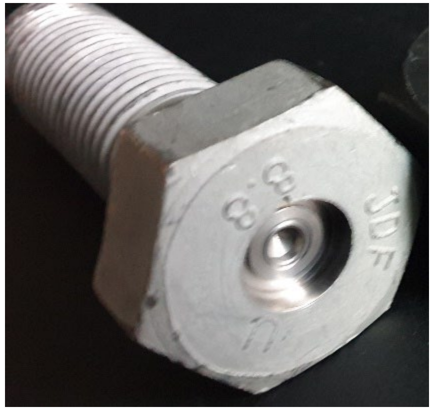
Methods for supervision of bolt pretension

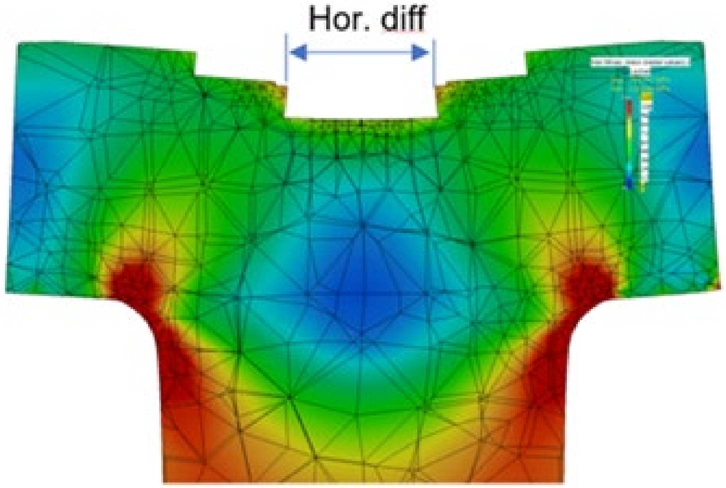
Validations by laboratory tests, field measurements and FE-analyses

Partners: RISE, TensionCam Systems, Bulten, Chalmers, Rabbalshede Kraft and Stena Renewable

Aim:

- Optimize the shape of the cavity for best measurement resolution
- Predict the impact of structural integrity of the bolt and nut, caused by the cavity.
- Validate the resolution of the pretension by workshop tests



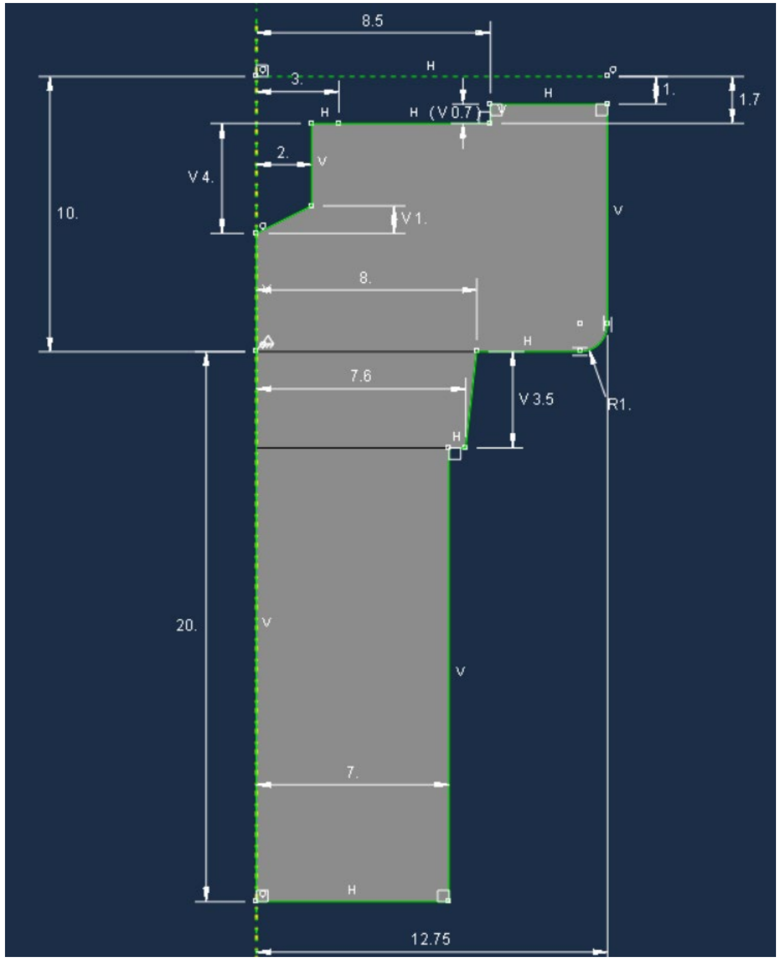


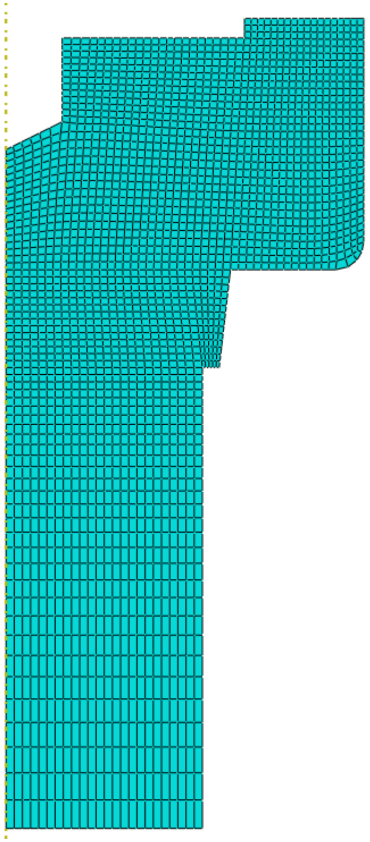
M36 bolt

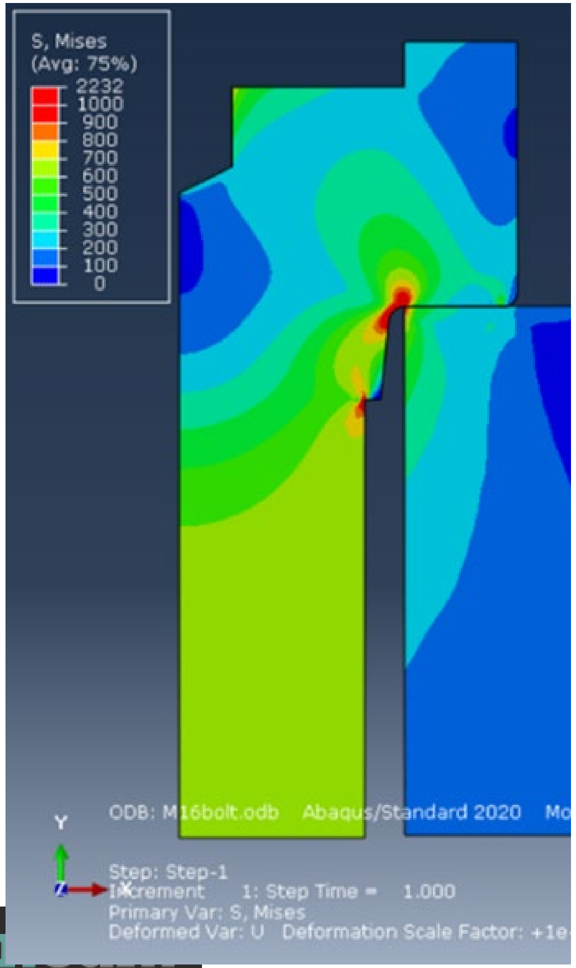
CHALMERS RISE TensionCam™ SWPTC SWEDISH WIND POWER TECHNOLOGY CENTRE

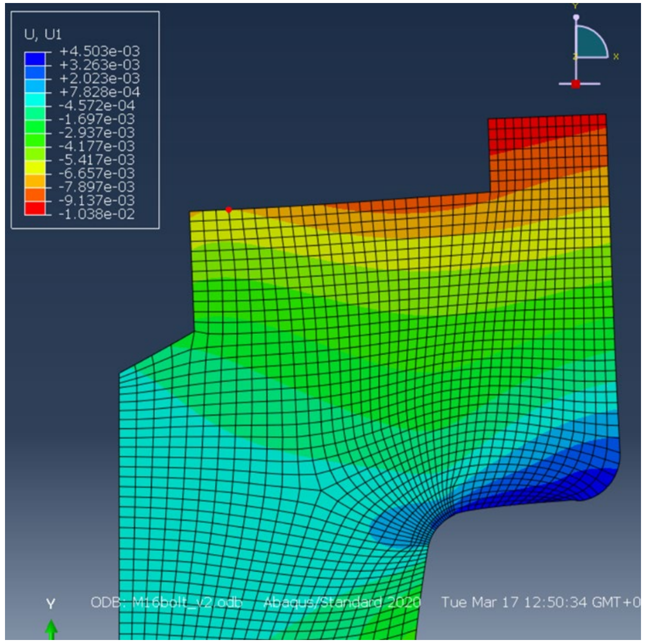
Methods for supervision of bolt pretension

Validations by laboratory tests, field measurements and FE-analyses









CHALMERS

RISE

Methods for supervision of bolt pretension

Environmental resistance

Aim:

- To present an efficient corrosion protection for the bolt and its cavity
- To check whether different covers may have sufficient protection.
- To validate the protection proposal by well-controlled accelerated corrosion testing.

Methods for supervision of bolt pretension

Environmental resistance

Test matrix - Environmental Resistance

2020-09-04

Description	Amount
Cavity + Sensor + Silicone + Cap	2
Cavity + Sensor + Silicone	1
Cavity + Silicone + Cap	3
Cavity + Silicone	3
Cavity + Cap	3
Cavity	3
Cavity + Sensor + Silicone overf. + Cap	2
Cavity + Sensor + Silicone overf.	1
Total	**18**

This matrix allows the assessment of:

- Determine if caps improve or worsen the corrosion phenomena on the bolt.
- Determine if the silicone potting material is adecuate for moisture/corrosion protection given the conditions of the accelerated corrosion test.
- Determine if the coating on the bolts is corrosion resistant given the conditions of the accelerated corrosion test.

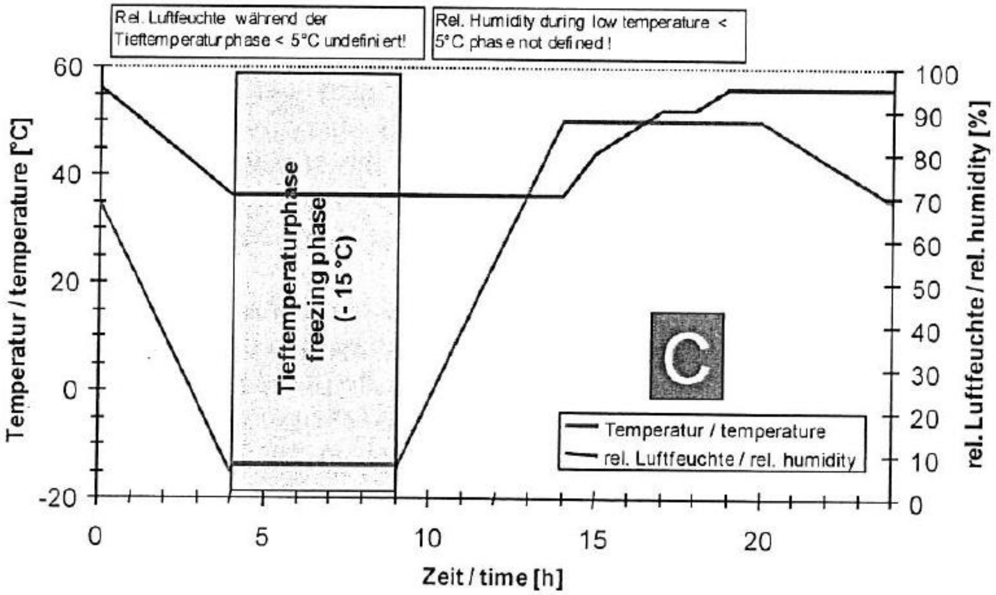
*Cavity: Bolts have been machined after surface treatment (GEOMET). The surface of these “as-received” bolts will be assessed as well.
*Silicone: Potting silicone applied in cavity.
*Silicone overf.: Potting silicone applied overflowing the cavity.
*Cap: Plastic protective cap.

Methods for supervision of bolt pretension

Environmental resistance

Accelerated corrosion test cabinet (salt spray) at RISE (Kista).

- The accelerated corrosion test will follow the standard VDA 233-102. The standard specifies how to simulate harsh atmospheric corrosion conditions.
- Relative humidity and temperature are cycled.
- A 1% NaCl solution is sprayed on the specimens.
- The specimens are placed in a non-metallic holder at an angle from 60° to 75°.



Accelerated corrosion test scheme from VDA 233-102

CHALMERS

RI. SE

Tensic

Methods for supervision of bolt pretension

Environmental resistance

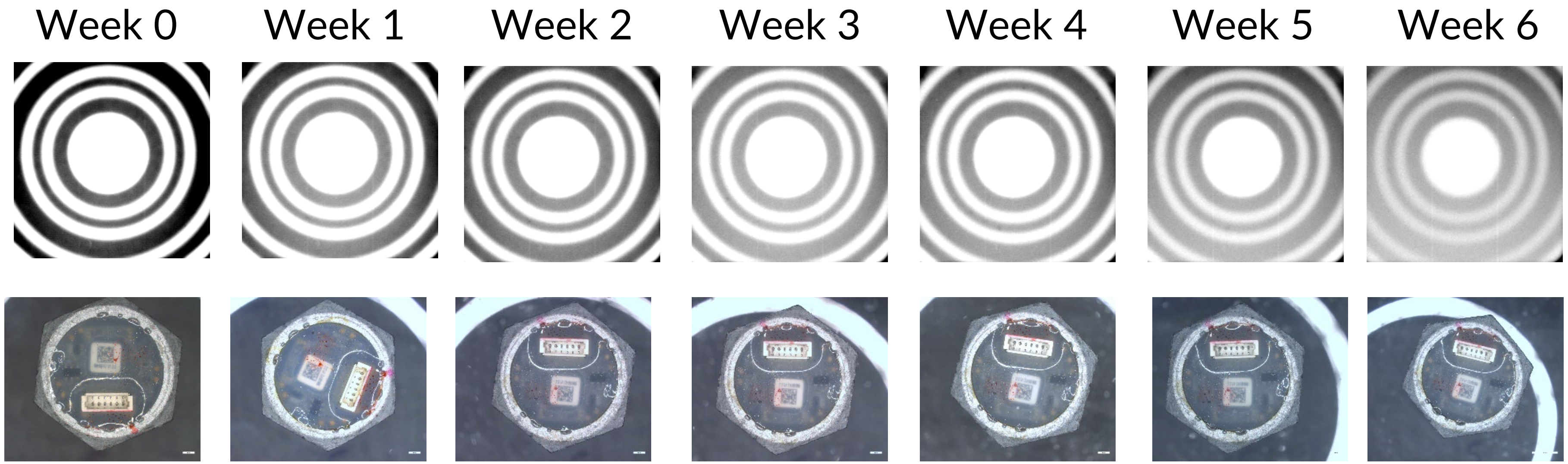
Sensor Image Bolt 4: No-cap

Week 0 Week 1 Week 2 Week 3 Week 4 Week 5 Week 6

Methods for supervision of bolt pretension

Environmental resistance

Sensor Image Bolt 5: Cap



Methods for supervision of bolt pretension

Environmental resistance

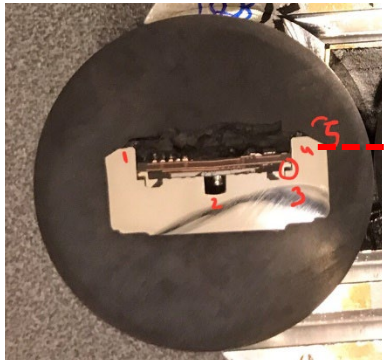
Scanning Electron Microscope/ Energy Dispersive X-Ray Spectroscopy (SEM/EDS)

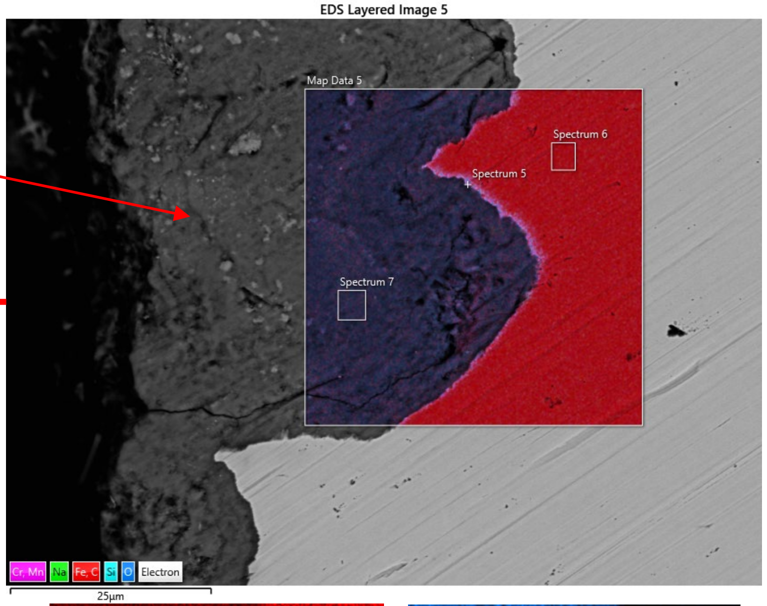
A techniques used in conjunction to obtain high resolution images and chemical characterization of a volume

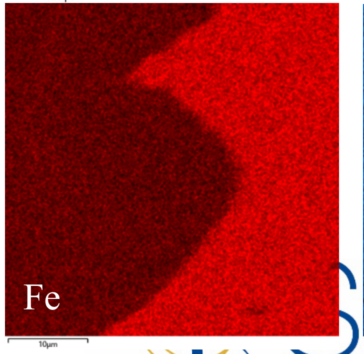
Sensor 1 – no cap

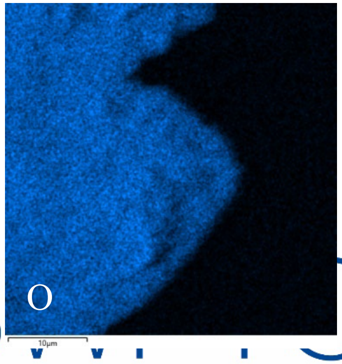
Week 6

Corrosion products found underneath the silicone layer







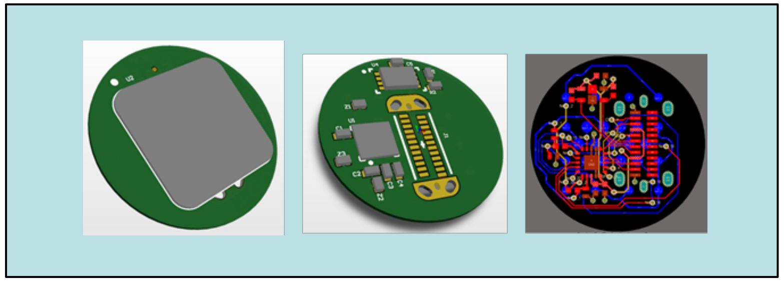


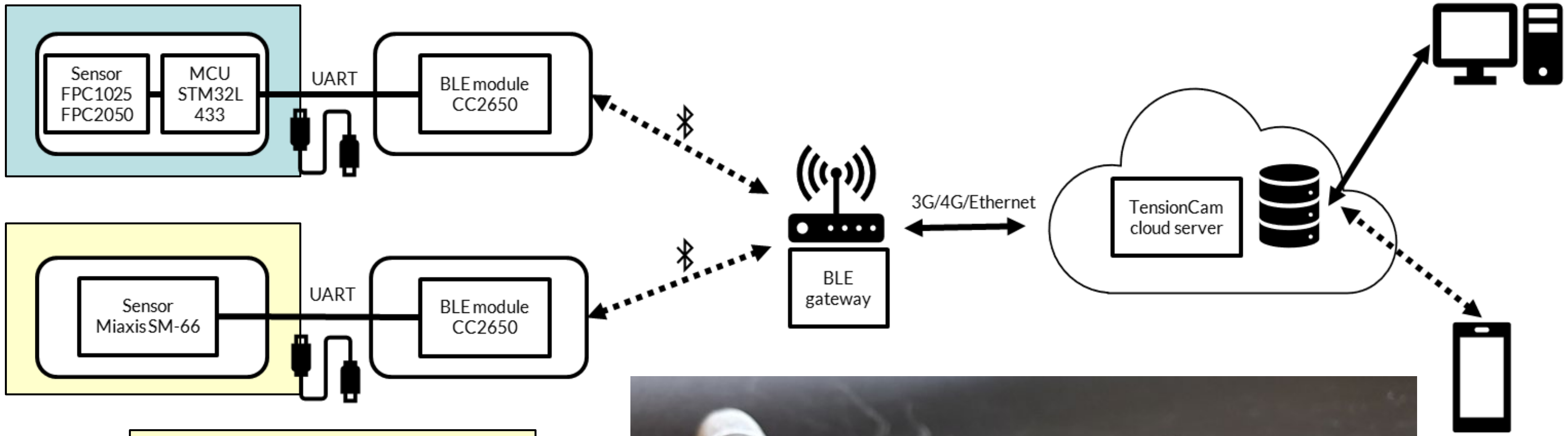
Methods for supervision of bolt pretension

Remote reading of bolt status

Achievements:

- ✓ Evaluation and selection of hardware solution
- ✓ System design and fabrication of demo hardware
- ✓ Evaluation of appropriate wireless protocols
- ✓ Benchmark to commercial hardware





Methods for supervision of bolt pretension

Scientific aspects, optimization and documentation

Aim and activities

- A scientific article will be compiled.
- Investigate the potential for optimization of bolt connections
- Recommendations on the design aspects, on how to design and dimension a robust bolted joints

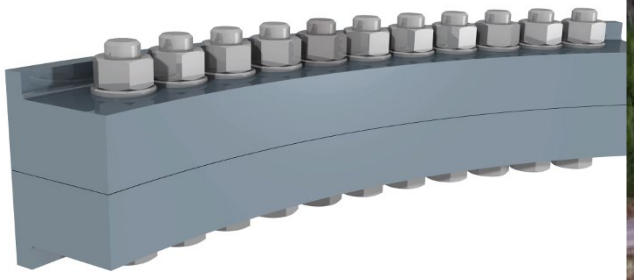


Figure 1. A traditional bolted flange connection which is studied and modified in this paper.

Methods for supervision of bolt pretension

Scientific aspects, optimization and documentation

Fatigue load evaluation

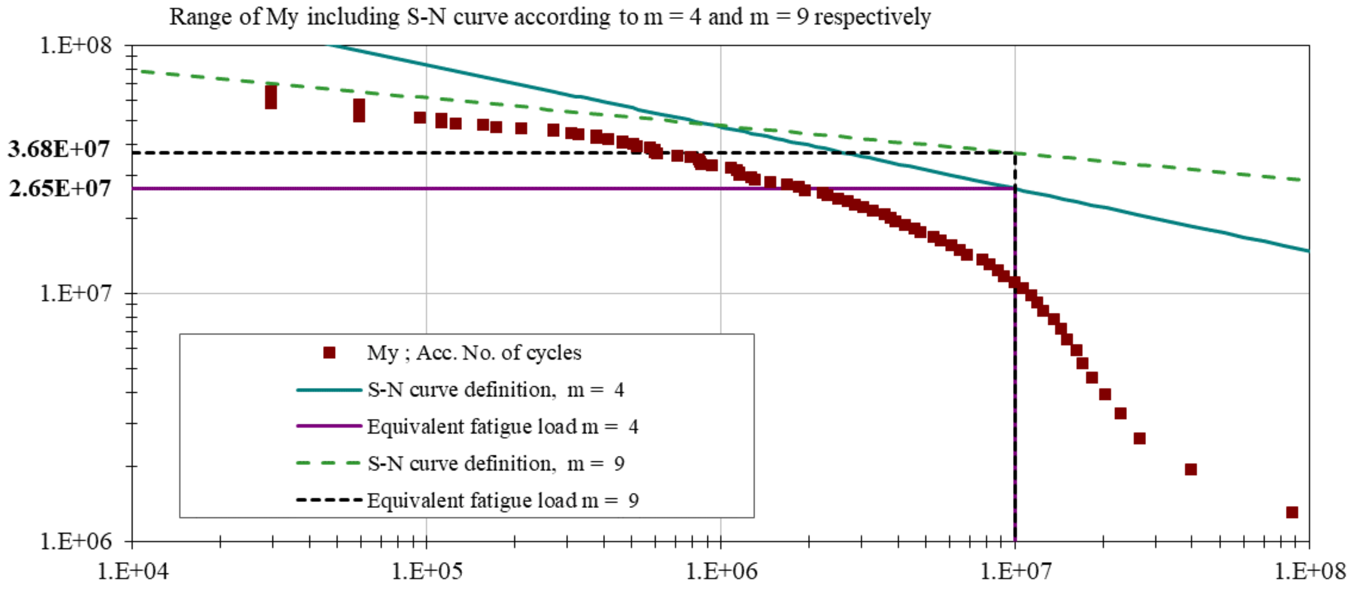


Figure 6. Calculation of equivalent bending moment My for 20 years life at a specific height of the tower. My = 2.65E+7 (m=4 and Neq=1E+7) and 3.68E+7 (m=9 and Neq=1E+7).

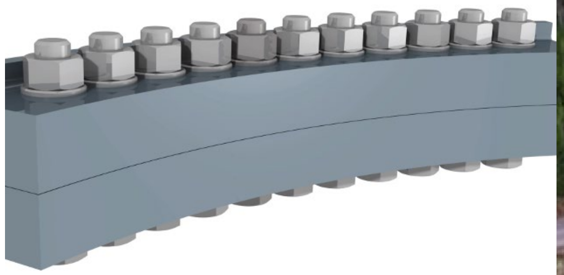


Figure 1. A traditional bolted flange connection which is studied and modified in this paper.

Finally, the total maximal external force on a bolt in the flange is the sum of the contribution from the bending moments and the normal force:

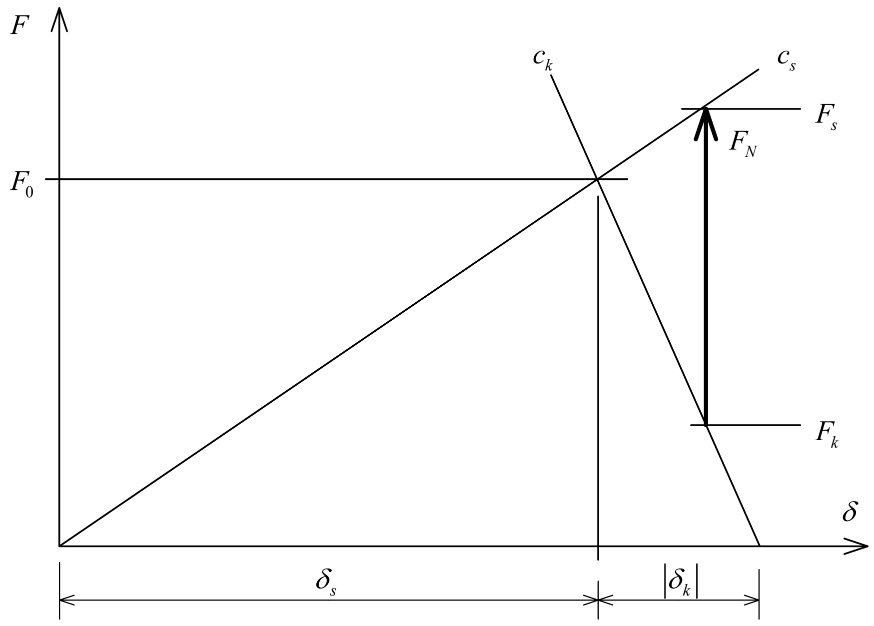
$$F_{b,\max}(t,z) = \frac{2M_y(t,z)}{Nr_b} + \frac{F_z(t,z)}{N} \qquad (9)$$

CHALMERS RI.SE TensionCam™ SWPTC SWEDISH WIND POWER TECHNOLOGY CENTRE

Methods for supervision of bolt pretension

Scientific aspects, optimization and documentation

Theory of bolted joints



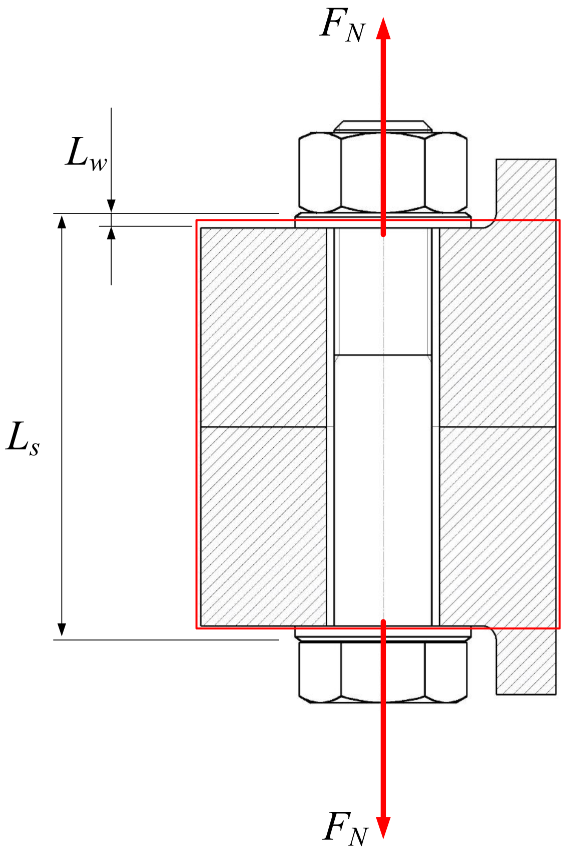


Figure 9. F, δ-diagram, showing how the external force F_N is distributed between bolt F_s and clamped parts F_k (flange).

CHALMERS RI.SE TensionCam™ SWPTC SWEDISH WIND POWER TECHNOLOGY CENTRE

Methods for supervision of bolt pretension

Scientific aspects, optimization and documentation

Theory of bolted joints Prying effect in L-flange joints

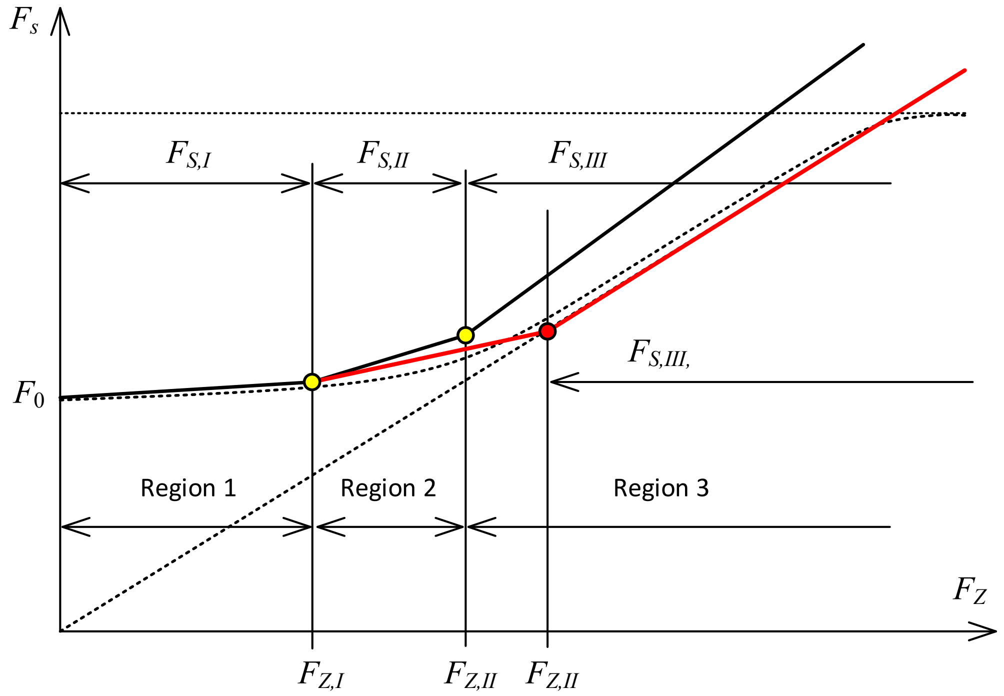


Figure 13. Tri-linear approximation of the elastic behavior of the bolted joint with non-conservative prying effect assuming planar faces without imperfections of the flanges.

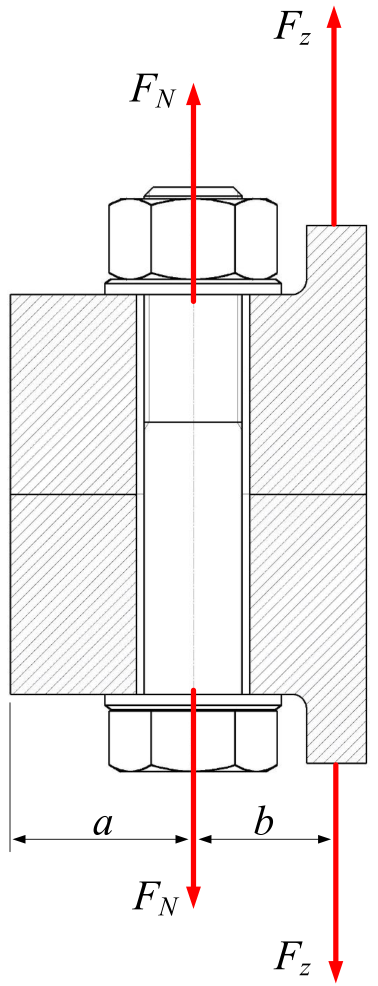


Figure 11. Eccentrically load bolt in an L-flange.

Methods for supervision of bolt pretension

Scientific aspects, optimization and documentation

Theory of bolted joints The effect of longer bolt and sleeve

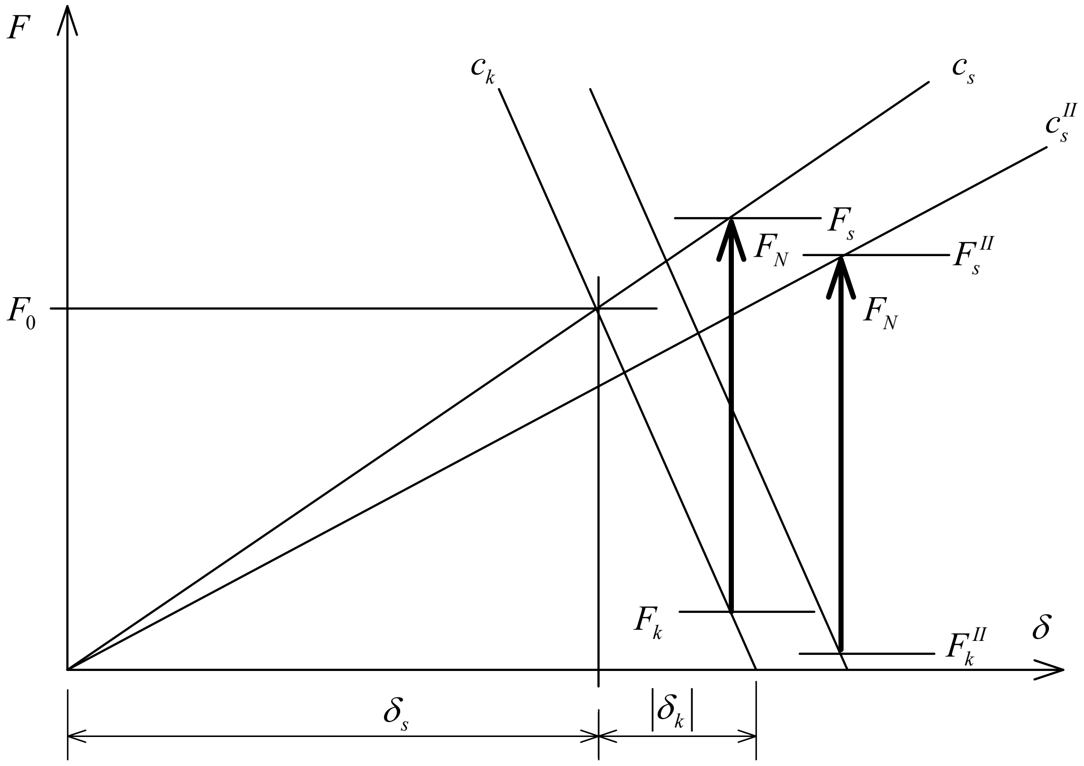
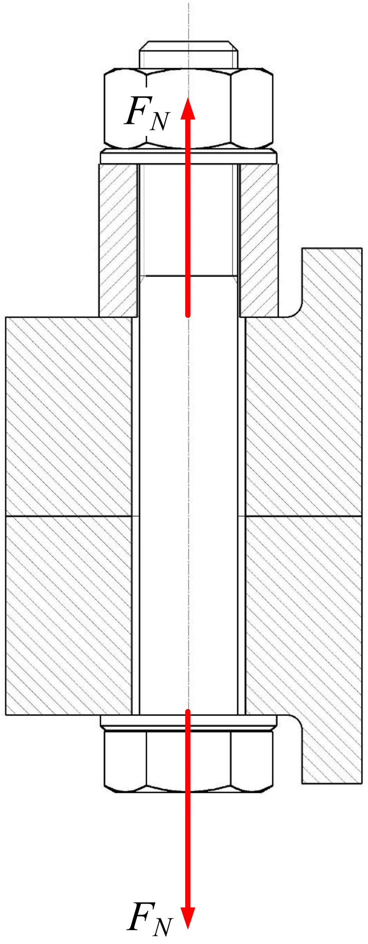


Figure 14. F,δ-diagram showing comparison between original and modified joint design.



Methods for supervision of bolt pretension

Scientific aspects, optimization and documentation

Benchmark between two potential bolt connections

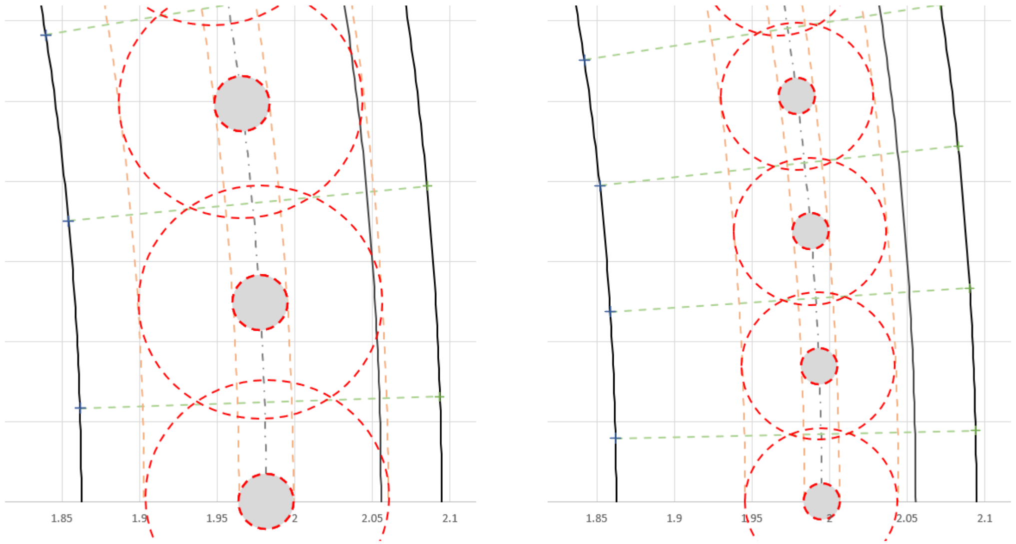
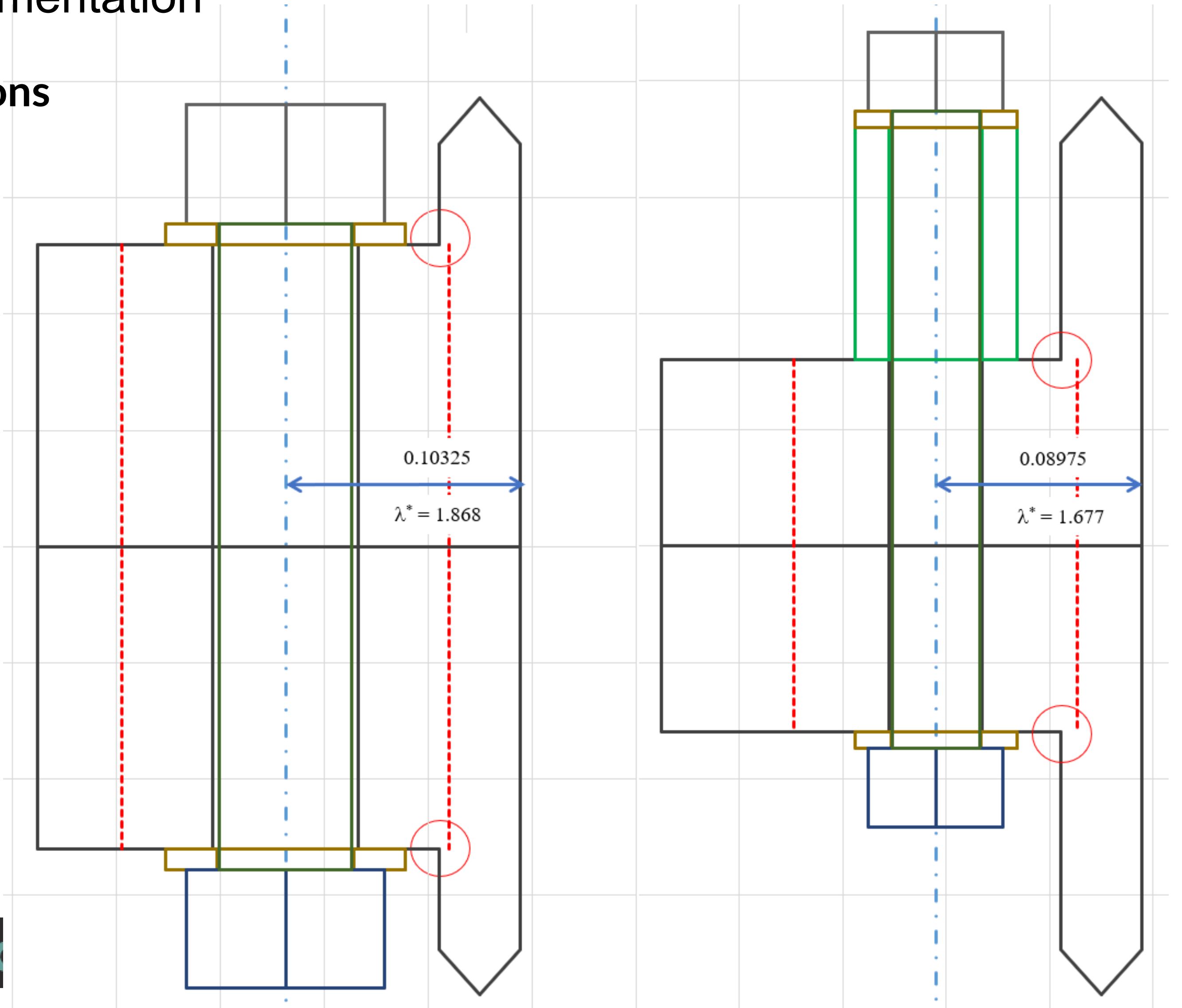


Figure 15. Two principle bolt connections solving the same task in a wind turbine tower. To the left, CASE 1, a typical "traditional" bolt flange connection. 100 M64 bolts. To the right, CASE 2, a new proposed flange with sleeve. 148 M42 bolts. Note that the bolt centre line is larger at CASE 2 which results in a lower λ, which has an impact to the prying impact. Still the distance between the bolt head and the tower shell remains the same. Also note the sharp edges (red circles) which are not allowed but out of scope for this study.*



CHALMERS

RISE

Tensio

Methods for supervision of bolt pretension

Scientific aspects, optimization and d

Scientific paper soon ready for submission

Improvements of Bolted Flange Joints in Wind Turbine Towers by Use of Slender Bolts and Sleeves

Magnus Evertsson, Chalmers University of Technology
Anders Wickström, RISE

Abstract

Bolted flange joints are commonly used for connection the sections in wind turbine towers. In this paper L-shaped joints are analysed with respect to fatigue life. The load and stress conditions are described and calculated with aeroelastic simulations in normal turbulent wind conditions. The theory of bolted joints is shown in detail, including the prying effect in L-flange joints. A tri-linear approach is adopted for the elastic behavior of the flange joint in order to facilitate an analytical prediction of the stresses at varying load levels. The theory and effect of longer bolt and sleeve is presented and how stress conditions can be improved.

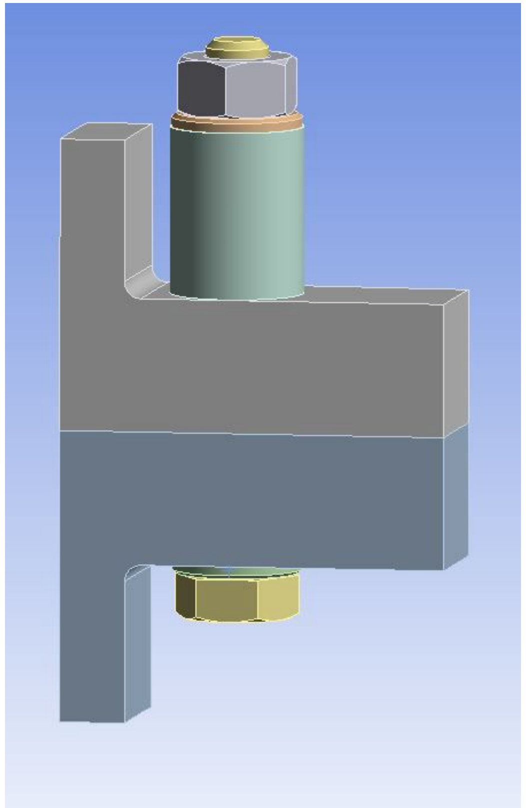
A benchmark between two potential bolt connections is carried out. A possible redesign with focus on saving overall mass in the joint while preserving or improving fatigue life is presented. Instead of using 100 M64 bolts, a connection with 148 M42 bolts and sleeves provide similar fatigue resistance at half the total weight. The results show that the tri-linear approach is a feasible method and that it can be used for comparison of alternative design options.

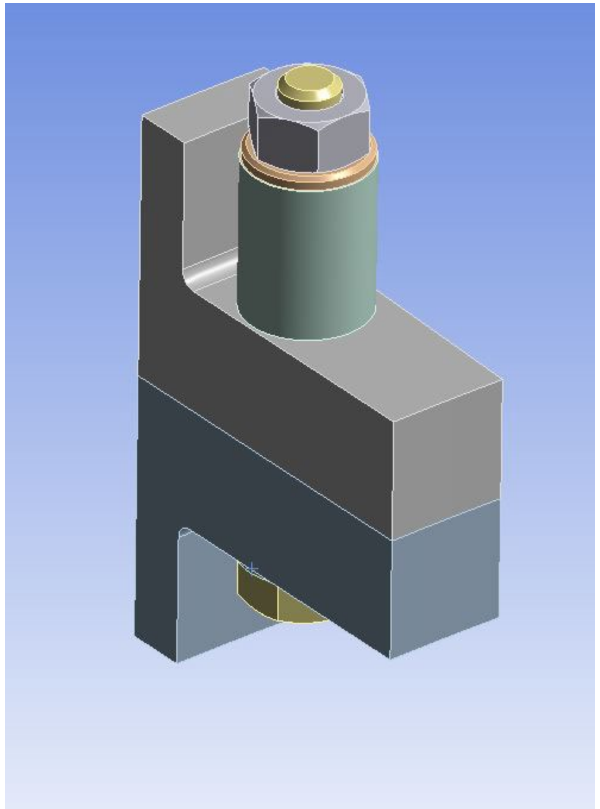
Sensitivity studies analyse the impact of flange thickness and detail geometry of the flange. The depth of the flange has a large impact on the life. The prying effect is in favour of large depth, i.e. large λ^*-value.

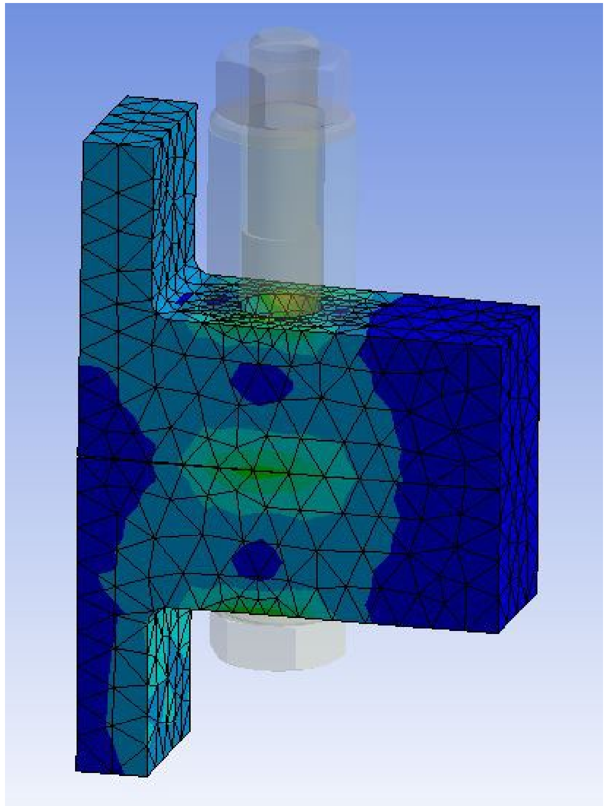
Correct bolt pretension is crucial. This article is part of a research project with the company TensionCam, which has developed a sensor technology for check and supervision of the pretension force in bolt connections.

Methods for supervision of bolt pretension

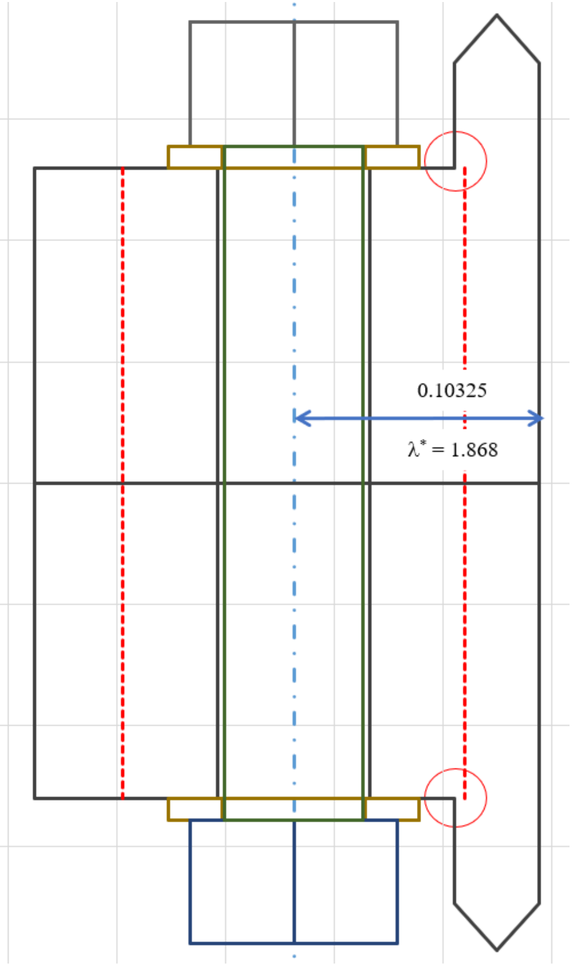
Check by FE-analyses

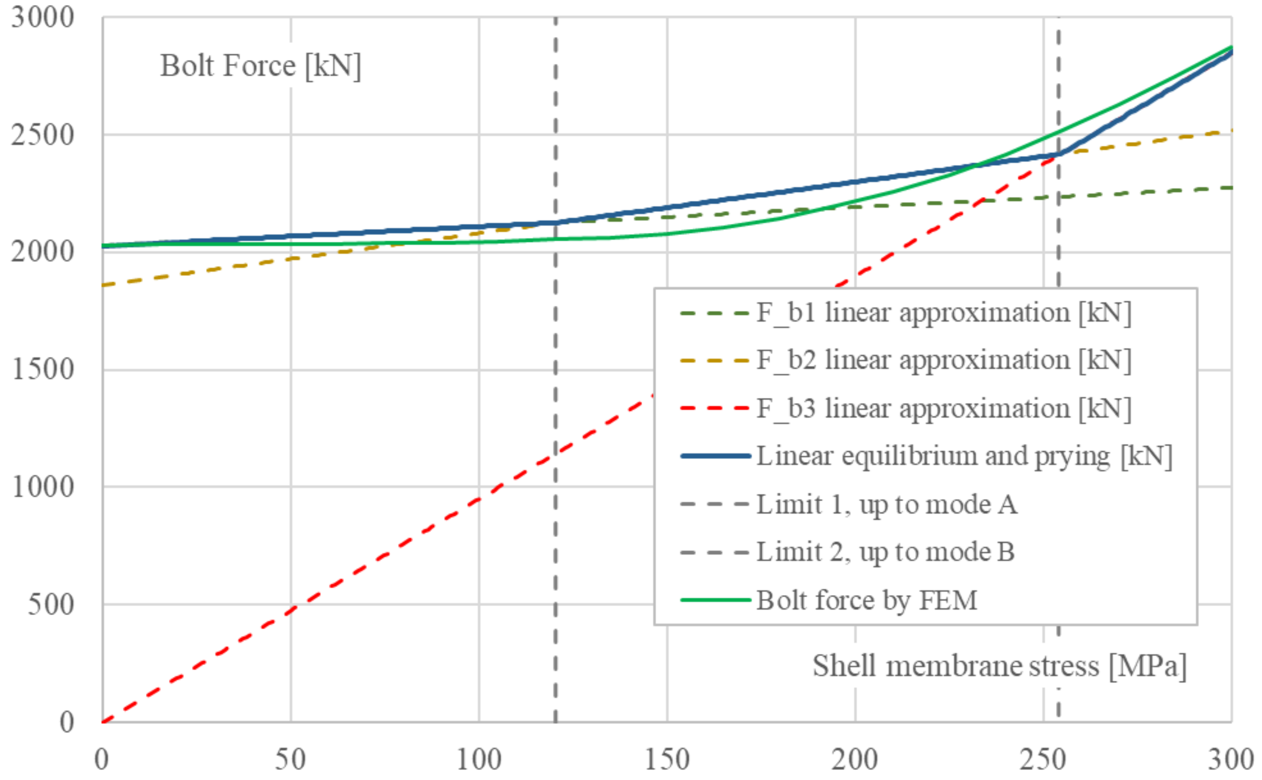




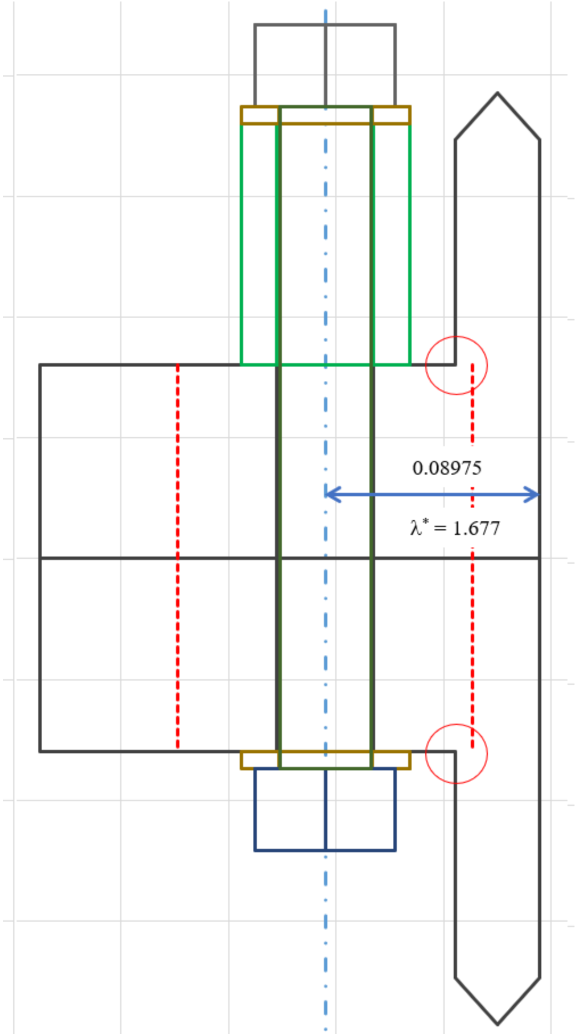


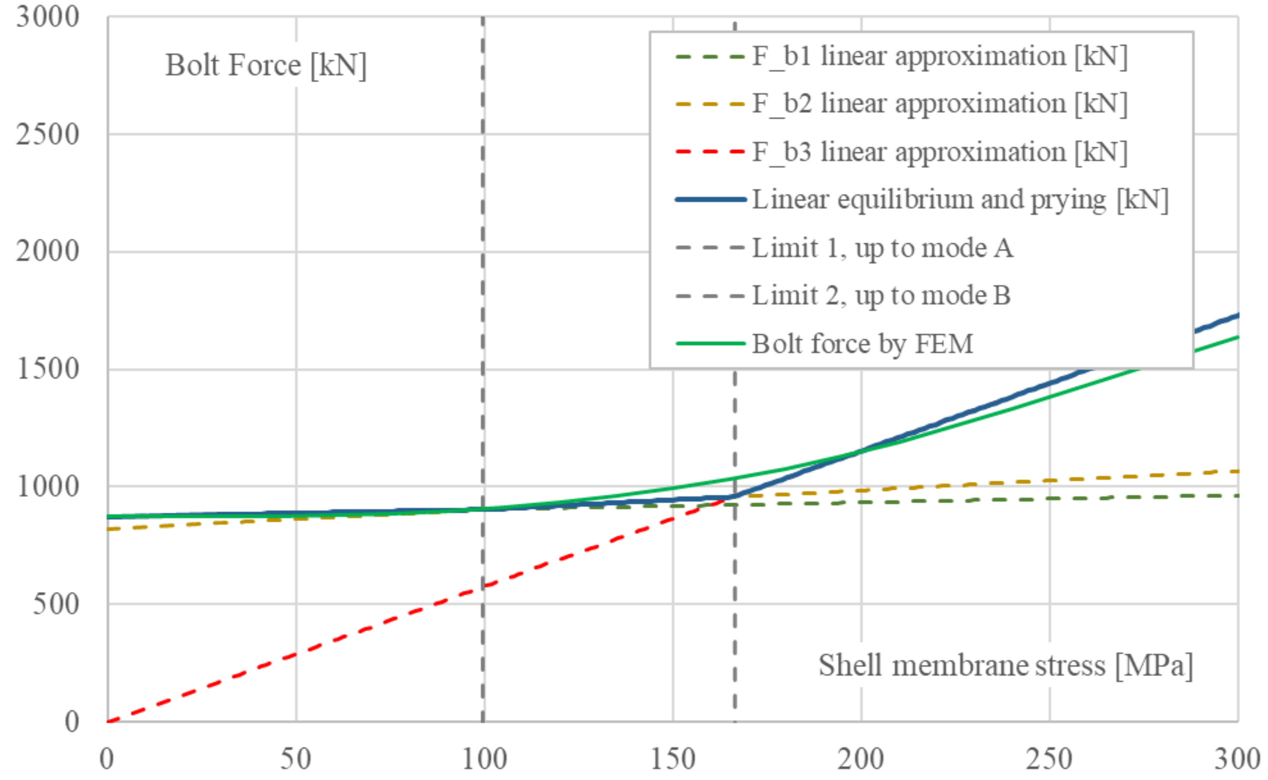
Methods for supervision of bolt pretension





Methods for supervision of bolt pretension

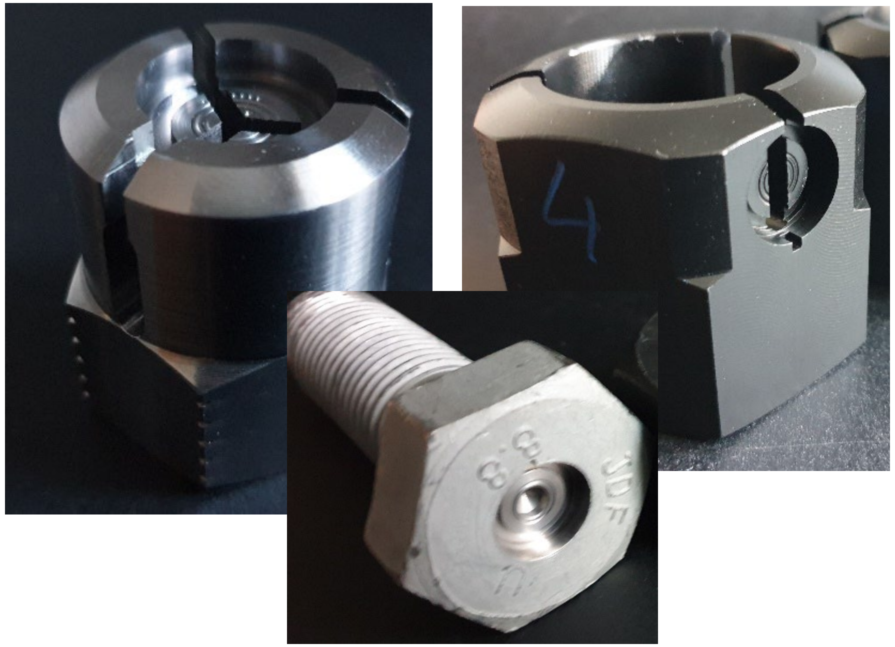




Methods for supervision of bolt pretension

Further development by TensionCam

- Manual docking version
  - Docking at each measurement
  - Connected via cable to Android device with TensionCam app to cloud
- Remote version
  - Permanent docking/battery driven
  - Wireless com to cloud via router
  - Under development



Types & Dimensions:

- Hex Cap Nuts: M16 –M100
- Hex Tall Nuts: M30 – M100
- Hex Screws: M16 – M36

Each nut & screw is marked with an individual bar code

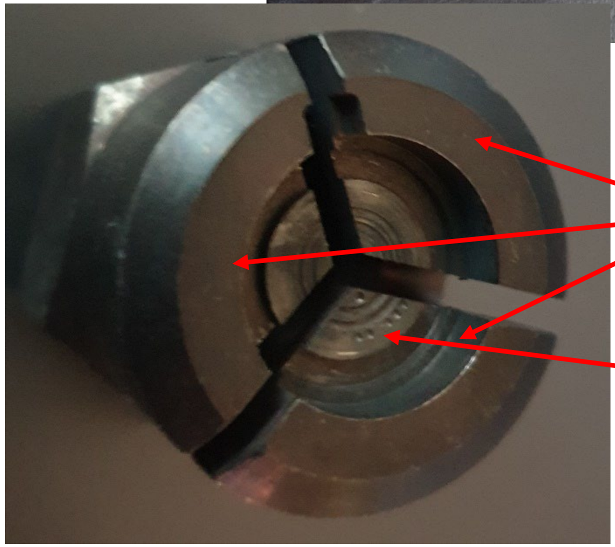
Data visible online in TensionCam webportal based on MS Azure platform

Methods for supervision of bolt pretension

Further development by TensionCam

”Measuring” part of nut (no internal threads)

”Load bearing” part of nut (with internal threads)

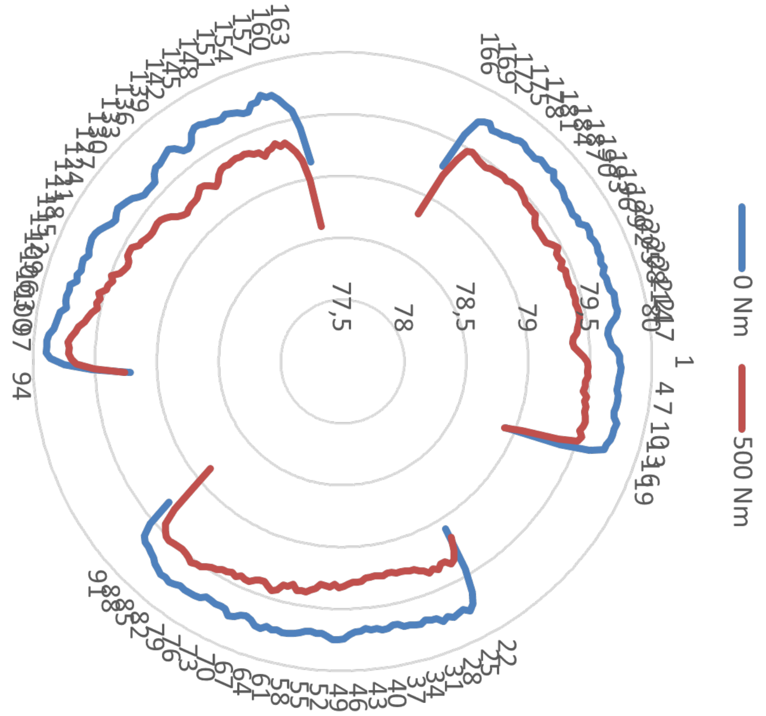


Three circle segments (120 degrees each)

ID bar code

Methods for supervision of bolt pretension

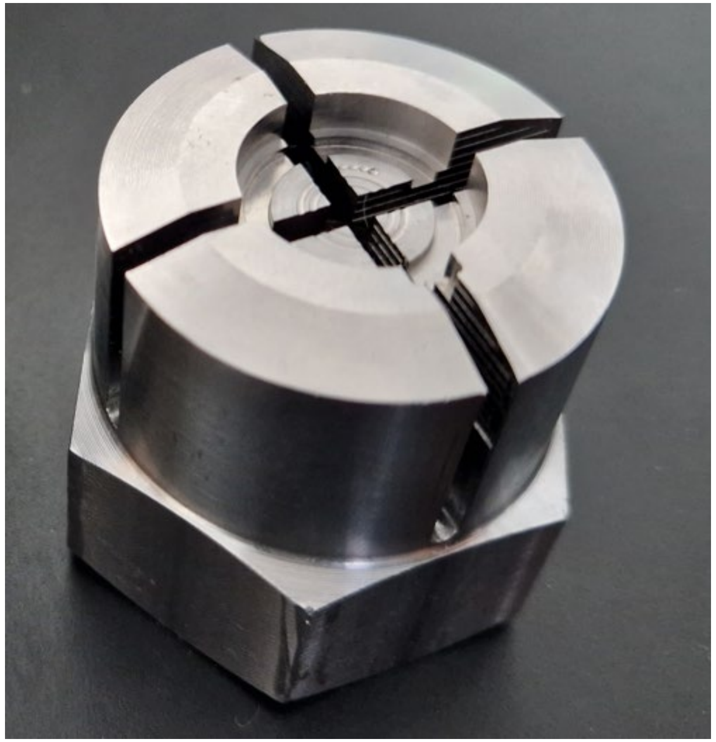
When the nut is exposed for axial load the diameters of the circle segments are reduced **unique linearly** vs the axial load level (axis in diagram below is in pixel units, 1 pixel is 0.05 mm)

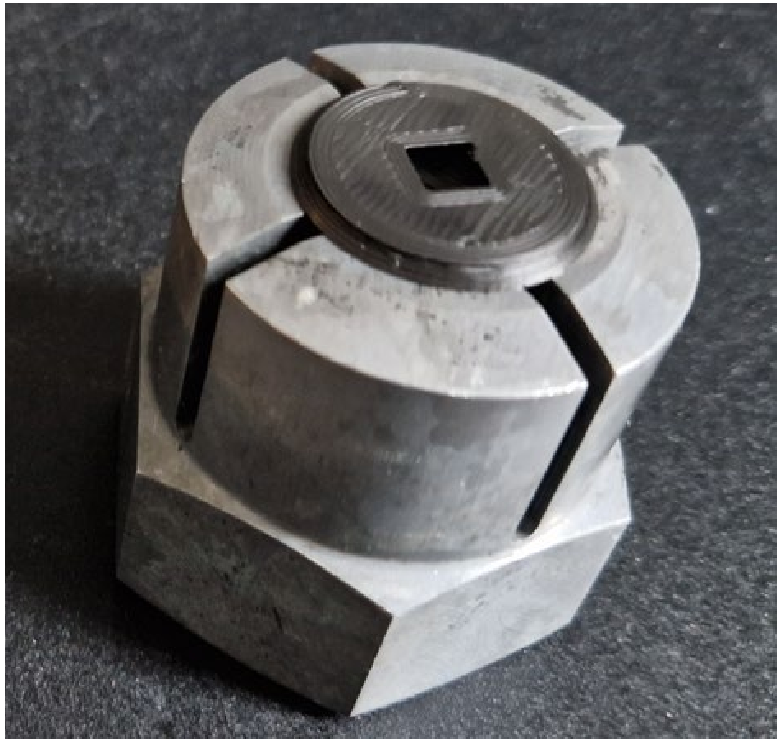


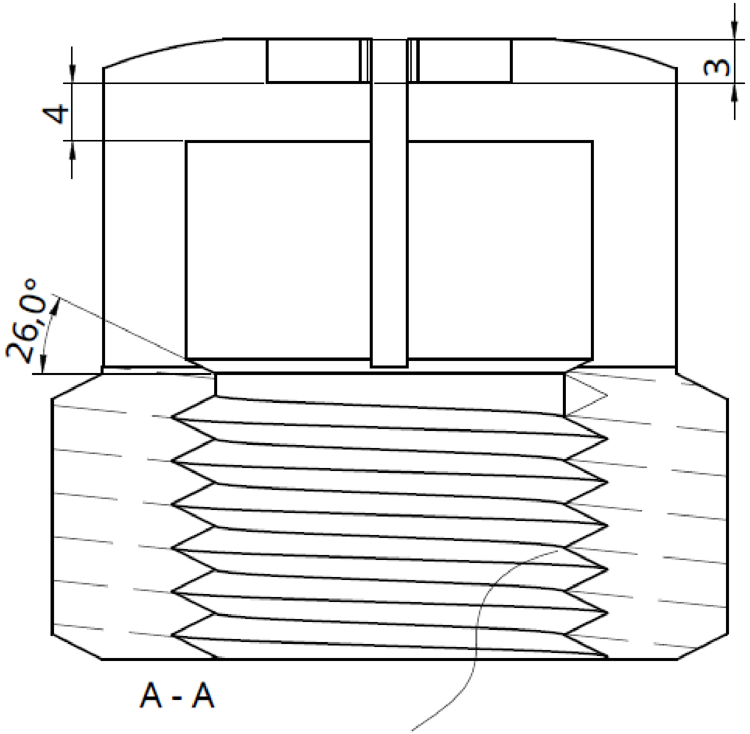
Clamp load in kN is calculated based on the **average** diameter reduction for the three circle segments.
Errors like load eccentricity, misalignment & friction can therefore be compensated for.

Methods for supervision of bolt pretension

M27 takmutter


Innan varmförzinkning


Efter varmförzinkning, med täcklock



Measurement of bolt clamp load on a Hawle DN600 valve

20 pcs TensionCam nuts were installed on one flange of a Hawle DN600 valve.
Date: June 21, 2022.
Nut: TensionCam Hex Cap M27 8.8 nut

Customer: Kungsbacka community, Sweden
Entrepreneur: Jord & Berg AB, Svanesunds Rör AB
Lubrication: Densiq Ecolube
Gasket: Densiq AB
Plastic caps: Radolid GmbH

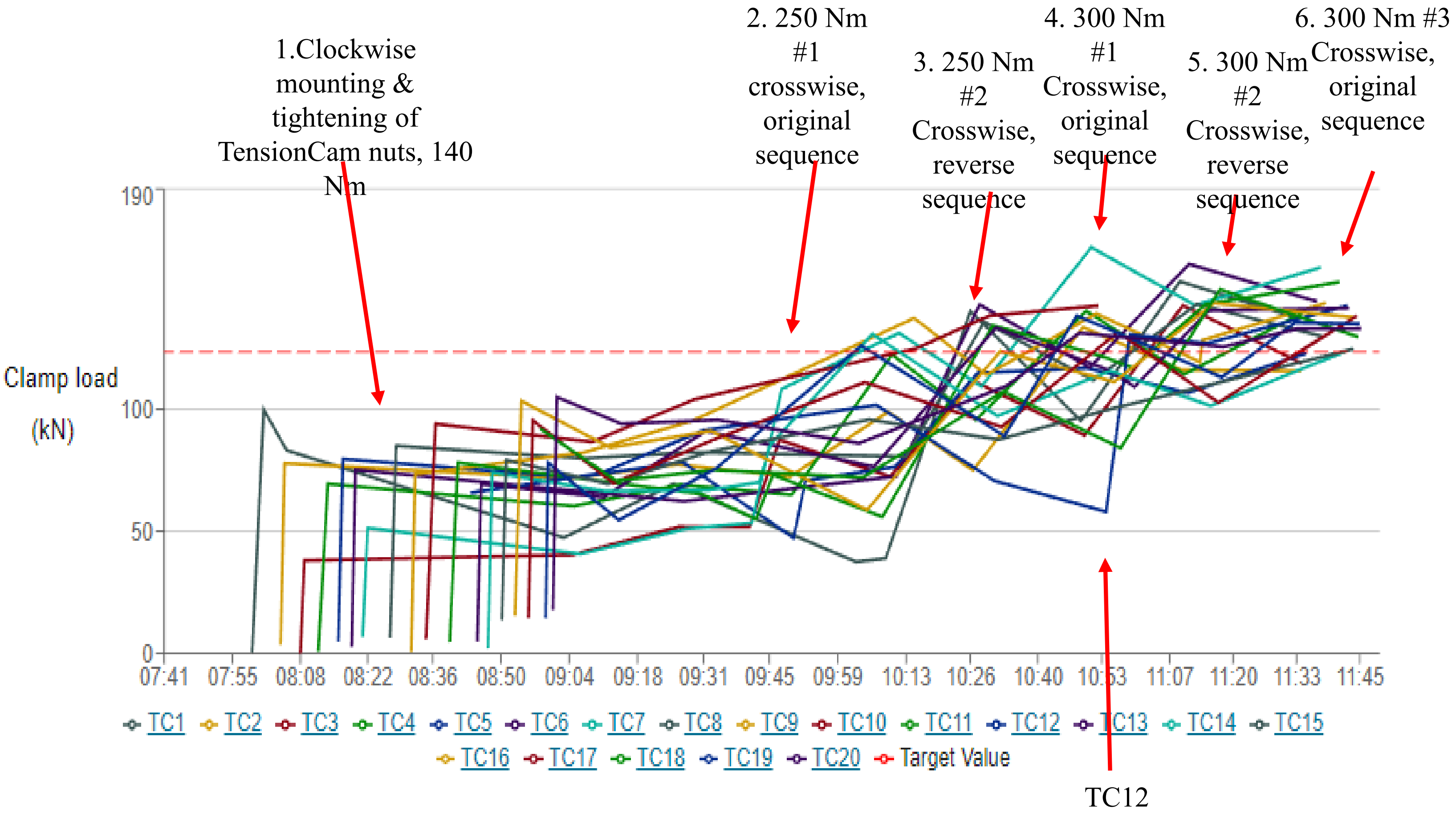
Target clamp load: **125 kN +/- 25 kN**
Corresponds to **42%** of the yield strength of the bolt

Three steps for applying torque:
140, 250 resp 300 Nm.
Crosswise tightening in two or three rounds.
Sequence switch between the rounds as to reduce ”neighbour effect”.

TensionCam™

Measurement of bolt clamp load on a Hawle DN600 valve

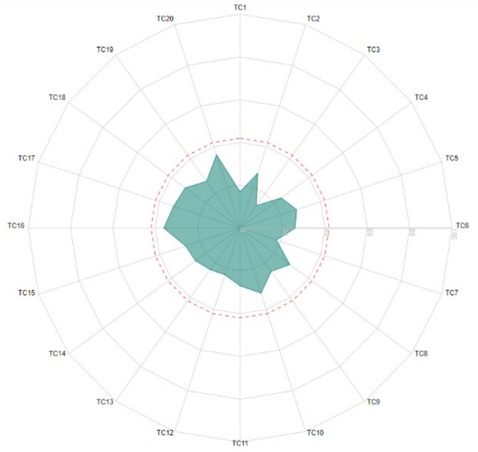
Installation June 21, 2022: Clamp forces and procedure



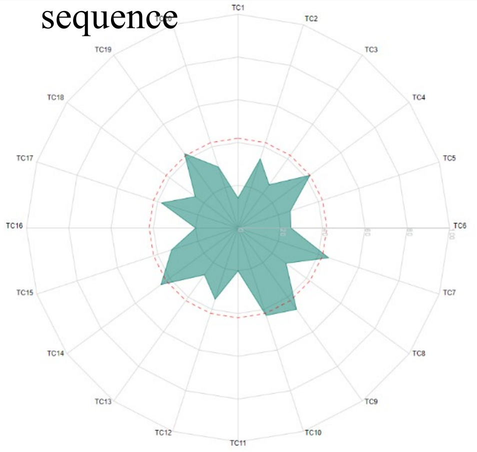
TensionCam™

Measurement of bolt clamp load on a Hawle DN600 valve

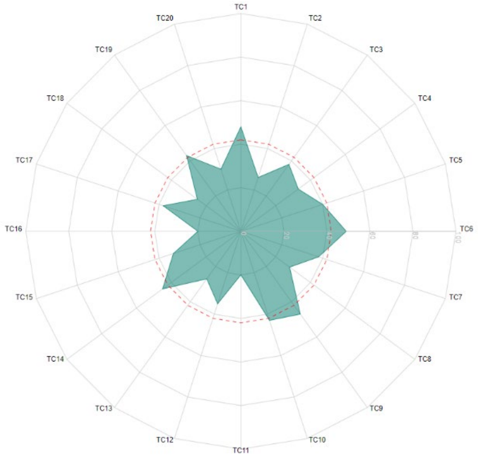
1. After 140 Nm #1, clockwise



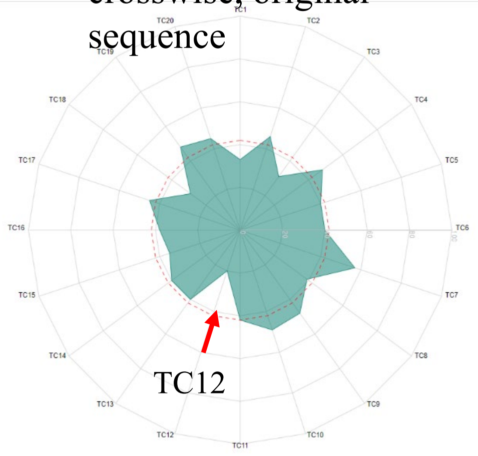
2. After 250 Nm #1, crosswise, original sequence



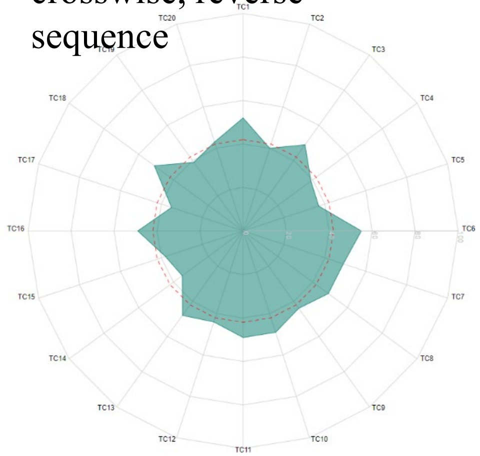
3. After 250 Nm #2, crosswise, reverse



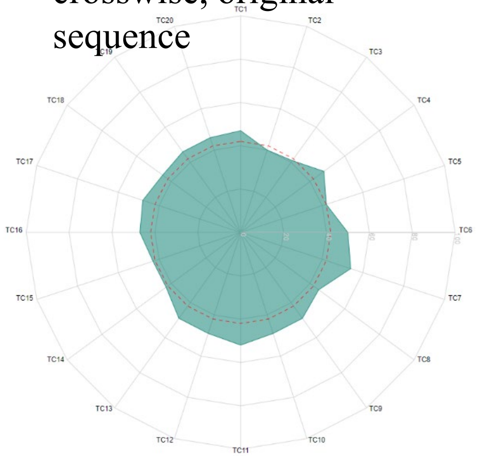
4. After 300 Nm, #1, crosswise, original sequence



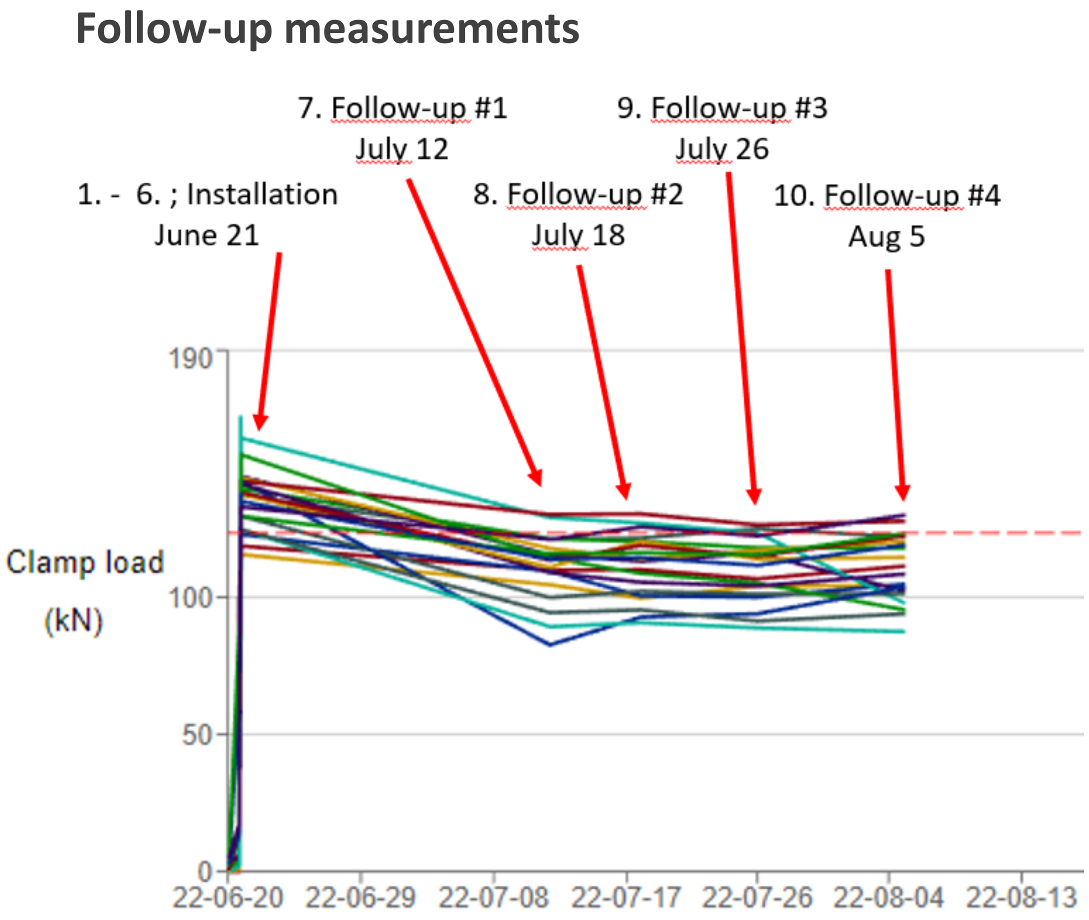
5. After 300 Nm #2, crosswise, reverse sequence



6. After 300 Nm #3, crosswise, original sequence

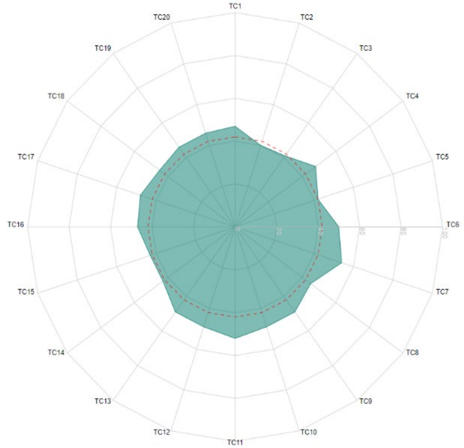


Measurement of bolt clamp load on a Hawle DN600 valve

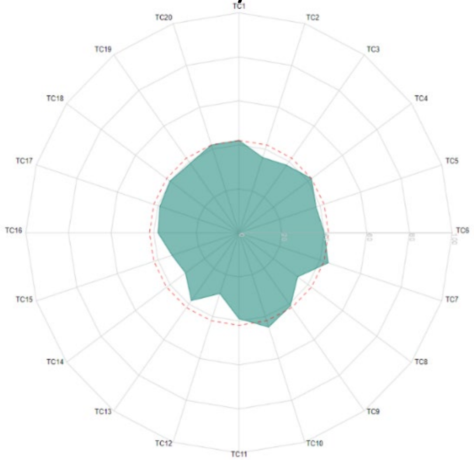


Measurement of bolt clamp load on a Hawle DN600 valve

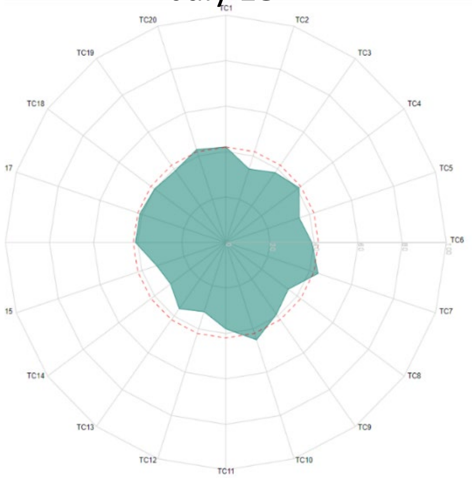
6. After installation,



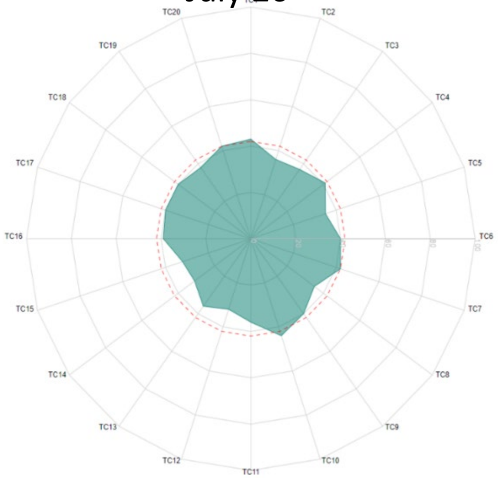
7. Follow-up #1, July 12



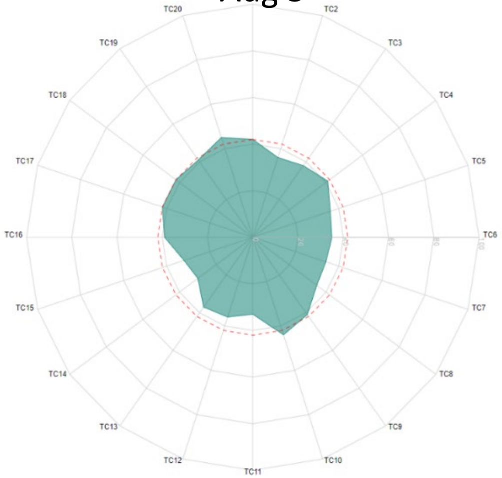
8.Follow-up #2 July 18



9. Follow-up #3 July 26



10. Follow-up #4 Aug 5



TensionCam nuts on a Double Tube heat exchanger

52 pcs TensionCam Hex cap nuts were installed on two flanges on a double tube heat exchanger

Flange ”LP”: 24 pcs TensionCam Hex Cap Nuts

Flange ”HP”: 28 pcs TensionCam Hex Cap Nuts

Nut Size: 7/8” UNC

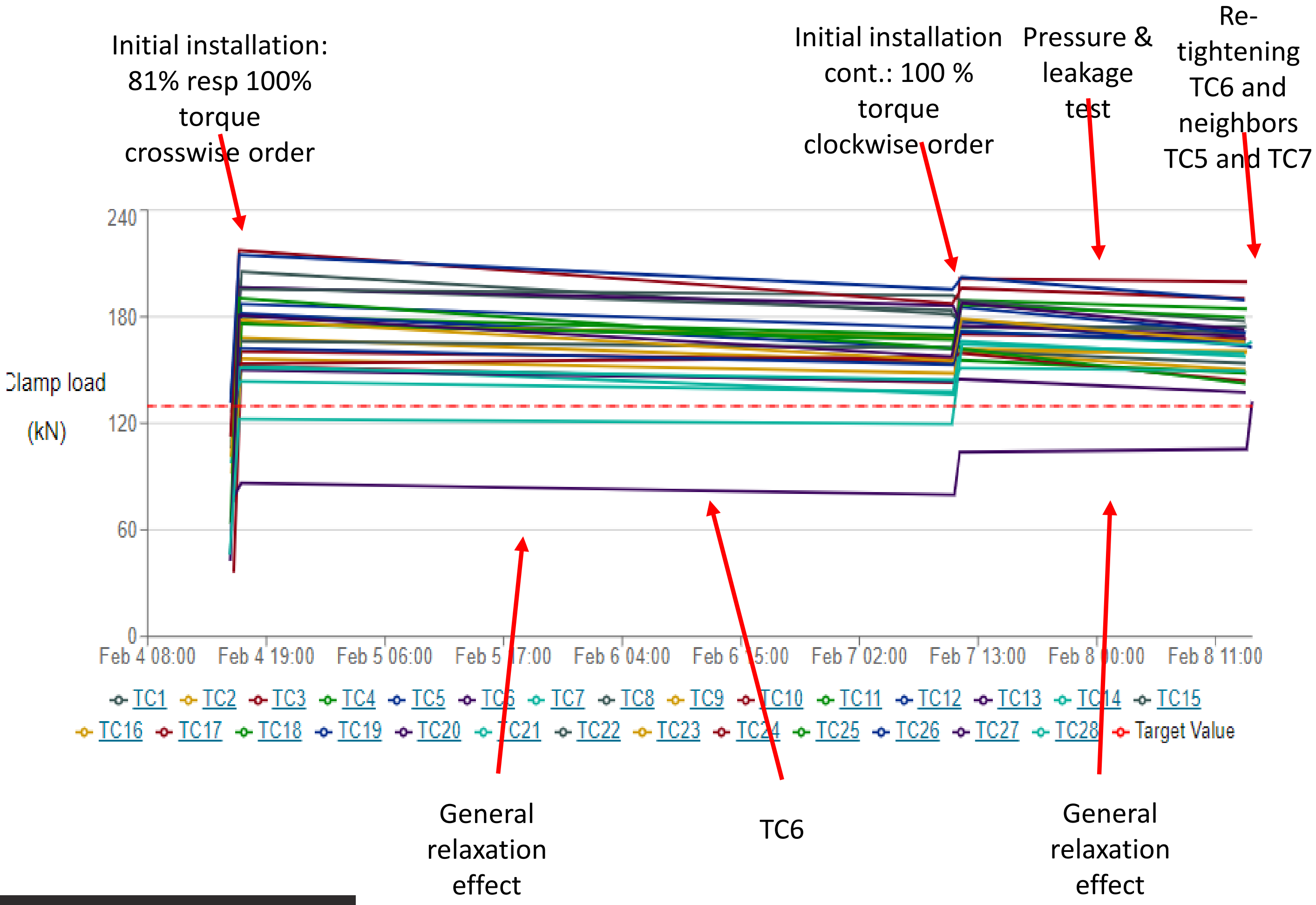
Nut material: Certified EN10269 1.7225 / ASME SA320 L7 / ASME SA193 B7

Target clamp load: 142 kN   Specified 100% Tightening torque: 494 Nm

TensionCam™

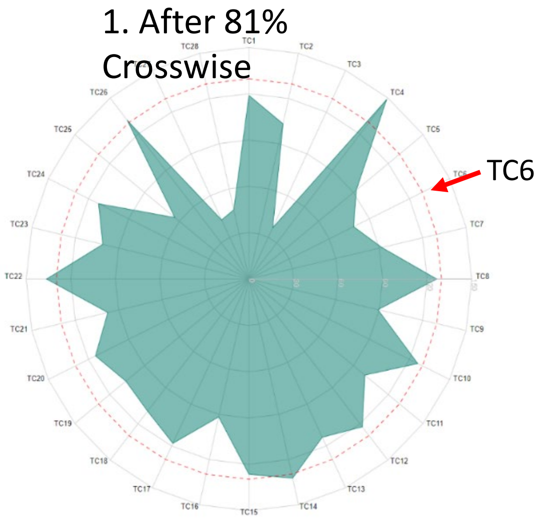
TensionCam nuts on a Double Tube heat exchanger

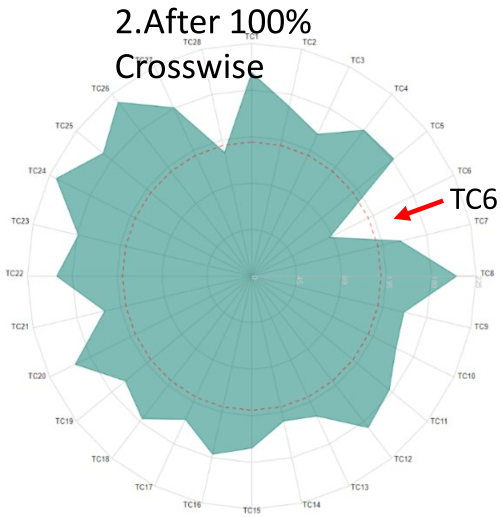
"HP" flange: Clamp load trend from Day 1 to Day 5

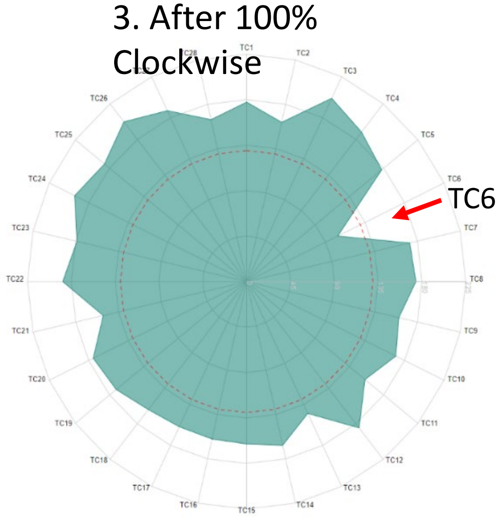


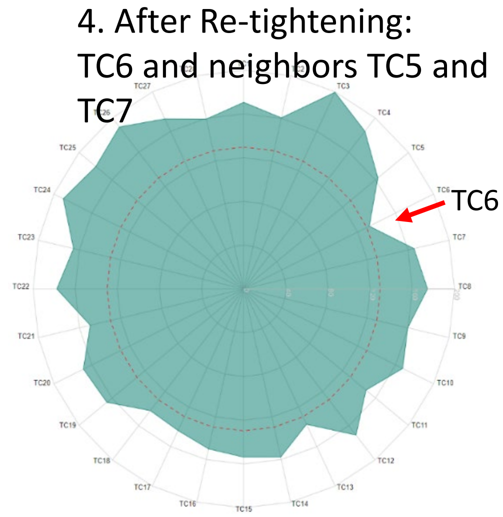
TensionCam™

TensionCam nuts on a Double Tube heat exchanger









TensionCam™

Correct pretension in blade bolts is critical for the structural integrity

TRANÅS TIDNING

Vindkraftsolyckan

TV: Rotorblad lossnade från vindkraftverk – grannar slog larm

2 maj 2022 20:21

Under måndagskvällen larmades räddningstjänsten till Södra Hyltan i Tranås kommun, efter att ett rotorblad lossnat från ett vindkraftverk.

Bild: Johan Hedberg

https://www.tranastidning.se/2022-05-02/tv-rotorblad-lossnade-fran-vindkraftverk--grannar-slog-larm

Thanks Questions?

Bild: Johan Hedberg