BoltSafe
Load Measuring Systems

# Bolt load Measurement Report

# Tensioning versus Torque

| | |
|---|---|
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| **Date:** | **7 July 2008** |
| **Test date:** | **25 June 2008** |

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# 1 Introduction

## *1.1 Hytorc Seis GmbH*

Hytorc Seis GmbH, Dörth is the dealer of Hytorc equipment, Hytorc equipment is used to torque bolts and nuts. Hytorc is the world biggest manufacturer of hydraulic and air driven torque tools. Other well known accessories to enhance safety, accuracy and speed are the Clamp Tensioning Nut and LoadDISC washer.

## *1.2 BoltSafe*

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.

## *1.3 Project target*

Hytorc Seis GmbH asked BoltSafe to engineer a system to monitor the bolt load in 24 pc. M48 bolts on a flange for a costumer, during the assembly of this flange with 24pc. hydraulic tensioners.

# 2 Measurement Description

## 2.1 Mean description

The measurement took place continuously but was saved on the following 6 moments:

1. Measurement - Preload 1 tensioning 1st pass;
2. Measurement - Residual load 1 tensioning 1st pass;
3. Measurement - Preload 2 tensioning 2nd pass;
4. Measurement - after second pass by repeating step - Residual load 2 tensioning 2nd pass;
5. Measurement - residual load after tightening by manual torque with hammer + slogging wrench;
6. Measurement - residual load after tightening by hydraulic Hytorc torque wrench.

Preload = load during hydraulic pulling of the tensioners.
Residual load= load after the nuts have been seated manually, the tensioners being unloaded and the nuts are uploaded (This so called relaxation only occurs if bolts are tensioned and not with any torque method).

## 2.2 Equipment

During the tests the following hardware was used:

- 3pc. BoltSafe CM1000 network boxes each for max 8 sensors
- 1pc. BoltSafe Power Data Interface box
- 24pc. BoltSafe M48 CMS BoltSafe Washer. Range 101-1.018kN, Accuracy +/- 2% full scale
- 24pc. ITH Hydraulic Tensioners with puller and bridges and pump unit 1.500 Bar
- 1pc. Hammer and slogging wrench 75mm
- 1pc. Hytorc Model 4-XLCT ratchet link 75mm and pump unit 700 Bar Torque range 535 Nm to 5460 Nm

The used BoltSafe equipment has an accuracy +/-3% full scale.

During the test the BS2000 Network Monitoring version 1.2.3 software was used.

Figure 1 presents a scheme with the network configuration for the application which was used for the test.

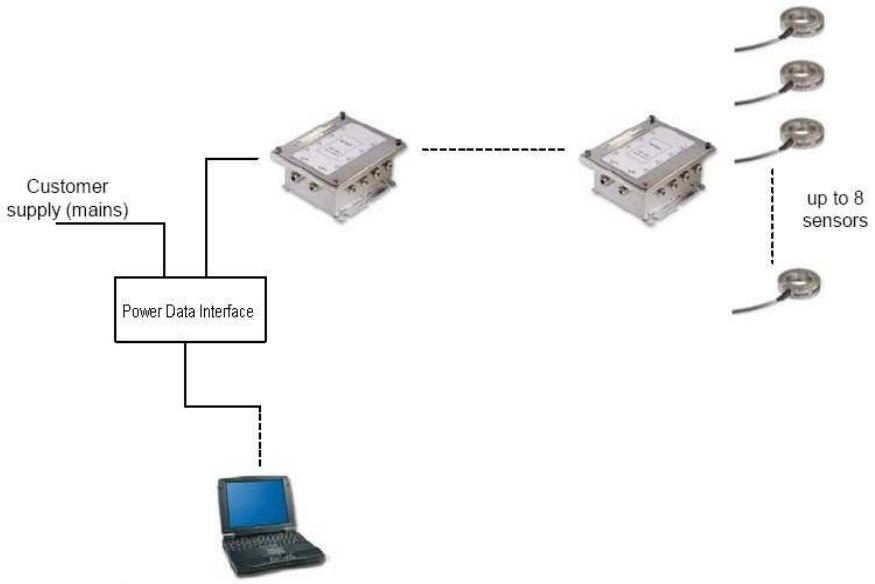


**Figure 1: Network configuration**

## 2.3 Environment

The measurements were done at the site of the costumer of Hytorc Seis GmbH, this costumer is a petrochemicals plant.

Application: reactor vessel with flange, 24 bolts in blind holes. In figure 2 is shown how the BoltSafe's were installed.

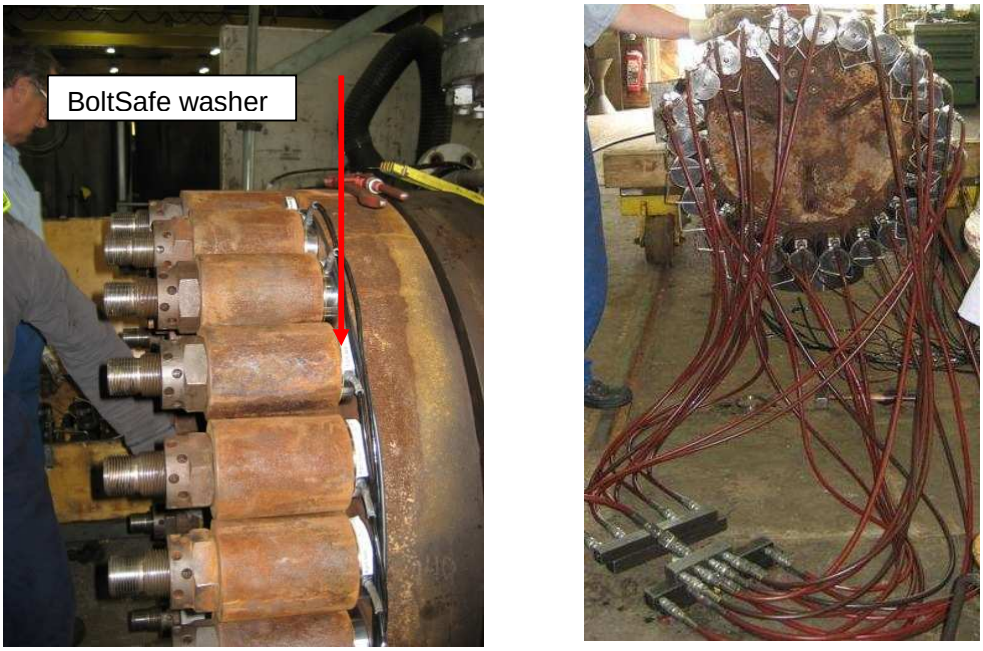


**Figure 2: BoltSafe's with tensioners on the flange**

## 2.4 BoltSafe positions

During the test the BoltSafe's were placed and numbered clockwise, see figure 3.

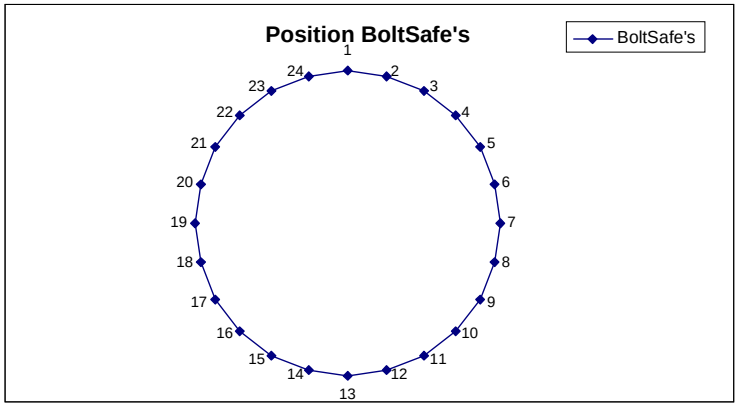


**Figure 3: BoltSafe positions on the flange**

# 3 Measurement results

## *3.1 Measurement: Preload 1 tensioning 1st pass*

During pre-installation BoltSafe nr. 13 was broken, this was not a BoltSafe failure. Table 1 shows the measured values by in digit and in figure 4 in diagram. The target preload was 480 kN.

**Table 1: Figures Preload 1 tensioning 1st pass**

| BoltSafe | Force (kN) | Mean (kN) | Difference with mean (%) |
|---|---|---|---|
| 1 | 490 | 466 | 4,9% |
| 2 | 490 | 466 | 4,9% |
| 3 | 480 | 466 | 2,8% |
| 4 | 460 | 466 | -1,5% |
| 5 | 460 | 466 | -1,5% |
| 6 | 460 | 466 | -1,5% |
| 7 | 440 | 466 | -5,8% |
| 8 | 420 | 466 | -10,1% |
| 9 | 480 | 466 | 2,8% |
| 10 | 480 | 466 | 2,8% |
| 11 | 470 | 466 | 0,6% |
| 12 | 500 | 466 | 7,1% |
| 13 | **** | 466 | **** |
| 14 | 460 | 466 | -1,5% |
| 15 | 460 | 466 | -1,5% |
| 16 | 460 | 466 | -1,5% |
| 17 | 490 | 466 | 4,9% |
| 18 | 480 | 466 | 2,8% |
| 19 | 440 | 466 | -5,8% |
| 20 | 480 | 466 | 2,8% |
| 21 | 450 | 466 | -3,6% |
| 22 | 490 | 466 | 4,9% |
| 23 | 450 | 466 | -3,6% |
| 24 | 450 | 466 | -3,6% |

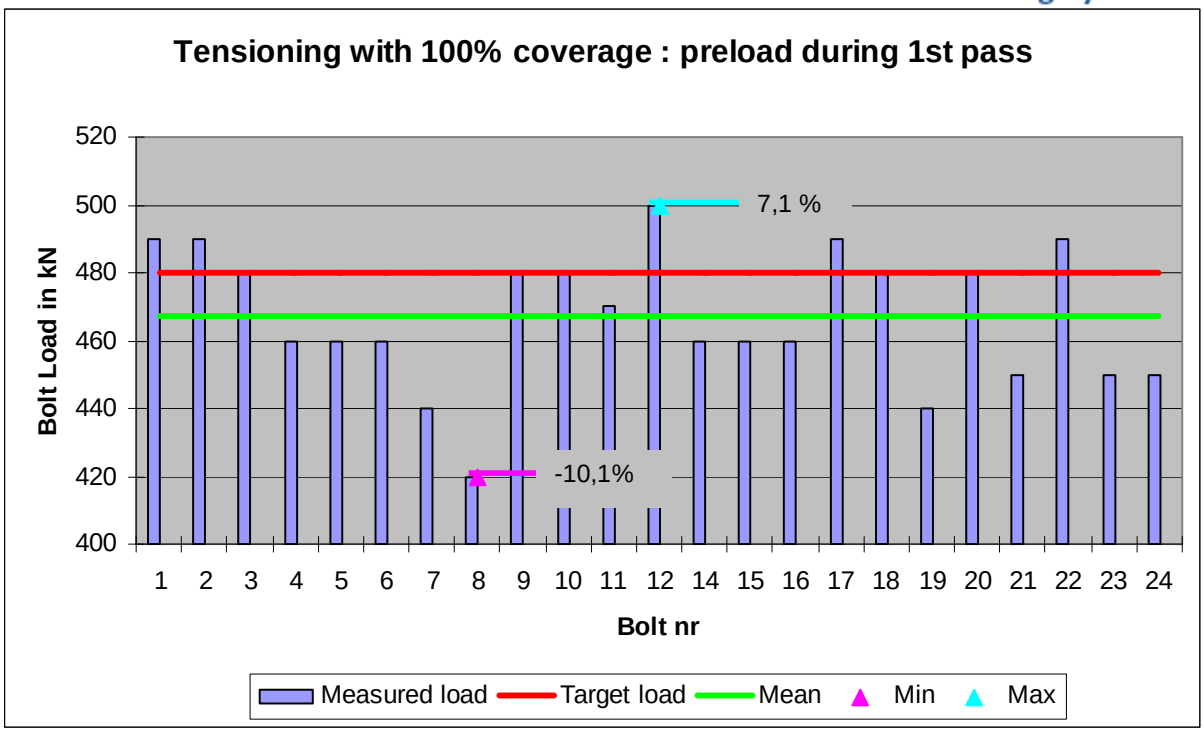


**Figure 4: Graph Preload 1 tensioning 1st pass**

## 3.2 Measurement: Residual load 1 tensioning 1st pass

The target bolting force was 460 kN. In Table 2 the measurement values are shown with residual load 1 tensioning 1st pass; and the curve is displayed in figure 4. As the BoltSafe's start measuring from 101 kN the data also starts from 101 kN.

**Table 2: Figures Residual load 1 tensioning 1st pass**

| BoltSafe | Force (kN) | Mean (kN) | Difference with mean (%) |
|---|---|---|---|
| 1 | 470 | 325 | 44,4% |
| 2 | 101 | 325 | -69,0% |
| 3 | 101 | 325 | -69,0% |
| 4 | 430 | 325 | 32,1% |
| 5 | 420 | 325 | 29,1% |
| 6 | 101 | 325 | -69,0% |
| 7 | 390 | 325 | 19,9% |
| 8 | 350 | 325 | 7,6% |
| 9 | 260 | 325 | -20,1% |
| 10 | 440 | 325 | 35,2% |
| 11 | 400 | 325 | 22,9% |
| 12 | 370 | 325 | 13,7% |
| 13 | *** | 325 | **** |
| 14 | 410 | 325 | 26,0% |
| 15 | 101 | 325 | -69,0% |
| 16 | 350 | 325 | 7,6% |
| 17 | 390 | 325 | 19,9% |
| 18 | 420 | 325 | 29,1% |
| 19 | 350 | 325 | 7,6% |
| 20 | 200 | 325 | -38,5% |
| 21 | 360 | 325 | 10,6% |
| 22 | 350 | 325 | 7,6% |
| 23 | 330 | 325 | 1,4% |
| 24 | 390 | 325 | 19,9% |

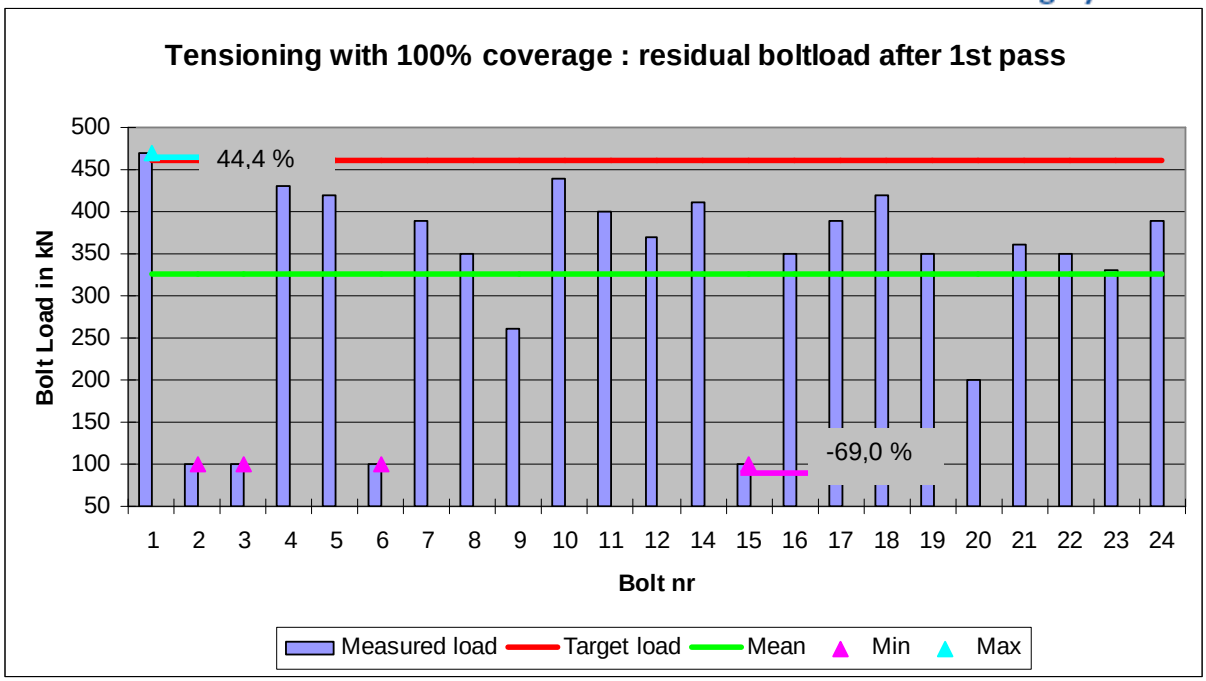


**Figure 5: Graph Residual load 1 tensioning 1st pass**

## 3.3 Measurement: Preload 2 tensioning 2nd pass

In Table 3 the measurement values are shown and the diagram is displayed in figure 6.
The target preload was 480 kN.

**Table 3: Figures Preload 2 tensioning 2nd pass**

| BoltSafe | Force (kN) | Mean (kN) | Difference with mean (%) |
|---|---|---|---|
| 1 | 490 | 467 | 4,9% |
| 2 | 490 | 467 | 4,9% |
| 3 | 480 | 467 | 2,8% |
| 4 | 460 | 467 | -1,5% |
| 5 | 460 | 467 | -1,5% |
| 6 | 460 | 467 | -1,5% |
| 7 | 440 | 467 | -5,8% |
| 8 | 420 | 467 | -10,1% |
| 9 | 480 | 467 | 2,8% |
| 10 | 480 | 467 | 2,8% |
| 11 | 470 | 467 | 0,7% |
| 12 | 500 | 467 | 7,1% |
| 13 | **** | 467 | **** |
| 14 | 460 | 467 | -1,5% |
| 15 | 460 | 467 | -1,5% |
| 16 | 460 | 467 | -1,5% |
| 17 | 490 | 467 | 4,9% |
| 18 | 480 | 467 | 2,8% |
| 19 | 440 | 467 | -5,8% |
| 20 | 480 | 467 | 2,8% |
| 21 | 450 | 467 | -3,6% |
| 22 | 490 | 467 | 4,9% |
| 23 | 450 | 467 | -3,6% |
| 24 | 450 | 467 | -3,6% |

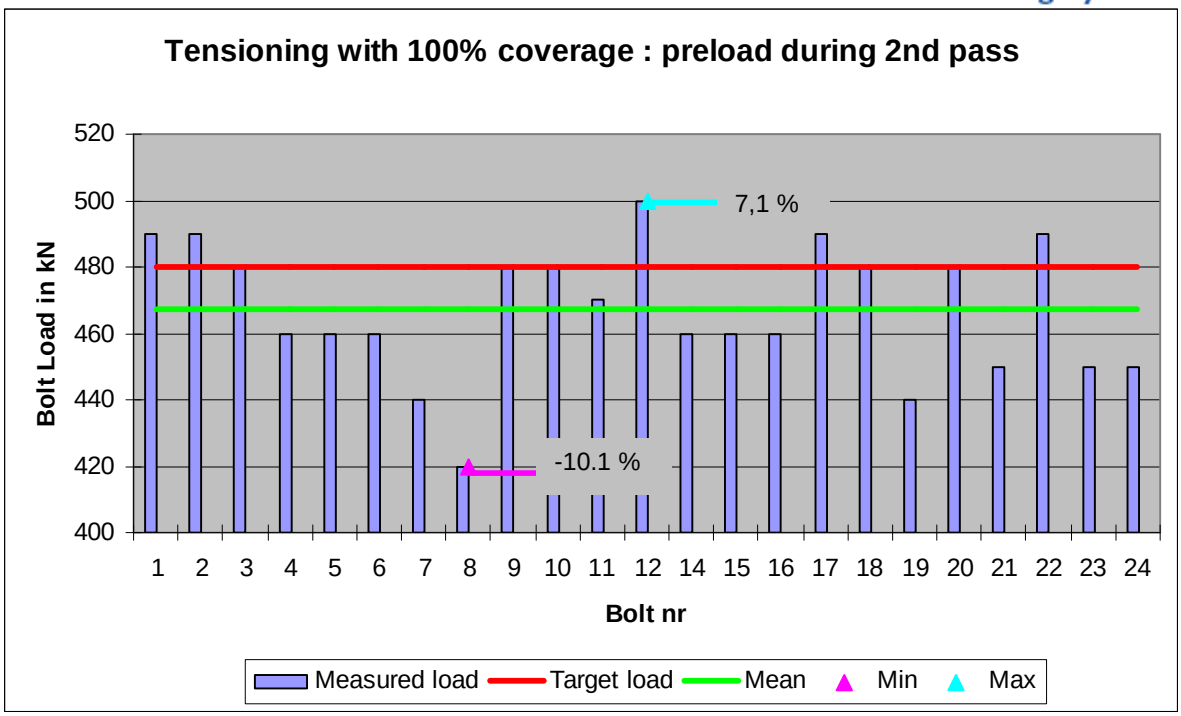


**Figure 6: Graph Preload 2 tensioning 2nd pass**

## 3.4 Measurement: Residual load 2 tensioning 2nd pass

The target Bolting force was 460 kN. In Table 4 the measurement values are shown after the second time the bolts were tensioned and the curve is displayed in figure 7. As the BoltSafe's start measuring from 101 kN the data also starts from 101 kN.

**Table 4: Figures Residual load 2 tensioning 2nd pass**

| BoltSafe | Force (kN) | Mean (kN) | Difference with mean (%) |
|---|---|---|---|
| 1 | 470 | 355 | 32,3% |
| 2 | 101 | 355 | -71,6% |
| 3 | 410 | 355 | 15,4% |
| 4 | 420 | 355 | 18,2% |
| 5 | 430 | 355 | 21,0% |
| 6 | 101 | 355 | -71,6% |
| 7 | 430 | 355 | 21,0% |
| 8 | 360 | 355 | 1,3% |
| 9 | 340 | 355 | -4,3% |
| 10 | 450 | 355 | 26,6% |
| 11 | 410 | 355 | 15,4% |
| 12 | 430 | 355 | 21,0% |
| 13 | **** | 355 | **** |
| 14 | 430 | 355 | 21,0% |
| 15 | 101 | 355 | -71,6% |
| 16 | 410 | 355 | 15,4% |
| 17 | 400 | 355 | 12,6% |
| 18 | 440 | 355 | 23,8% |
| 19 | 370 | 355 | 4,1% |
| 20 | 180 | 355 | -49,3% |
| 21 | 360 | 355 | 1,3% |
| 22 | 380 | 355 | 6,9% |
| 23 | 350 | 355 | -1,5% |
| 24 | 400 | 355 | 12,6% |

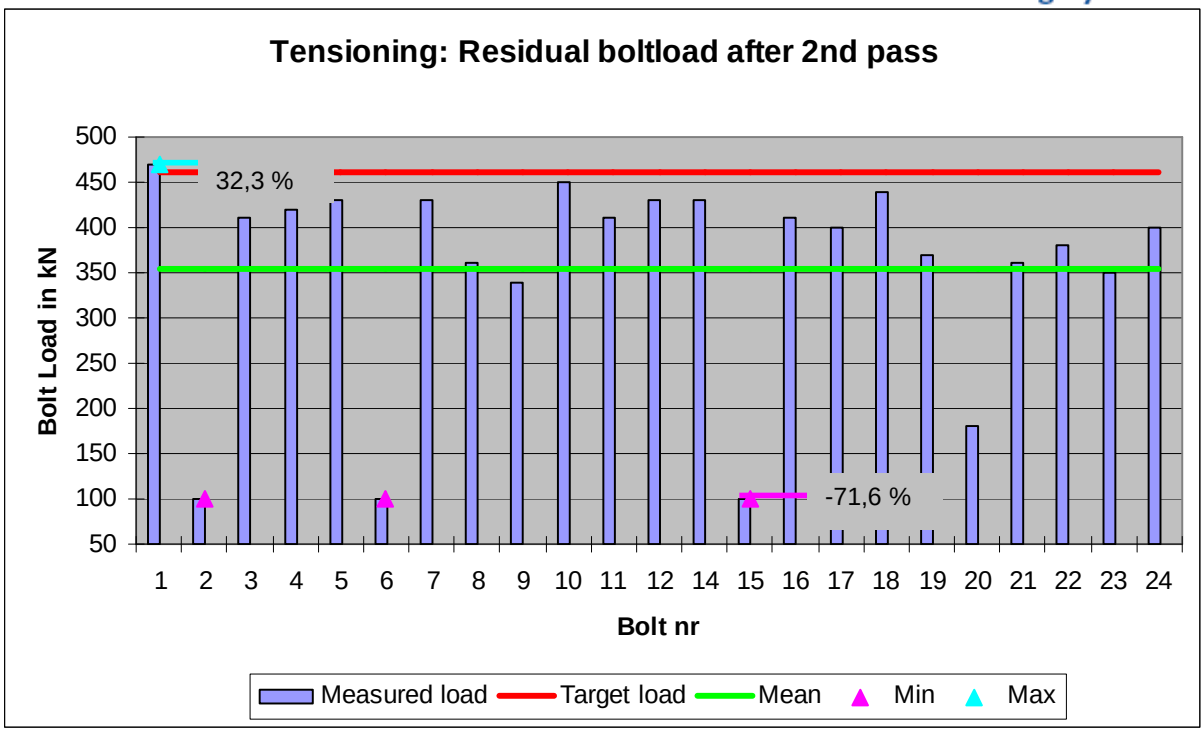


**Figure 7: Graph Residual load 2 tensioning 2nd pass**

## 3.4 Measurement: residual load after tightening by manual

After the two rounds of hydraulic tensioning the target bolt load of 460kN was by far not reached within expected accuracy. It was for that reason the costumer proposed to finish with an extra pass by using hammer and slogging wrench. Table 5 shows the results after tensioning while figure 8

As the BoltSafe's start measuring from 101 kN the data also starts from 101 kN.

**Table 5: Figures residual load after tightening by manual**

| BoltSafe | Force (kN) | Mean (kN) | Difference with mean (%) |
|---|---|---|---|
| 1 | 460 | 373 | 23,4% |
| 2 | 101 | 373 | -72,9% |
| 3 | 400 | 373 | 7,3% |
| 4 | 420 | 373 | 12,7% |
| 5 | 390 | 373 | 4,7% |
| 6 | 380 | 373 | 2,0% |
| 7 | 420 | 373 | 12,7% |
| 8 | 350 | 373 | -6,1% |
| 9 | 350 | 373 | -6,1% |
| 10 | 460 | 373 | 23,4% |
| 11 | 410 | 373 | 10,0% |
| 12 | 430 | 373 | 23,4% |
| 13 | **** | 373 | **** |
| 14 | 420 | 373 | 15,4% |
| 15 | 220 | 373 | 12,7% |
| 16 | 410 | 373 | -41,0% |
| 17 | 420 | 373 | 10,0% |
| 18 | 440 | 373 | 12,7% |
| 19 | 390 | 373 | 18,1% |
| 20 | 200 | 373 | 4,7% |
| 21 | 370 | 373 | -46,3% |
| 22 | 380 | 373 | -0,7% |
| 23 | 350 | 373 | 2,0% |
| 24 | 400 | 373 | -6,1% |

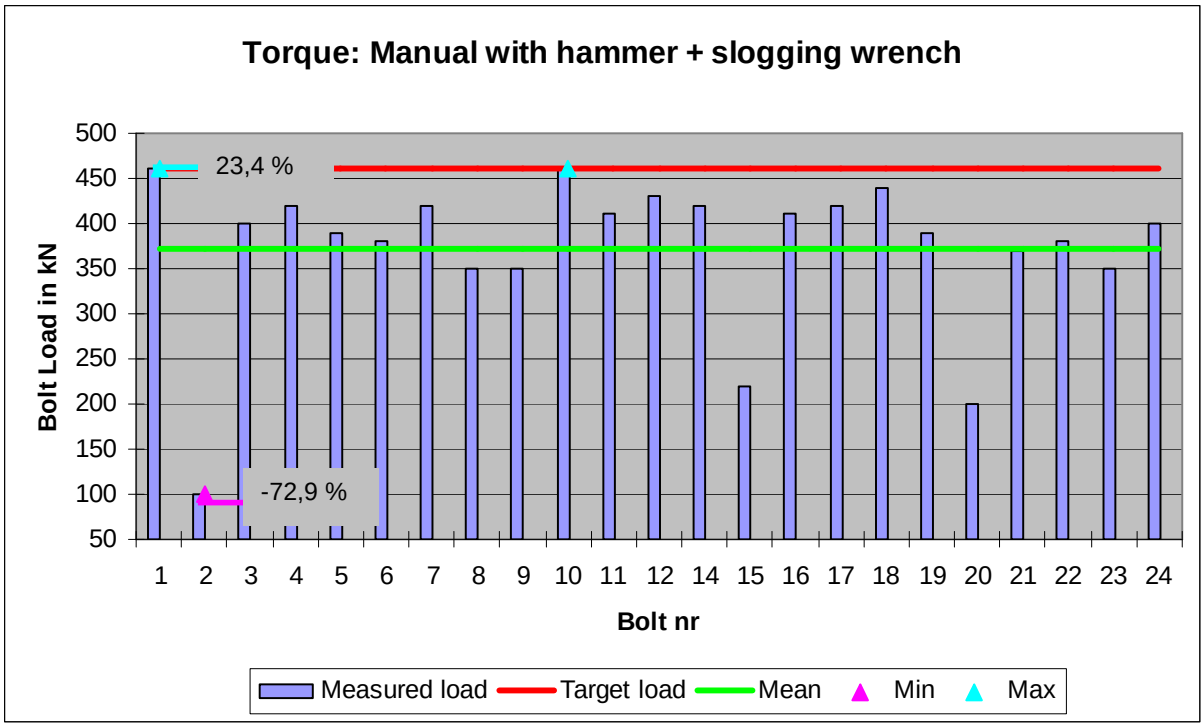


**Figure 8: Graph residual load after tightening by manual**

## 3.5 Measurement: Residual load after tightening by hydraulic Hytorc torque wrench

After the manual torque with hammer another pass was done by using a Hytorc hydraulic torque wrench model XLCT-4 that was set at 460 Nm (350 bar). The tool was not precisely adjusted however bolt 1 was used for adjusting.
Results are shown in Table 6 and figure 9. Because this size BoltSafe starts measuring from 101 kN there are no values lower than 101 kN shown.

**Table 6: Figures residual load after tightening by hydraulic Hytorc torque wrench**

| BoltSafe | Force (kN) | Mean (kN) | Difference with mean (%) |
|---|---|---|---|
| 1 | 470 | 432 | 8,8% |
| 2 | 550 | 432 | 27,3% |
| 3 | 430 | 432 | -0,5% |
| 4 | 440 | 432 | 1,8% |
| 5 | 460 | 432 | 6,4% |
| 6 | 390 | 432 | -9,8% |
| 7 | 430 | 432 | -0,5% |
| 8 | 370 | 432 | -14,4% |
| 9 | 500 | 432 | 15,7% |
| 10 | 470 | 432 | 8,8% |
| 11 | 440 | 432 | 1,8% |
| 12 | 430 | 432 | -0,5% |
| 13 | **** | 432 | **** |
| 14 | 490 | 432 | 13,4% |
| 15 | 240 | 432 | -44,5% |
| 16 | 410 | 432 | -5,1% |
| 17 | 420 | 432 | -2,8% |
| 18 | 440 | 432 | 1,8% |
| 19 | 410 | 432 | -5,1% |
| 20 | 400 | 432 | -7,4% |
| 21 | 410 | 432 | -5,1% |
| 22 | 420 | 432 | -2,8% |
| 23 | 420 | 432 | -2,8% |
| 24 | 500 | 432 | 15,7% |

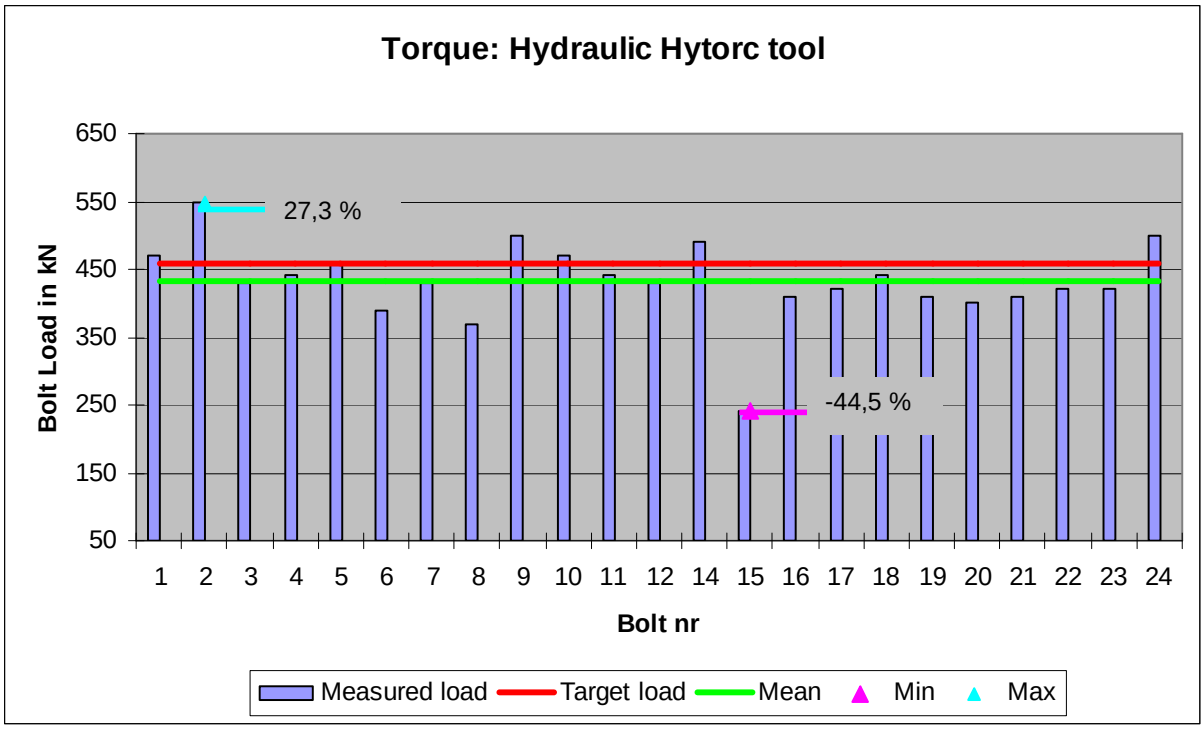


**Figure 9: Graph residual load after tightening by hydraulic Hytorc torque wrench**

## 3.6 Comparison

In figure 10 is the comparison of methods displayed, the comparison is done with the mean values.

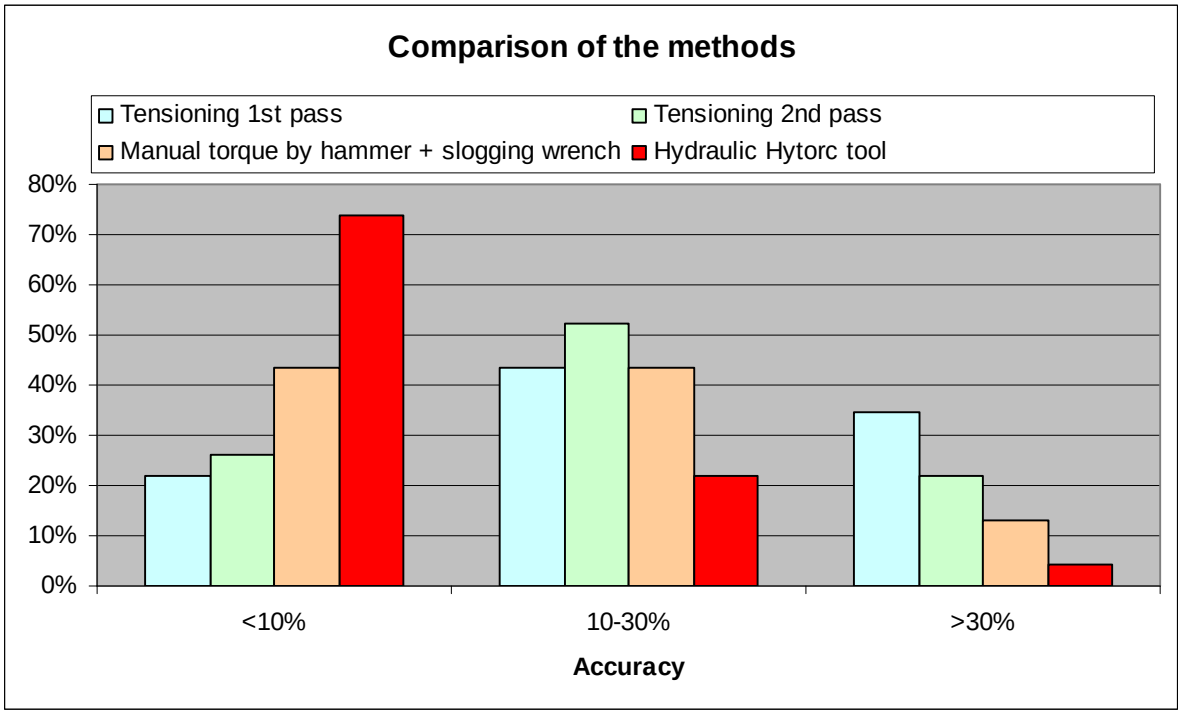


**Figure 10: Accuracy of the 4 methods compared**

# 4 Conclusions of comparison

- The best result was achieved with an hydraulic torque wrench
- The result with hammer was better then with hydraulic tensioners
- With hydraulic tensioners a 2nd pass was necessary to improve the results
- The Boltsafe's cannot measure <10% of maximum: the minimum value were assumed to be 10%, therefore the results for tensioners can be worse as shown
- The bolts were used: the negative effect of minor flaws occurred mostly with tensioning system

# 5 Test: Torque with Avanti 5 and LoadDISC

After discussing the results of the first test the costumer asked for a test with LoadDISC's and Hytorc Equipment.

## *5.1 Measurement description*

The target of the measurement was to monitor the boltload during and after assembly with the Hytorc Avanti 5 tool and LoadDISC. During the test there was a 100% coverage of the bolts The measurement took place continuously but was saved on the following 3 moments

- Boltload after first round Torque with LoadDISC's
- Boltload after second round Torque with LoadDISC's
- Boltload after third round Torque with LoadDISC's

## *5.2 Equipment*

During the tests the following hardware was used:

- 3pc. BoltSafe CM1000 network boxes each for max 8 sensors
- 1pc. BoltSafe Power Data Interface box
- 24pc. BoltSafe M48 CMS BoltSafe Washer. Range 101-1.018kN, Accuracy +/- 2% full scale
- 24pc. M48 LoadDISC's
- 4pc. Hytorc Model Avanti 5 and pump unit 700 Bar Torque range 701 Nm to 6907 Nm
- 6pc. M48 nuts class 8
- 10pc. M48 nuts class 10
- 8pc. M48 nuts class 11

The used lubrication during the test was Gleitmu 160 neu

The used BoltSafe's are the same one as used in the previous test, only the broken BoltSafe was displace with a new one.

The used BoltSafe equipment has an accuracy +/-3% full scale.

During the test the BS2000 Network Monitoring version 1.2.3 software was used.

## 5.4 Environment

The measurements were done at the site of the costumer of Hytorc Seis GmbH, this costumer is a petrochemicals plant.

Application: reactor vessel with flange, 24 bolts in blind holes. In figure 11 is shown how the BoltSafe's and LoadDISC's were installed.

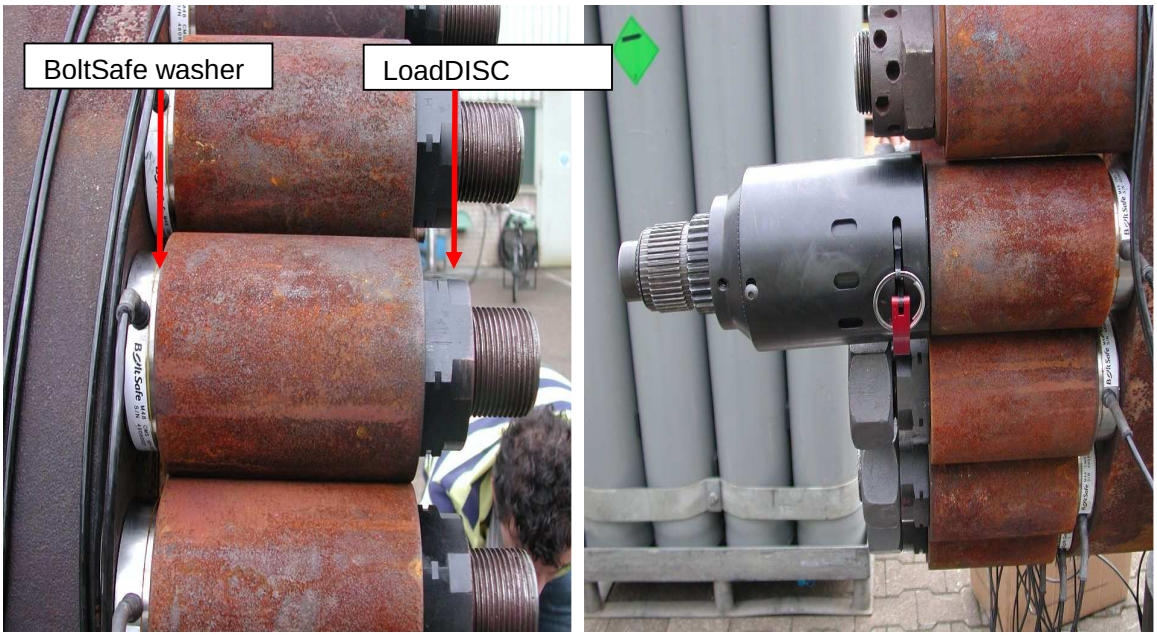


**Figure 11: BoltSafe's with LoadDISC's on the flange**

During the test were 4 Hytorc Avanti 5 tools used in figure 12 is the shown how these tools were placed in start position.

**Figure 12: Start position of the Hytorc Avanti 5 tools**

## 5.5 BoltSafe positions

During the test the BoltSafe's were placed and numbered clockwise, see figure 13.

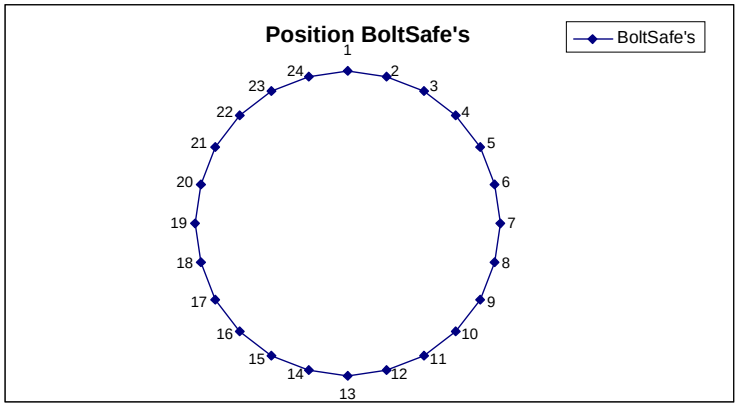


**Figure 13: BoltSafe positions on the flange**

The type of nuts according the BoltSafe's is:

- Class 8 : BoltSafe 1 t/m 6
- Class 10: BoltSafe 7 t/m 16
- Class 11: BoltSafe 17 t/m 24

# 6 Measurement results

## *6.1 Boltload after first round Torque with LoadDISC's*

During the first round torque BoltSafe 8 was turning and the connection almost breaks, this was not a BoltSafe failure. Table 7 shows the measured values by in digit and in figure 14 in diagram. The target preload was 460 kN.

**Table 7: Figures Boltload after first round Torque with LoadDISC's**

| BoltSafe | Force (kN) | Mean (kN) | Difference with mean (%) |
|---|---|---|---|
| 1 | 300 | 348 | -13,8% |
| 2 | 230 | 348 | -33,9% |
| 3 | 400 | 348 | 15,0% |
| 4 | 300 | 348 | -13,8% |
| 5 | 330 | 348 | -5,1% |
| 6 | 480 | 348 | 38,0% |
| 7 | 370 | 348 | 6,4% |
| 8 | **** | 348 | **** |
| 9 | 420 | 348 | 20,8% |
| 10 | 390 | 348 | 12,1% |
| 11 | 350 | 348 | 0,6% |
| 12 | 400 | 348 | 15,0% |
| 13 | 360 | 348 | 3,5% |
| 14 | 310 | 348 | -10,9% |
| 15 | 360 | 348 | 3,5% |
| 16 | 320 | 348 | -8,0% |
| 17 | 330 | 348 | -5,1% |
| 18 | 470 | 348 | 35,1% |
| 19 | 280 | 348 | -19,5% |
| 20 | 250 | 348 | -28,1% |
| 21 | 330 | 348 | -5,1% |
| 22 | 290 | 348 | -16,6% |
| 23 | 260 | 348 | -25,3% |
| 24 | 470 | 348 | 35,1% |

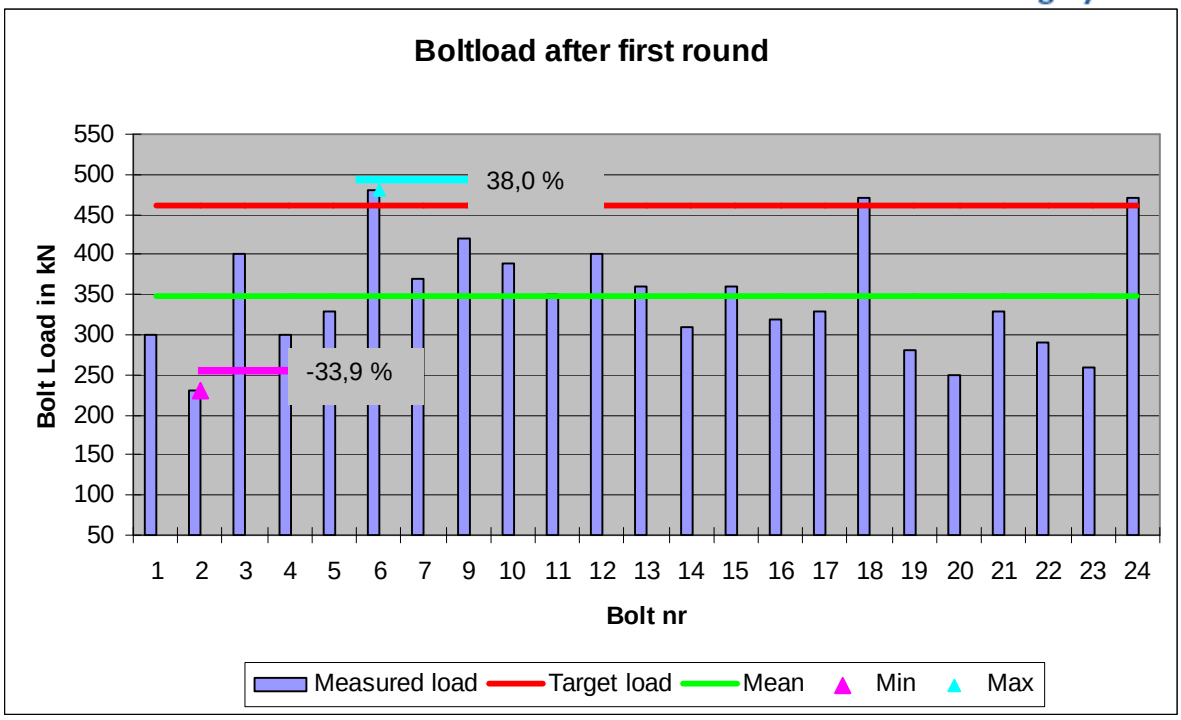


**Figure 14: Graph boltload after first round torque with LoadDISC's**

## 6.2 Boltload after second round Torque with LoadDISC's

The target Bolting force was 460 kN. In Table 8 the measurement values are shown after the second time the bolts were tensioned and the curve is displayed in figure 15.

**Table 8: Figures Boltload after second round Torque with LoadDISC's**

| BoltSafe | Force (kN) | Mean (kN) | Difference with mean (%) |
|---|---|---|---|
| 1 | 370 | 429 | -13,8% |
| 2 | 460 | 429 | 7,2% |
| 3 | 390 | 429 | -9,1% |
| 4 | 460 | 429 | 7,2% |
| 5 | 430 | 429 | 0,2% |
| 6 | 480 | 429 | 11,9% |
| 7 | 500 | 429 | 16,5% |
| 8 | **** | 429 | **** |
| 9 | 410 | 429 | -4,5% |
| 10 | 510 | 429 | 18,8% |
| 11 | 440 | 429 | 2,5% |
| 12 | 410 | 429 | -4,5% |
| 13 | 450 | 429 | 4,9% |
| 14 | 430 | 429 | 0,2% |
| 15 | 360 | 429 | -16,1% |
| 16 | 430 | 429 | 0,2% |
| 17 | 450 | 429 | 4,9% |
| 18 | 490 | 429 | 14,2% |
| 19 | 420 | 429 | -2,1% |
| 20 | 400 | 429 | -6,8% |
| 21 | 320 | 429 | -25,4% |
| 22 | 390 | 429 | -9,1% |
| 23 | 370 | 429 | -13,8% |
| 24 | 500 | 429 | 16,5% |

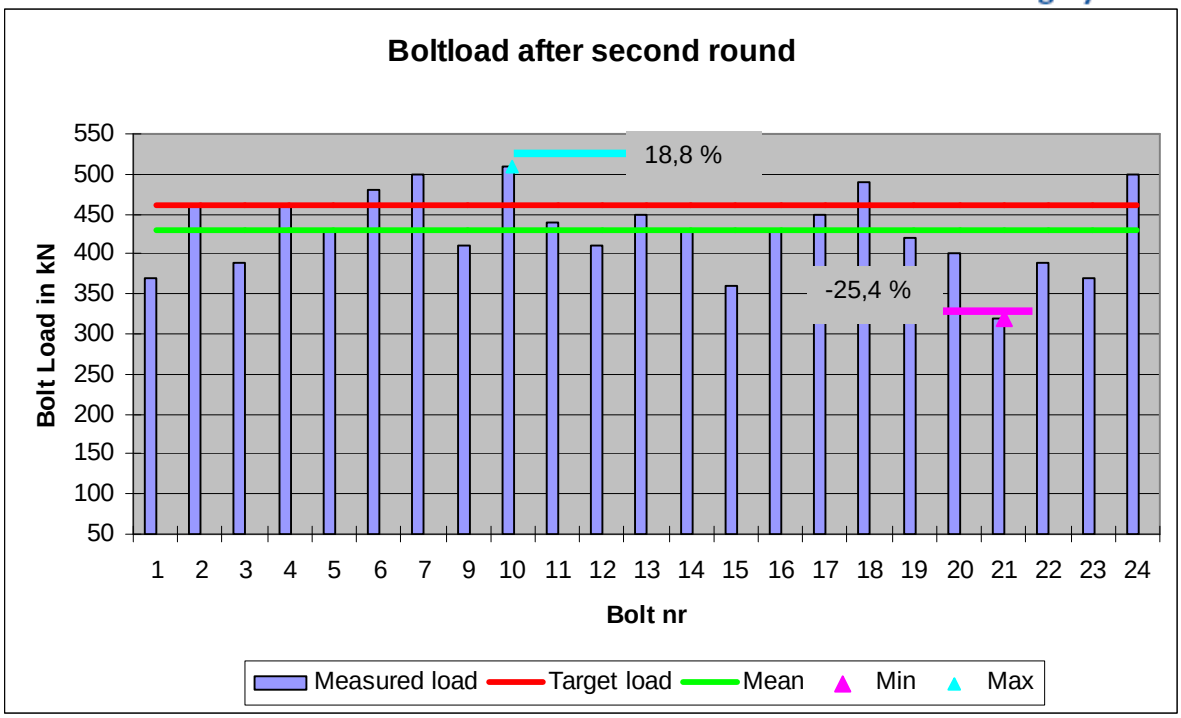


**Figure 15: Graph boltload after second round torque with LoadDISC's**

## 6.3 Boltload after third round Torque with LoadDISC's

The target Bolting force was 460 kN. In Table 9 the measurement values are shown after the second time the bolts were tensioned and the curve is displayed in figure 15.

**Table 8: Figures Boltload after third round Torque with LoadDISC's**

| BoltSafe | Force (kN) | Mean (kN) | Difference with mean (%) |
|---|---|---|---|
| 1 | 410 | 442 | -7,3% |
| 2 | 490 | 442 | 10,8% |
| 3 | 410 | 442 | -7,3% |
| 4 | 480 | 442 | 8,6% |
| 5 | 430 | 442 | -2,8% |
| 6 | 490 | 442 | 10,8% |
| 7 | 410 | 442 | 15,3% |
| 8 | **** | 442 | **** |
| 9 | 510 | 442 | -5,0% |
| 10 | 420 | 442 | 22,1% |
| 11 | 540 | 442 | -0,5% |
| 12 | 440 | 442 | -9,5% |
| 13 | 400 | 442 | 8,6% |
| 14 | 480 | 442 | -2,8% |
| 15 | 430 | 442 | -14,1% |
| 16 | 380 | 442 | 1,8% |
| 17 | 450 | 442 | -0,5% |
| 18 | 440 | 442 | 10,8% |
| 19 | 490 | 442 | 4,0% |
| 20 | 460 | 442 | -7,3% |
| 21 | 410 | 442 | -25,4% |
| 22 | 330 | 442 | -7,3% |
| 23 | 410 | 442 | -16,3% |
| 24 | 500 | 442 | 13,1% |

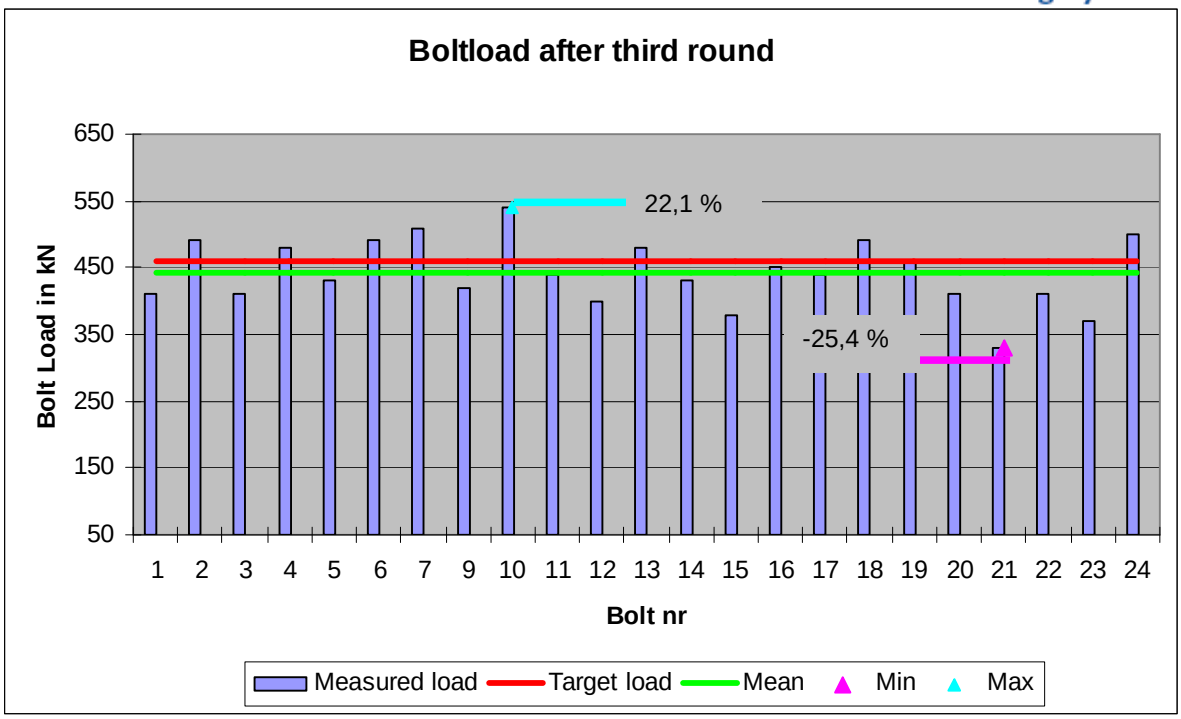


**Figure 15: Graph boltload after third round torque with LoadDISC's**

## 6.4 Comparison of the rounds

In figure 16 is the comparison of rounds displayed, the comparison is done with the mean values.

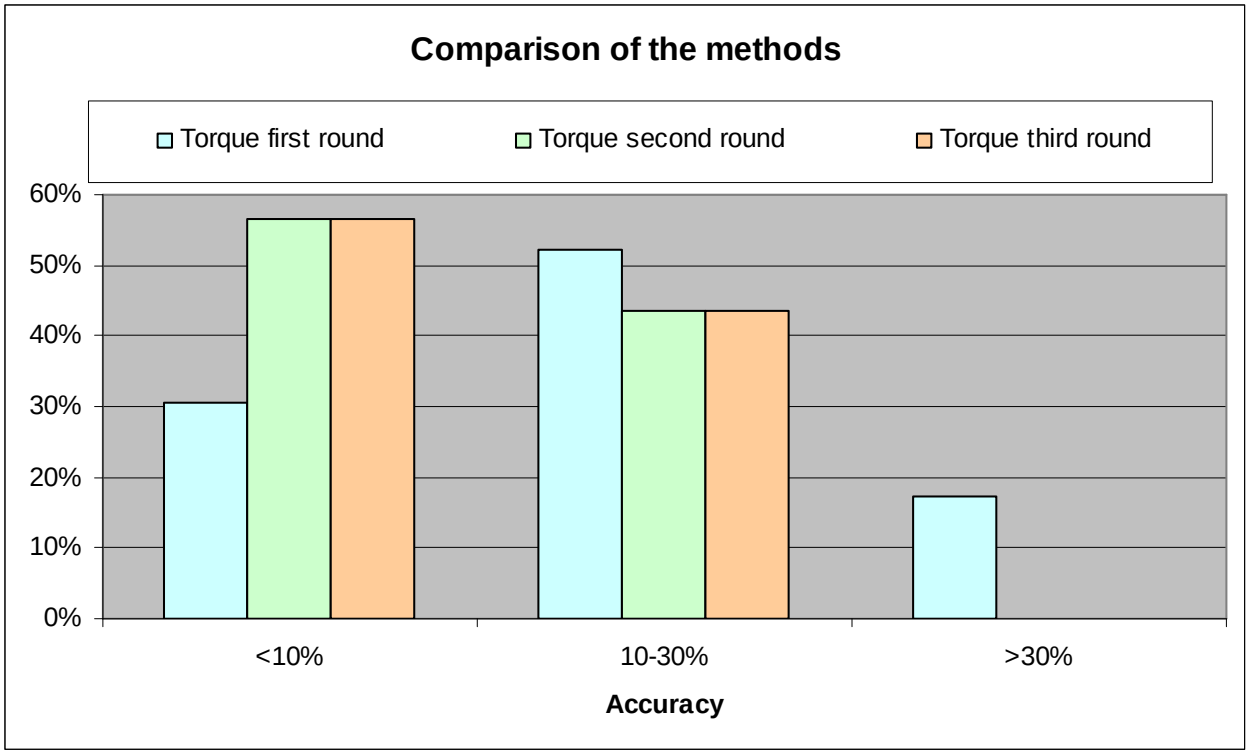


**Figure 16: Accuracy of the 3 rounds compared**