination with a BoltSafe Sensor the lumped material would decrease the accuracy. Normally this uneven surface will be squeezed flat when the load is increased. This means that the error in general will be more apparent at low load levels.

In normal use galvanized nuts will only have small effects on the accuracy, but should always check the nut for extremity. An obvious consequence is that the marking of the nut should not be used against the BoltSafe Sensor. Always check the nut for extremity. An obvious consequence is that the marking of the nut should not be used against the BoltSafe Sensor.

1.3.2 Ultrasonic elongation measurement

This chapter presents a brief description of fastener elongation measurement using ultrasonic's. For more details on ultrasonic testing in general, ULTRASONIC TESTING OF MATERIALS, by Josef and Herbert Krautkramer, 4th Edition 1990, (IBSN 0-387-51231-4), is highly recommended.

Ultrasonic properties

The Ultrasonic measurement device measures the time of flight of a shock wave as it travels through a fastener. This type of shock wave is called a longitudinal wave. A shock wave is created when an electrical pulse is applied to a piezoelectric element inside the transducer. The frequency of the shock wave is controlled by the thickness of the piezoelectric element. The frequencies useful for fastener measurements range from 1 to 10 megahertz. This range of ultrasound will not travel through air. A dense liquid substance, usually glycerin or oil, must be used to couple the ultrasound from the transducer into the fastener.

When the ultrasonic wave encounters an abrupt change in density, such as the end of the fastener, most of the wave reflects. This reflection travels back through the length of the fastener, through the layer of couplant and back into the transducer. When the shock wave enters the piezoelectric element, a small electrical signal is produced. This signal is amplified by the ultrasonic measurement device and used to stop the timing counter.

Ultrasound travels in a fastener at a constant speed determined by many material factors, such as density, temperature and stress. The velocity may be found by dividing twice the physical length of the fastener by the transit time. It is important to realize that the sound velocity varies from sample to sample even when the sample materials composition is tightly controlled. Therefore, the ultrasonic reference length is not exactly the same as the physically measured length. Even if the length of a fastener is very tightly controlled, the ultrasonic length may vary by as much as one percent. For accurate measurements of elongation, the change in ultrasonic length can be used. This requires a before and after measurement of the ultrasonic length for each fastener.

The ultrasonic measurement device measures an ultrasonic reference length by measuring the time from the launching of the ultrasonic wave to the reception of the echo from the end of the fastener. This time is divided by 2 and then multiplied by the sound velocity to produce the length. In order to obtain the required resolution, multiple samples are averaged. Sufficient time must be allowed for the ultrasound to diminish before firing another pulse into the fastener to obtain a stable reading.

Effects of stress

When a fastener is placed under stress, its length changes. The greater the stress the greater the length change. In the
elastic region, below the yield stress of the bolt, this relationship is linear and described by Hooke´s law. The modulus of elasticity is the constant describing the ratio of stress to strain for a given material.

The velocity of sound in a material is also effected by stress. As a fastener is stretched, velocity of ultrasound through the fastener decreases. This makes the fasteners ultrasonic length longer than the physical length change due to stress. A great deal of confusion surrounds this effect. If a reference length is recorded on a faster with no applied load, then a load is applied and a new reference length is taken, the difference between the two reference lengths is about three times the physical elongation of the fastener. In the Ultrasonic measurement device, a constant known as the Stress Factor (K) compensates for the change in ultrasonic velocity due to stress.

It is important to note that in order to change the sound velocity; stress must be applied in the same direction as the travel of the ultrasound. Thus stress due to shear loading or torsional stress due to tightening does not affect the sound velocity along the length of the fastener.

Effects of temperature

The temperature of a fastener effects its physical length and the velocity the ultrasound travels. As the temperature of
a fastener increases, its ultrasonic length increases at a rate greater than the physical length changes. The Ultrasonic measurement device temperature compensation corrects the ultrasonic length of a fastener to normalize it to 72 degrees Fahrenheit. Therefore, a fastener will always measure the same length at all temperatures if properly compensated. The thermal expansion of the fastener and ultrasonic velocity change with temperature are two separate effects. However, for the purpose of the Ultrasonic measurement device they are combined into a single factor known as the Temperature Coefficient (Cp).

Requirements of ultrasonic measurement

Not all fastener applications are suitable for measurement by ultrasonic methods. An understanding of the limitations will prevent frustration and erroneous results. Fastener applications where equal distribution of load is critical, typically find ultrasonic techniques indispensable. These applications include pipe flanges and head bolts, where gaskets must be com- pressed evenly for optimum performance.

Significant Stretch

Since ultrasonic technique measures the change in length of a fastener, a significant amount of stretch is required to pro-
duce accurate measurements. Applications where a fastener is clamping a very short grip length, such as a screw holding
a piece of sheet metal, have large accuracy problems. Because the stress is applied over a very short effective length, little, if any, elongation of the fastener occurs. The amount of stretch is small compared to the error involved in removing and replacing the transducer. Another difficult application is the measurement of very low loads. At low stress levels, below 10% of ultimate tensile stress, similarly low elongation takes place. The small errors in measurement associated with removing and replacing the transducer become very significant when trying to measure such a small amount of elongation.

Flat Ends for Transducer

In order to inject and receive ultrasound from a bolt, the bolt must have a flat surface for the transducer to contact. The opposite end of the bolt should also have a parallel surface to reflect the ultrasound back to the transducer, although the surface finish is not as important.

Material Must Conduct Ultrasound
Most metals are excellent conductors of ultrasound. However, certain cast irons and many plastics absorb ultrasound and cannot be measured with the Ultrasonic measurement device.

Surface Finish
A very flat, smooth surface is extremely important to proper coupling of the transducer. A common problem occurs when
a small peak is left in the center of a bolt head after milling the fastener head flat on a lathe. This small bump prevents the transducer from achieving proper contact and greatly reduces the signal amplitude.

2 Measurement description

2.1 Measurements

To compare the 3 different bolting methods there were 3 continues measurements with BoltSafe system, and a measuring with the ultrasonic measurement device.

- Measurement 1; The bolting experts of Jetyd did a full job on the demo flange with the Hytorc washer technology, during this test the bolt load is continues logged with the BoltSafe system, and the load was measured after the test with the ultrasonic measurement device.
- Measurement 2; The bolting experts of a local bolting contractor did a full job on the demo flange with hydraulic bolt tensioning, during this test the bolt load is continues logged with the BoltSafe system, and the load was measured after the test with the ultrasonic measurement device.
- Measurement 3; The bolting experts of Jetyd did a full job on the demo flange with conventional torque, during this test the bolt load is continues logged with the BoltSafe system, and the load was measured after the test with the ultrasonic measurement device.

In all the 3 tests the target load is 646 kN. The 3 jobs are done like they would be done in practice, and the test was done at a maintenance company on a flange that is used by the refinery. So to compare the 3 methods all the things that could influence the result that have nothing to do with the method was eliminated, and the test was completely equal to the practice.

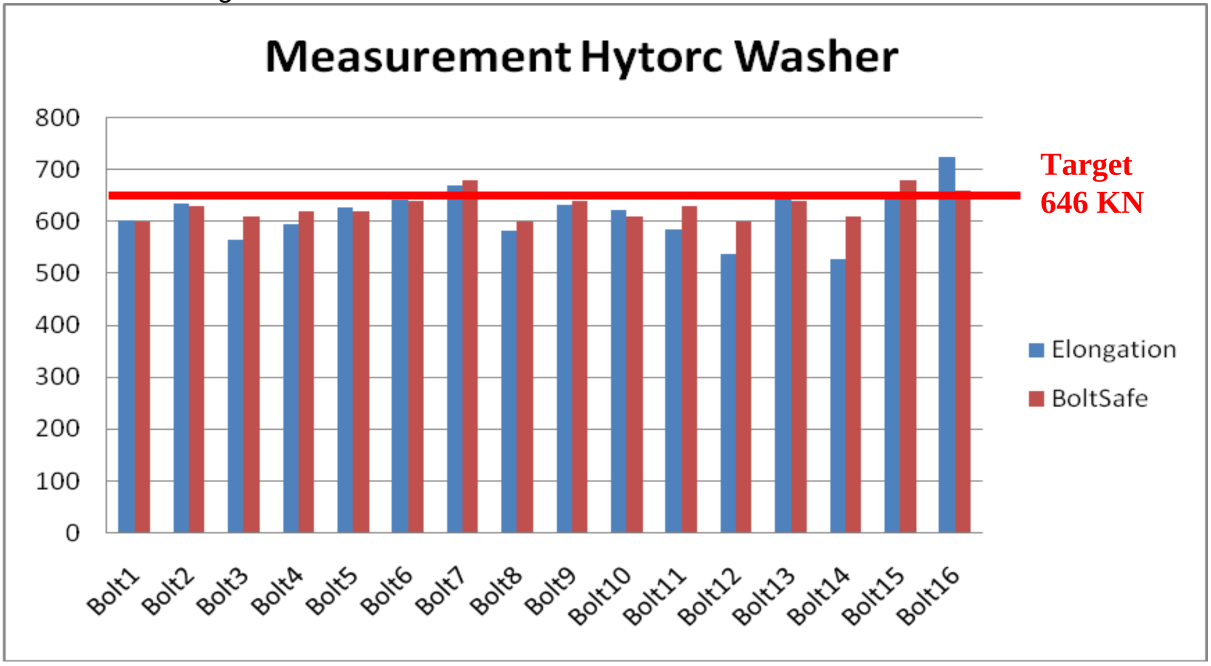
2.2 BoltSafe Equipment

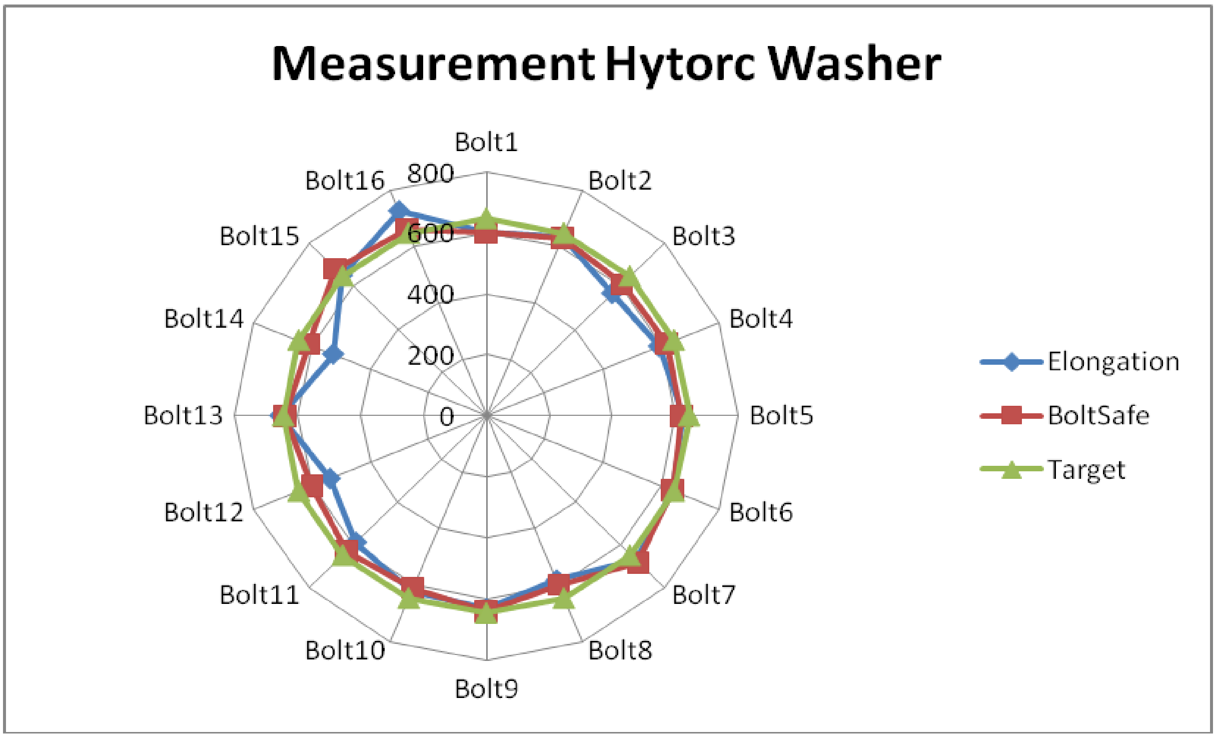
The test is done on a flange in a workshop with 16 pcs. 2” stud bolts.
During the 3 tests the follow BoltSafe hardware is used:

- 16 pcs. 2” CMS BoltSafe sensors the calibration reports of each sensor is at attached on the end of this report.
- 1 pcs. PDT-NT with continues logging

3 Measurements Hytorc washer Technology

In the pictures below are the results shown of the measurement with the Hytorc Washer technology, the pictures are showing the BoltSafe measurements and the elongation measurements.
In picture 1 you will find the load for each bolt and in picture 2 you will find the bolt load dived on the flange.

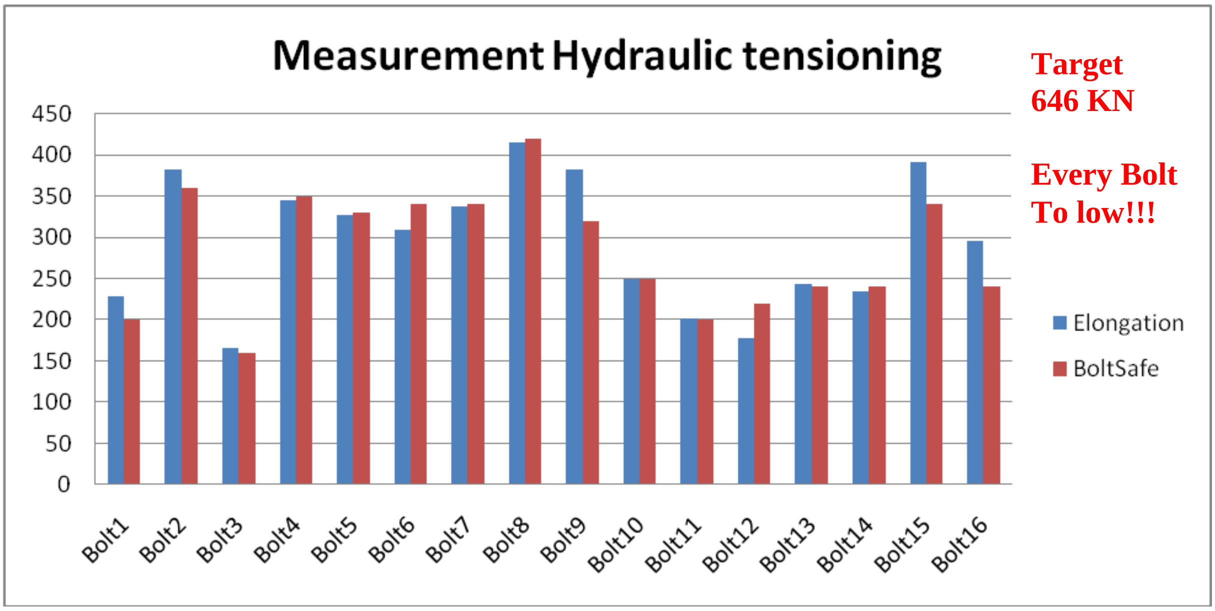


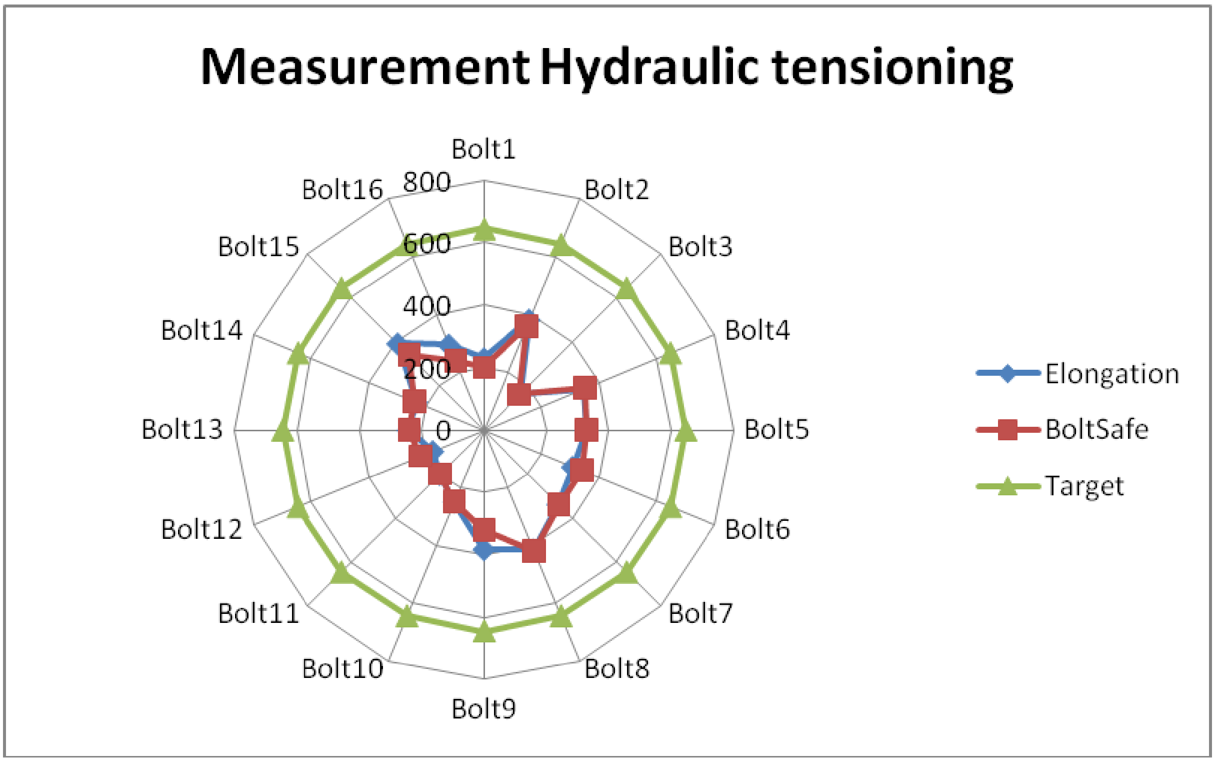


4 Measurements Hydraulic tensioning

In the pictures below are the results shown of the measurement with the hydraulic tensioning method, the pictures are showing the BoltSafe measurements and the elongation measurements.

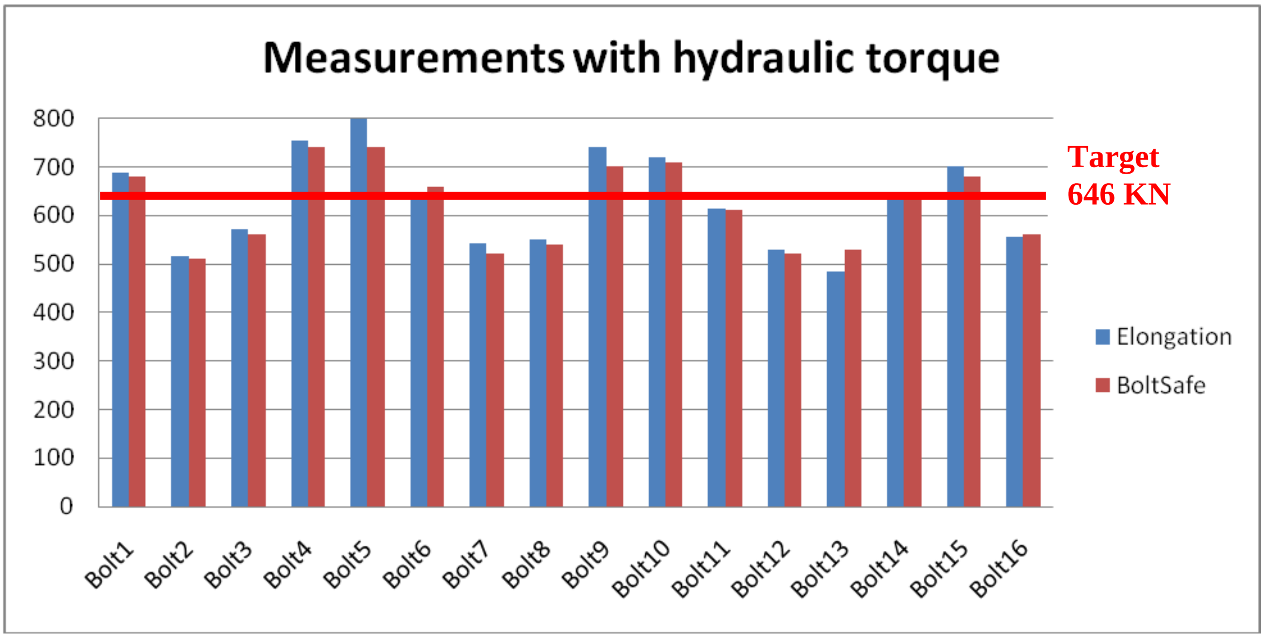
In picture 1 you will find the load for each bolt and in picture 2 you will find the bolt load dived on the flange.

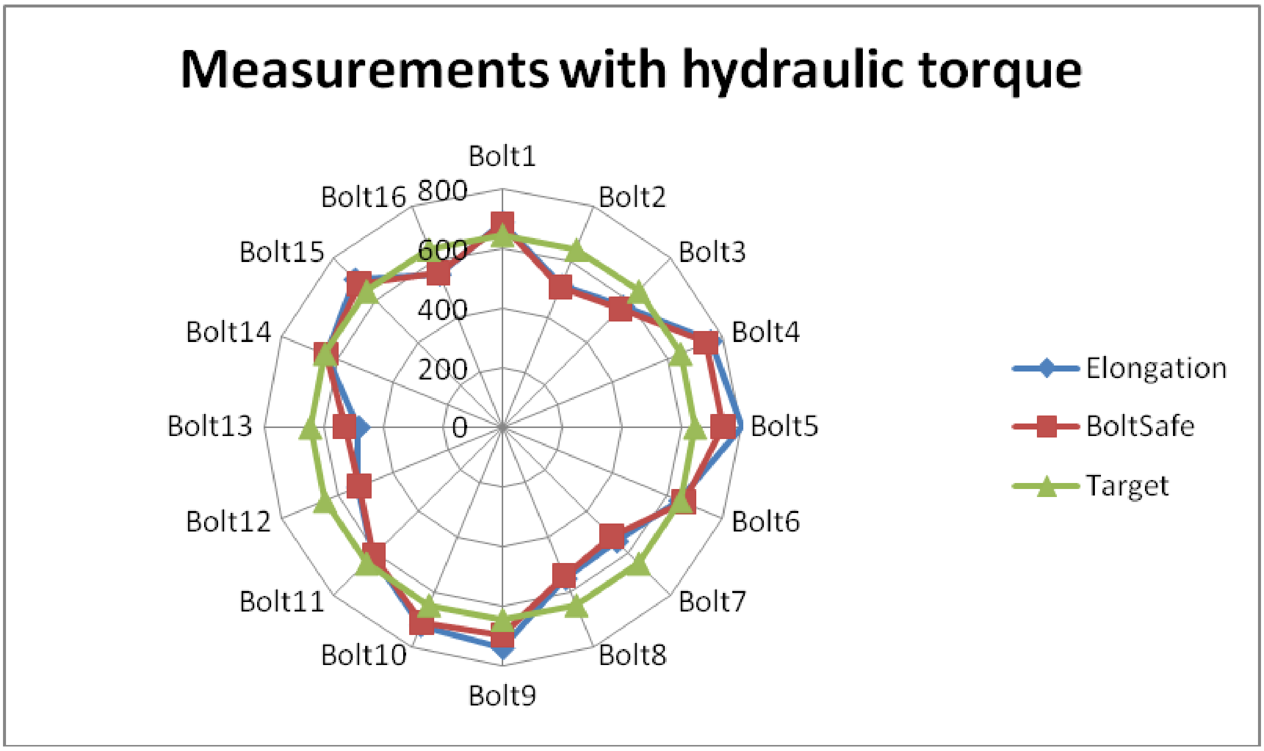




5 Measurements with conventional torque

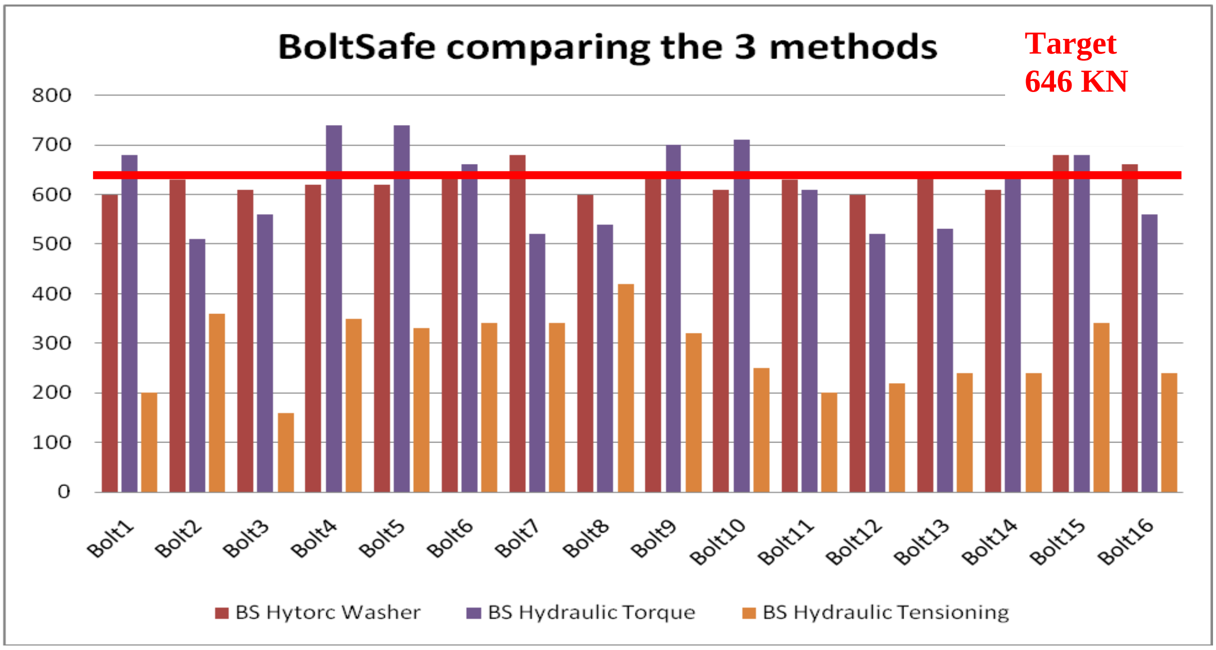
In the pictures below are the results shown of the measurement with conventional torque, the pictures are showing the BoltSafe measurements and the elongation measurements. In picture 1 you will find the load for each bolt and in picture 2 you will find the bolt load dived on the flange.

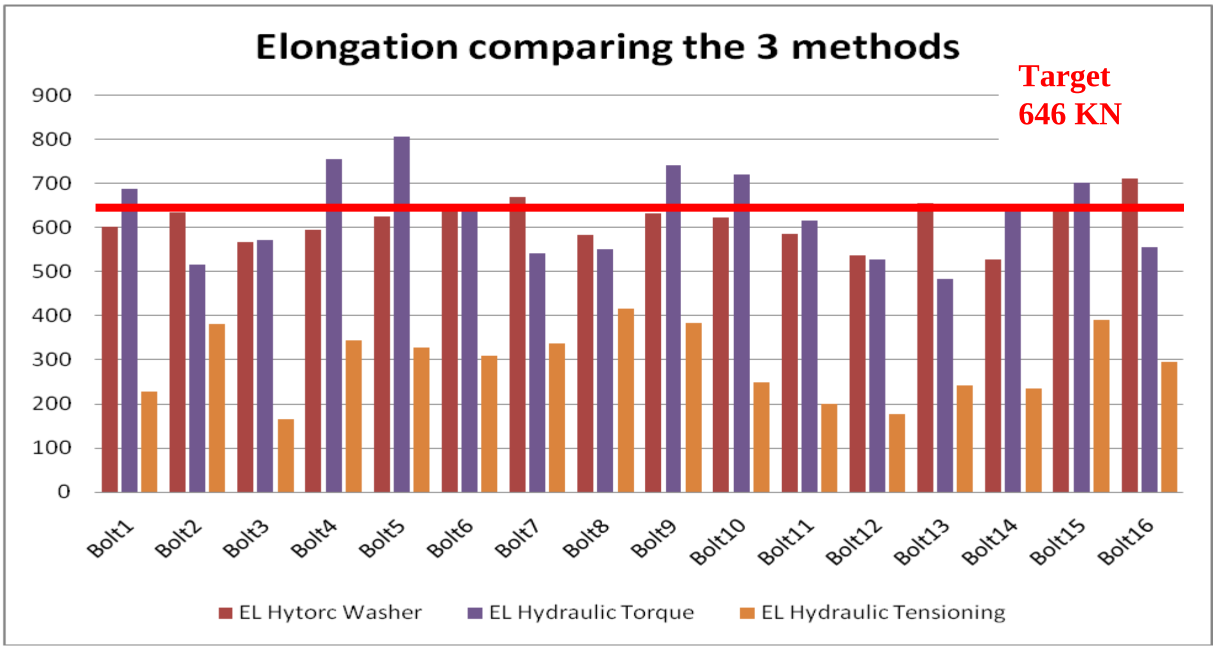




6 Comparing the 3 methods

In the pictures below are the results of the measurements of the 3 methods shown, the first picture is the result measurerd with the BoltSafe system. The second picture is the measuerment with the ultrasonic measerement.





7 Conclusion

The test was done to compare 3 different bolting methods, on a test flange. The situation for all the methods where equal and for all the methods where well trained experts who do this way of bolting as their daily job. So with this we could conclude that this test shows the results only depending of the bolting method.

In this report are the results shown of 2 measurement systems:

- The BoltSafe CMS measurement system
- Ultrasonic measurement

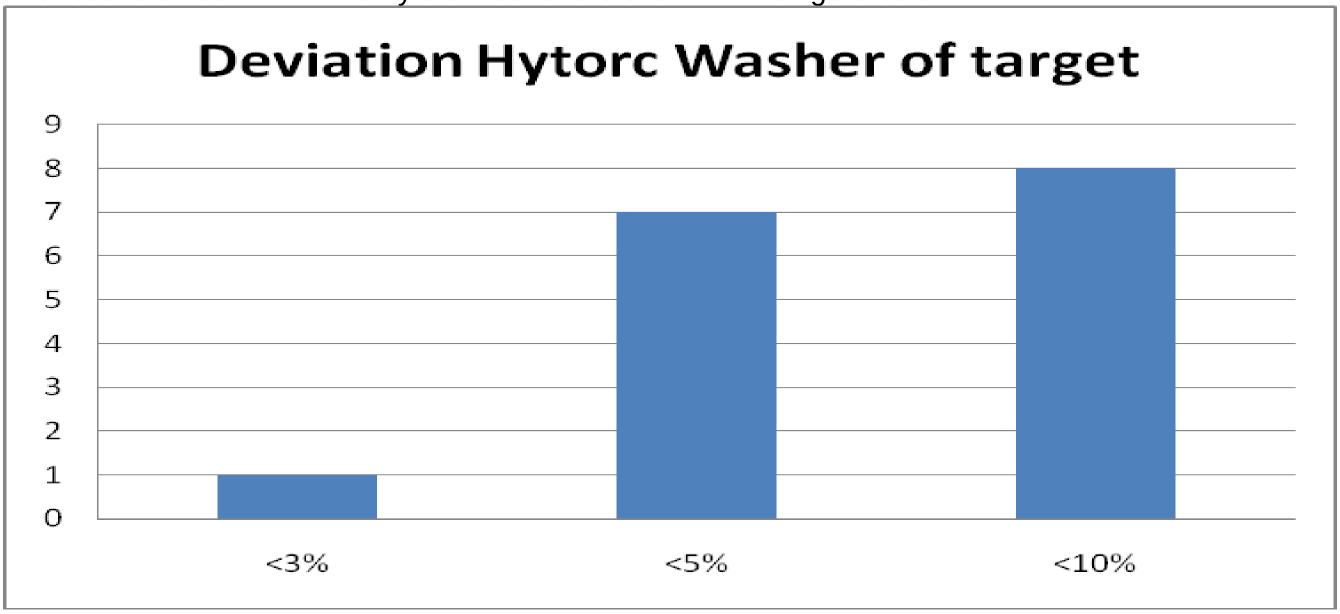
The BoltSafe system visualize a direct load with a accuracy of 5%, the Ultrasonic measurement is a measurement based on an ultrasonic signal wich is depending of several influences like:

- Position of placing the measuring probe by the operator
- The placing of lubricate for the measuring probe by the operator
- Temperature influence that is assumed in the calculations
- Finishing of the bolts

In this conclusion we are using the BoltSafe measurements but we could also conclude that the differences between the both systems are in the most measurements almost equal.

7.1 Conclusion measurements

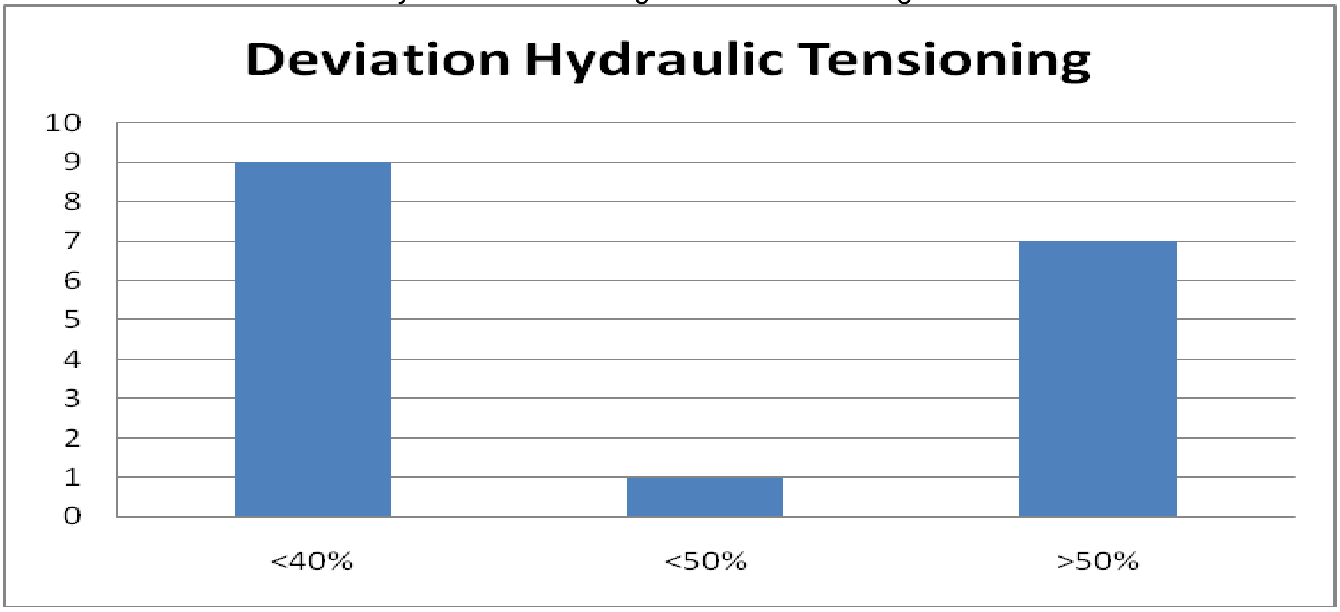
The results of test 1 with the Hytorc washer are shown in the figure below:



We can conclude that:

- 1 bolt is within 3% of target
- 7 bolts are within 5% of target
- 8 bolts are within 10% of target

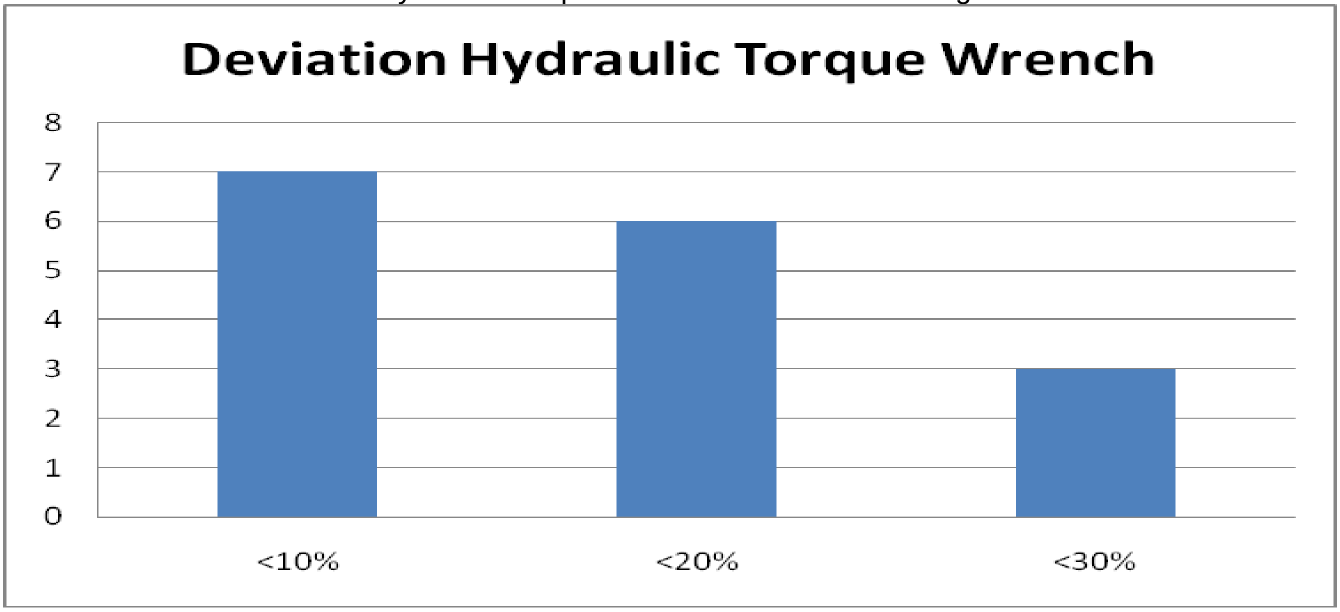
The results of test 1 with the Hydraulic Tensioning are shown in the figure below:



We can conclude that:

- 9 bolts are within 40% of target
- 1 bolts is within 50% of target
- 7 bolts are more then 50% of target

The results of test 1 with the Hydraulic Torque Wrench are shown in the figure below:



We can conclude that:

- 7 bolts are within 10% of target
- 6 bolts is within 20% of target
- 3 bolts are more then 30% of target