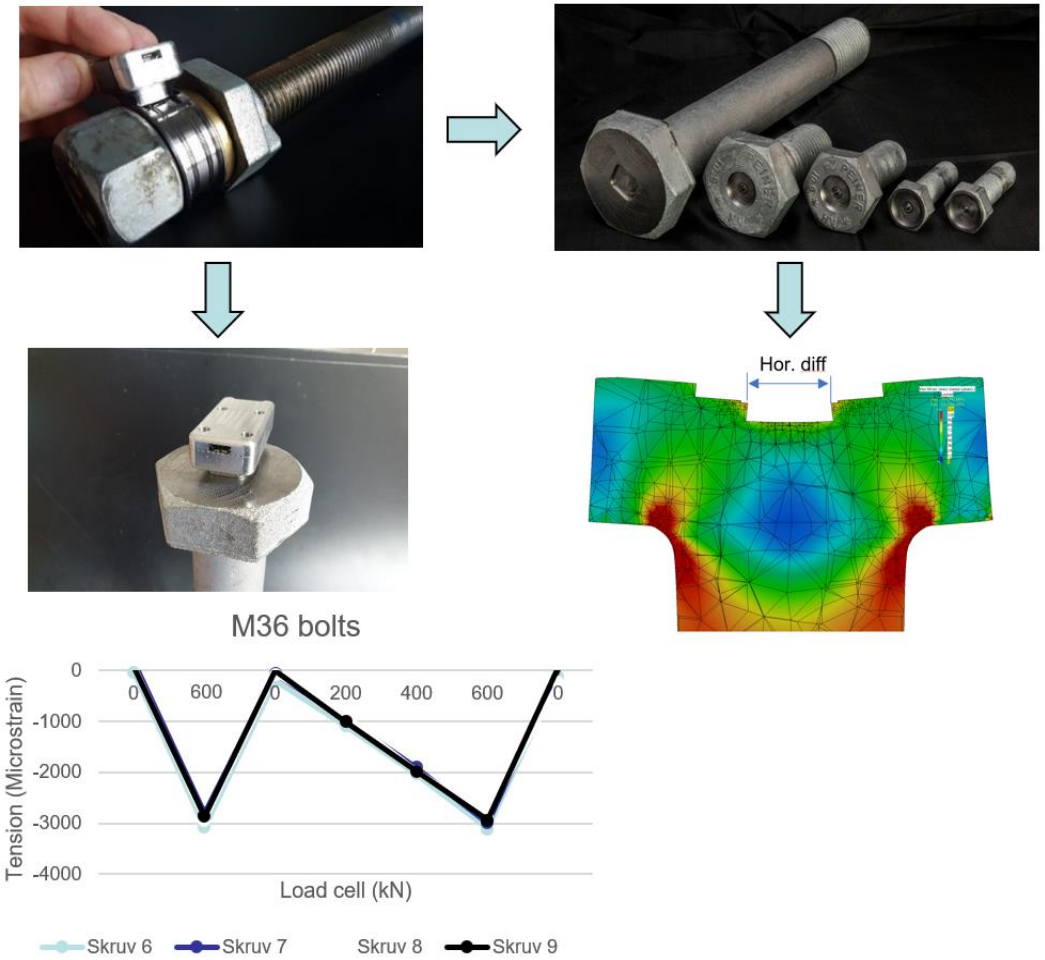
# Control of tower bolt connections and challenges in cold climate

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*Wind Power*

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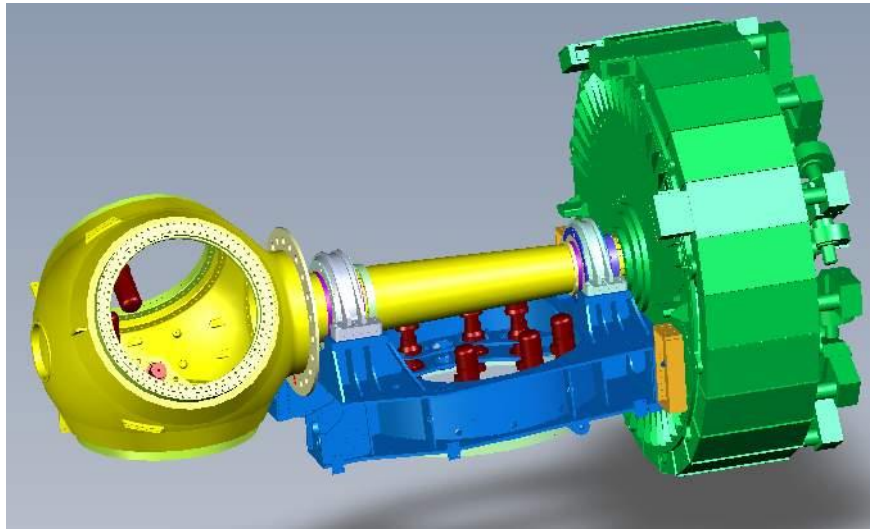
# Anders Wickström Experience from wind turbine design

***ScanWind*** started in 1999

Mission:
Design large direct drive turbine
for harsh Norwegian conditions



# Christmas Eve 2015

Statens haverikommission
Swedish Accident Investigation Authority

RO 2017:01

## 1. FAKTAREDOVISNING

### 1.1 Redogörelse för händelseförloppet

På morgonen strax efter kl. 09.00 torsdagen den 24 december 2015 hörde en lantbrukare som bodde i närheten av Lemnhults vindkraftspark ett ljud som lät som en hög metallisk klang. Han arbetade vid tillfället i sin ladugård och även om den miljön var bullrig kunde han utan problem höra det metalliska ljudet. Några minuter senare hörde lantbrukaren ytterligare ett kraftigt metalliskt ljud eller dån.

www.havkom.se/assets/reports/RO2017_01-Slutrapport-Lemnhult.pdf

1.2.1 ***Skador på vindkraftverket***

Tornet föll i ostlig/nordostlig riktning, och alla utom ett av de skruvförband som höll ihop tornets segment brast vid fallet. Det skruvförband som klarade fallet var det som höll ihop det andra och det tredje segmentet. Det första segmentet som var fäst i bottenplattan (betongfundamentet) stod kvar efter fallet. Den lokala transportvägen i området blockerades av den havererade tornet.

Figur 3. Det havererade vindkraftverket. Foto: Vestas Wind Systems A/S

# Correct pretension is crucial for the integrity of bolt connection

Statens haverikommission
Swedish Accident Investigation Authority

RO 2017:01

The total collapse of a wind turbine at Lemnhult was mainly caused by incorrect pretension.

If the pretension of the tower bolt joint would have been correct, the accident would not have occurred.

Winter conditions during the tower installation!

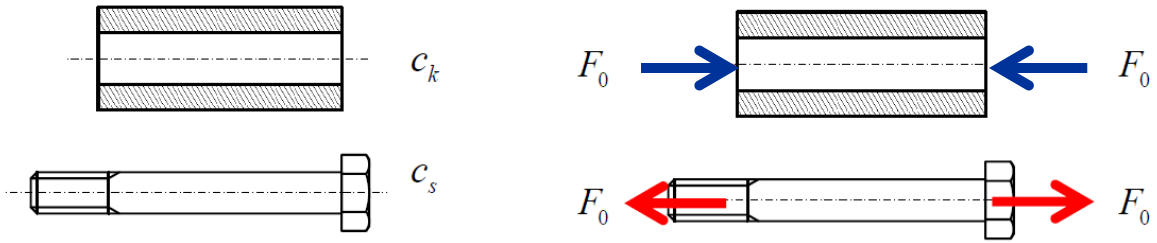
Figur 14. Bild på tornskruvarna med utmattningsbrott och varierande grad av restbrott.

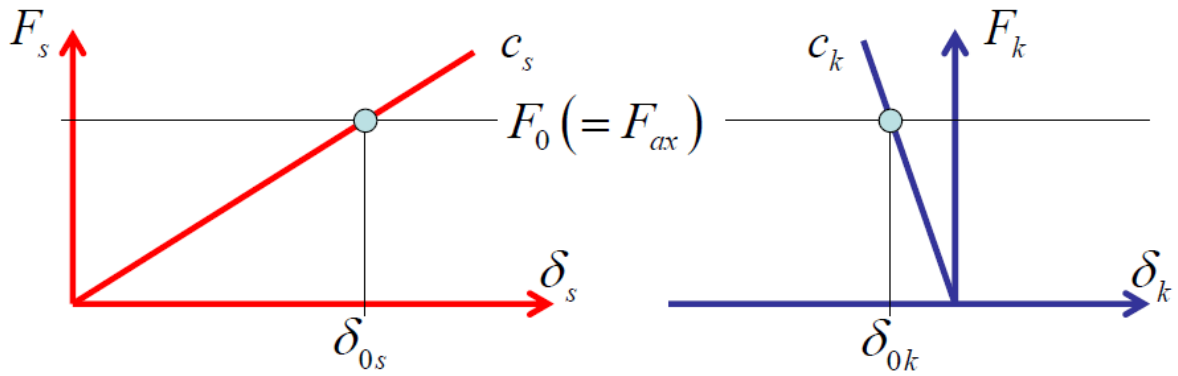
www.havkom.se/assets/reports/RO2017_01-Slutrapport-Lemnhult.pdf

# The principle of pretension of a bolted joint

The bolt and the sleeve normally have different axial stiffnesses, $c_k$ and $c_s$.

The bolt and sleeve are assumed to be elastic and affected by the same preload force $F_0$



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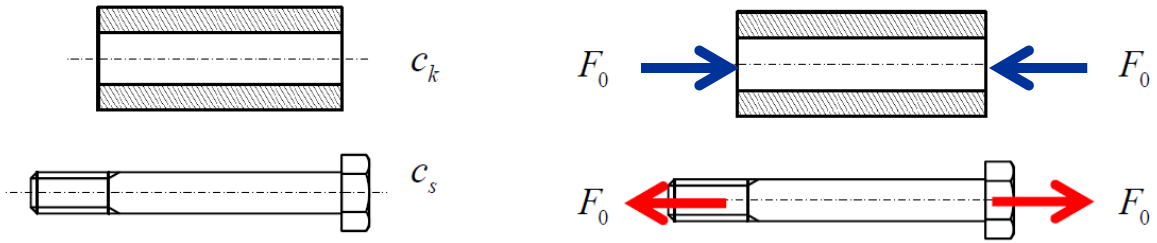
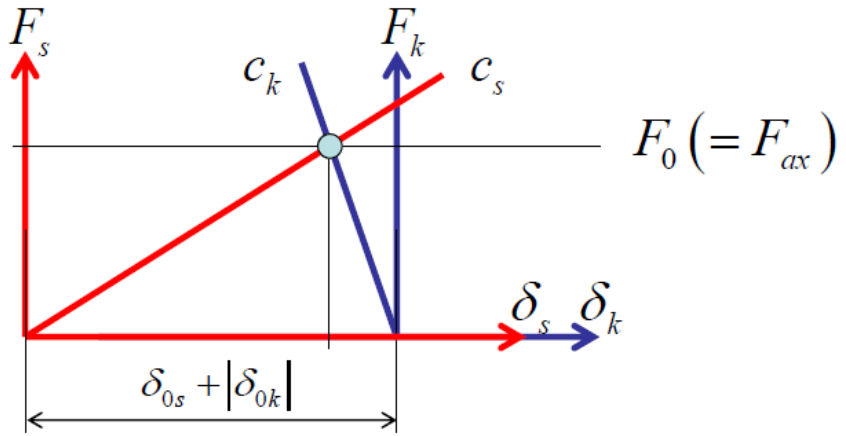
Free body diagram.



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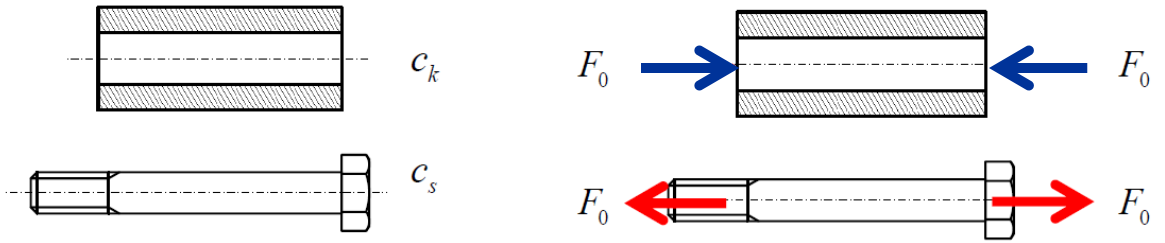
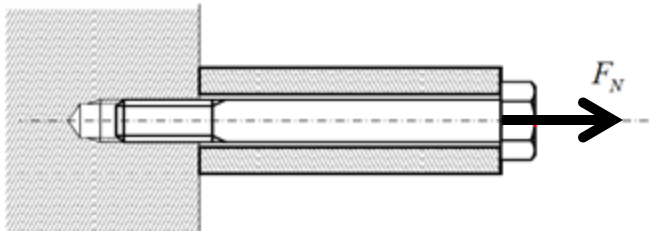
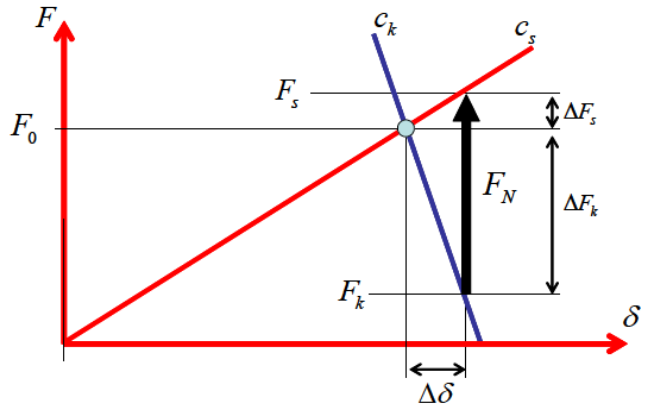



$$\Delta F_s = c_s \cdot \Delta\delta$$

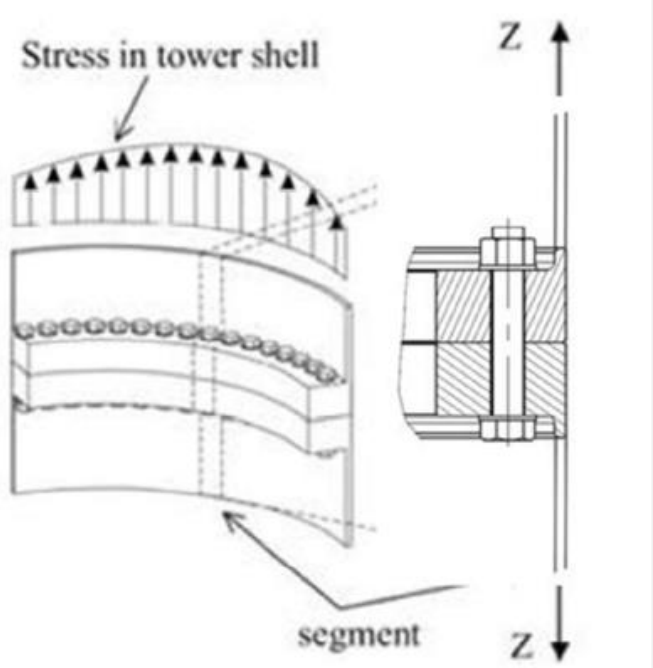
$$\Delta F_k = c_k \cdot \Delta\delta$$

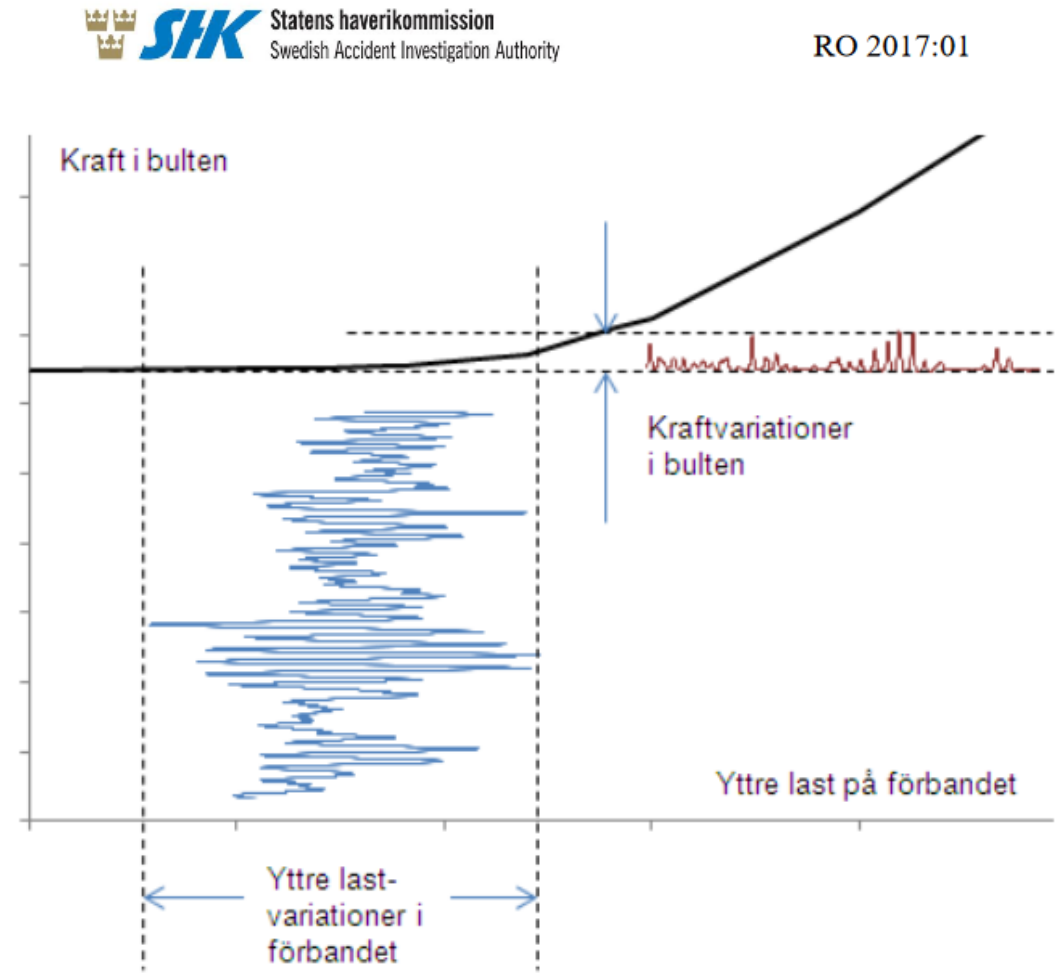
$$F_N = \Delta F_s + \Delta F_k = (c_s + c_k)\Delta\delta$$

$$\rightarrow \quad \Delta\delta = \frac{F_N}{c_s + c_k}$$

# Loads acting on a bolt flange connection

In case of correct pretension, small variations in the external loads in a screw joint result in neglectable variations of the bolt loading.



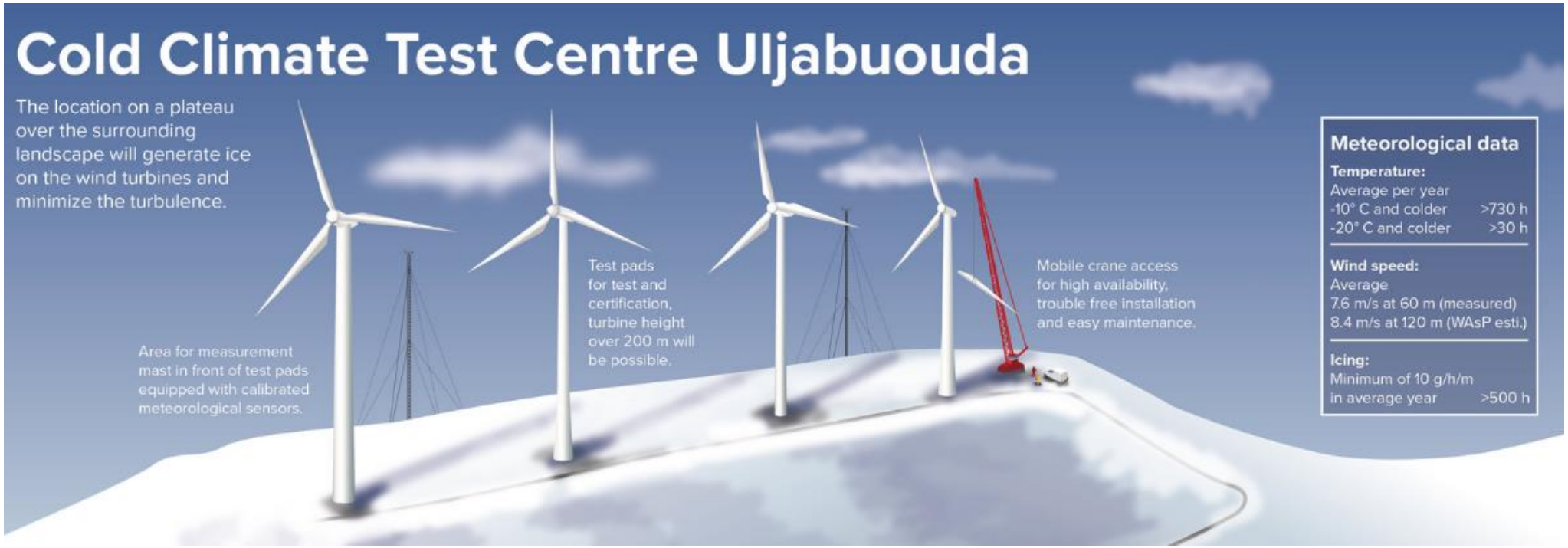

Figur 33. Principiell graf som visar hur relativt stora variationer av de yttre lasterna i ett skruvförband endast resulterar i små variationer av kraften i skruven. Förutsättningen för denna, för skruven gynnsamma, effekt är förspänningskraften av skruven.

# Cold climate impact on the bolt pretension

There are additional challenges related to winter and cold climate conditions:

- Bolt lubricant removed by snow.
- Lubricant property change depending on the ambient temperature.
- Thin ice on contact surfaces during tightening
- Less attractive to work and handle heavy equipment

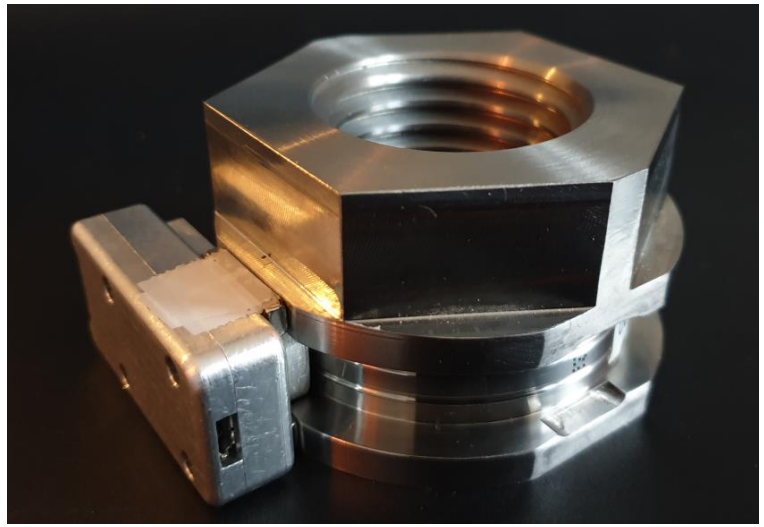
All of these aspects might have an impact on the bolt pretension over time.



# Fingerprint technology to measure small displacements

Fingerprint standard reader device for measurement of displacements between pre-machined lines on a washer.

TensionCam sensor module with image sensor from Fingerprint Cards AB.



# Early installation on a wind turbine

A TensionCam nut mounted on the foundation's M42 bolt connection.

# Research project at Chalmers and SWPTC

To develop the method further and validate the results, a research project has been started

Methods and material for sustainable and cost effective structural supporting systems for wind power plants

WP6 Methods for supervision of bolt pretension

Tensioncam™

Industry partners:

TensionCam, Stena Renewables, Rabbalshede kraft

Academic partners:

Chalmers, RISE

# Cavity on the bolt head

Within the project, an alternative method was invented:

Normal bolts with a circular cavity pattern drilled at the bolt head

# Analyses of bolt displacements by FE calculations

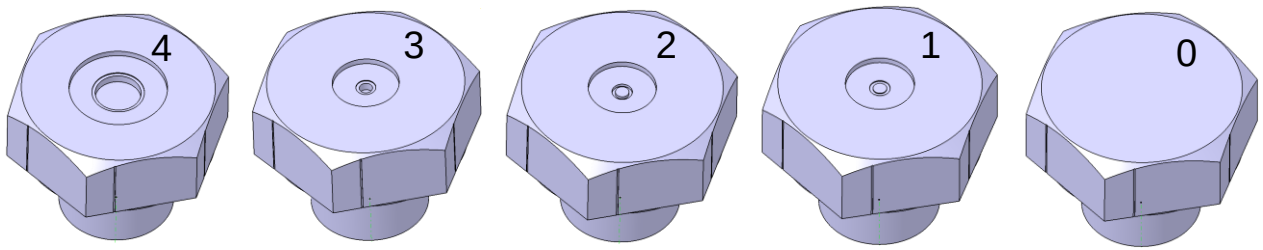
A number of different cavity patterns were analysed.

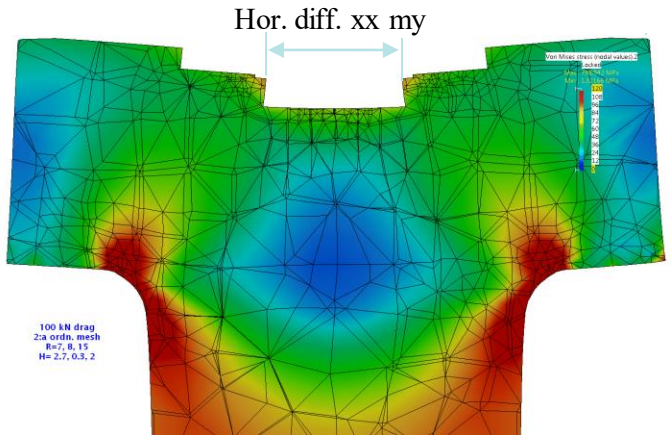
0 Standard bolt without any machining on top of the screwhead

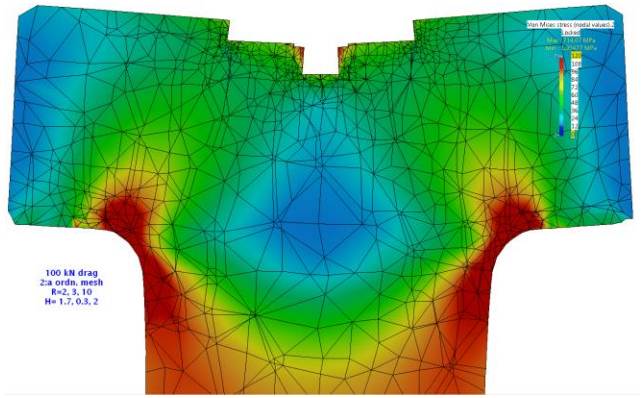
3 Small cavity on top of the screwhead

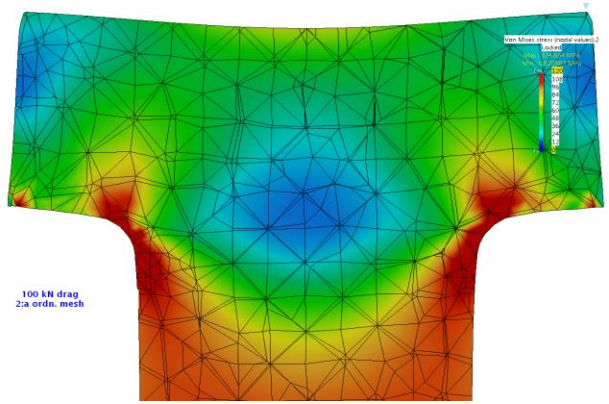
4 Selected cavity pattern

The horizontal displacement is measured with an accuracy of 1 μm (= 0.001 mm)

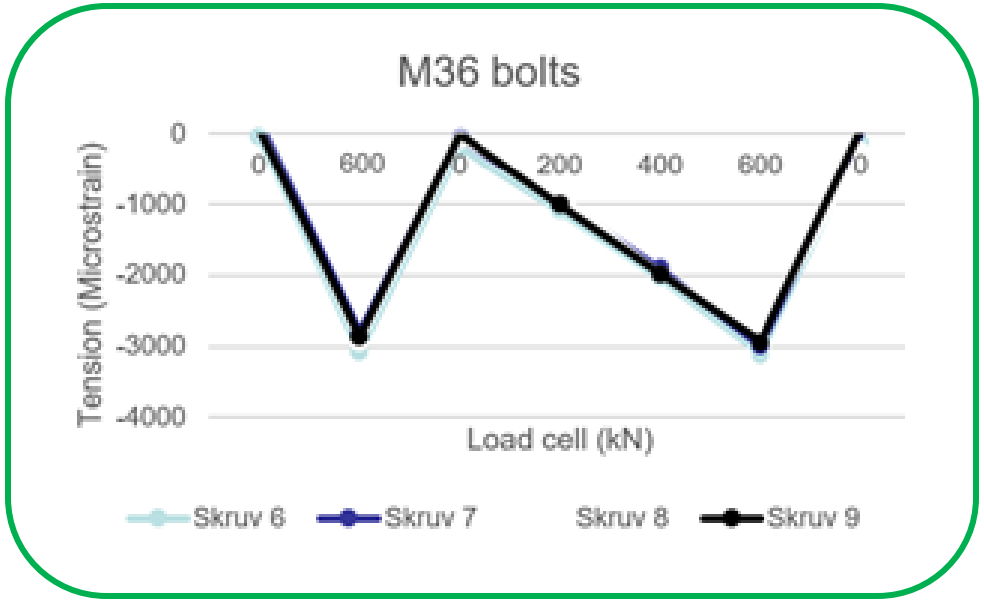


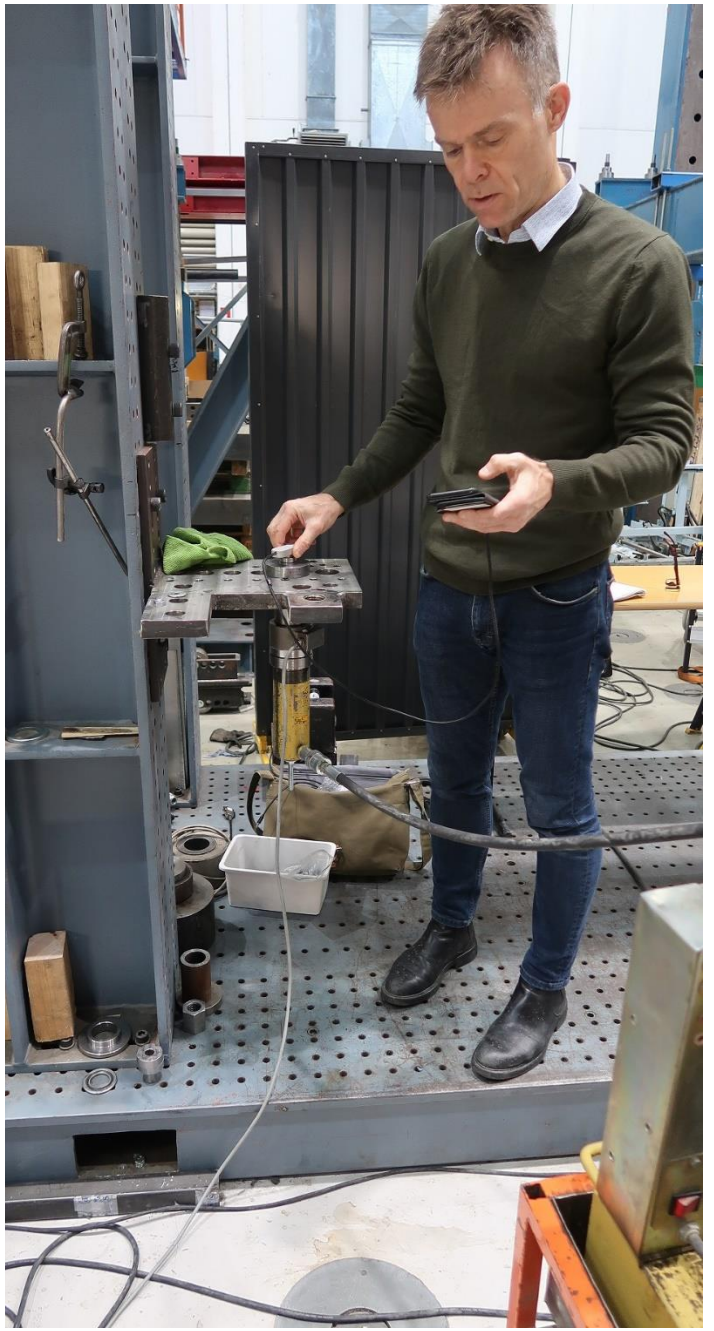





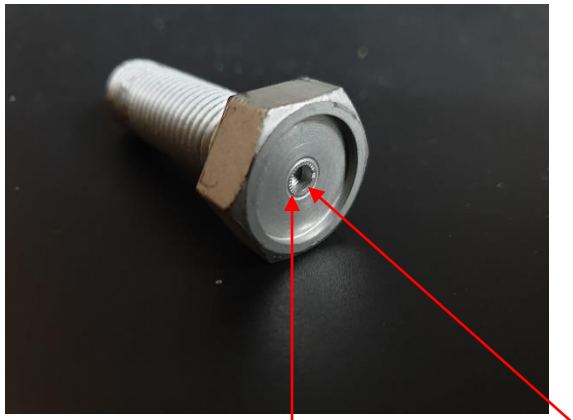
# Results: Cavity on the bolt head



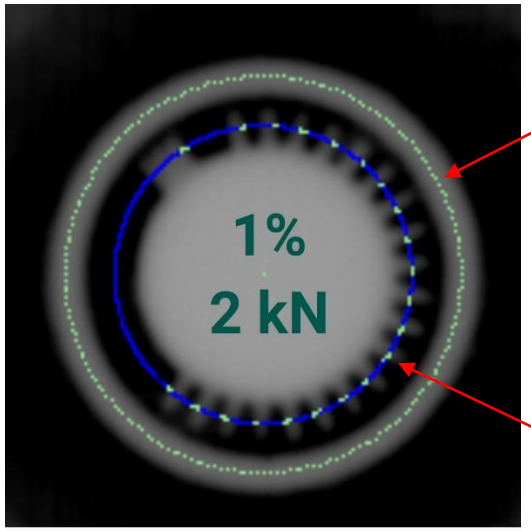



# Details to measure cavity & bolt ID

Sample image of groove pattern with circular groove and bar code



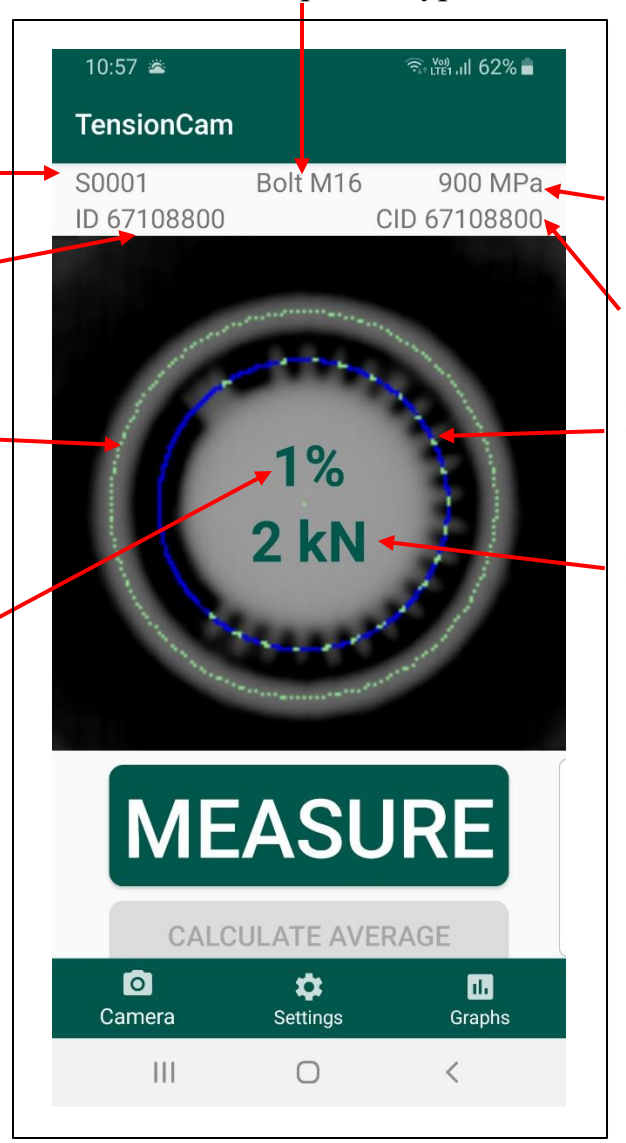
Precision milled circular groove & ID bar code on bottom of cavity on M16 bolt head.

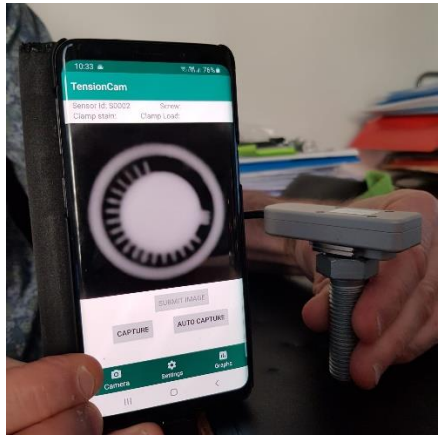



The image analysis defines the diameter of the circular groove. When the bolt is exposed for pretension the diameter is reduced with up to 30 microns. This reduction is linear to the pretension.

Bar code gives bolt ID.

# User interface



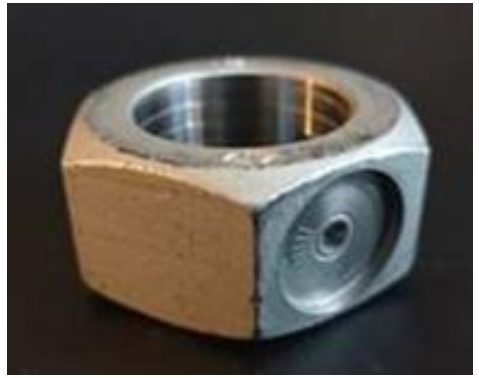
# Next step

Application for an extension of the SWPTC project

WP6 Methods for supervision of bolt pretension

The extension proposal to focus on:

1. Validations and structural integrity of the nut, caused by the cavity
2. Environmental resistance and corrision
3. Remote reading of bolt status, standards, security and evaluation
4. Scientific aspects, optimization and documentation



SWPTC
SWEDISH WIND POWER TECHNOLOGY CENTRE

**Project extension proposal** 1 (13)
SWPTC
2020-01-31

**Applicant**

| | | |
|---|---|---|
| Company/organisation: RISE & Chalmers | | Organisation number: 556464-6874 |
| Department/Division: Industrial and Materials / Division Product Development | | |
| Postal address: | | |
| Postcode: | City: Borås/Göteborg | Country: Sweden |
| Project leader (first name, family name): Anders Wickström, RISE | | |
| Phone: 070-261 00 71 | | |
| E-mail: anders.wickstrom@ri.se | | |

**Project**

| | |
|---|---|
| Project title (in Swedish): Metoder och material för hållbara och kostnadseffektiva torn och fundament till vindkraftverk<br>Förlängning av AP6 Metoder för övervakning av förspänning av bultar | |
| Project title (in English): Methods and material for sustainable and cost effective structural supporting systems for wind power plants<br>Extension of WP6 Methods for supervision of bolt pretension | |
| Date for project start | 2020-03-01 |
| Date for end of project | 2021-12-31 |
| Total cash budget for project: 1826 kSEK | |

# Generation 2: Wireless sensor module

Wireless Bluetooth communication.

Powering via re-chargeable battery

For Android and PC

Temporary & Semi-permanent installations

To be completed 2020

# Generation 3: Wireless ”Coin” sensor module

Same technology as for biometric smart cards

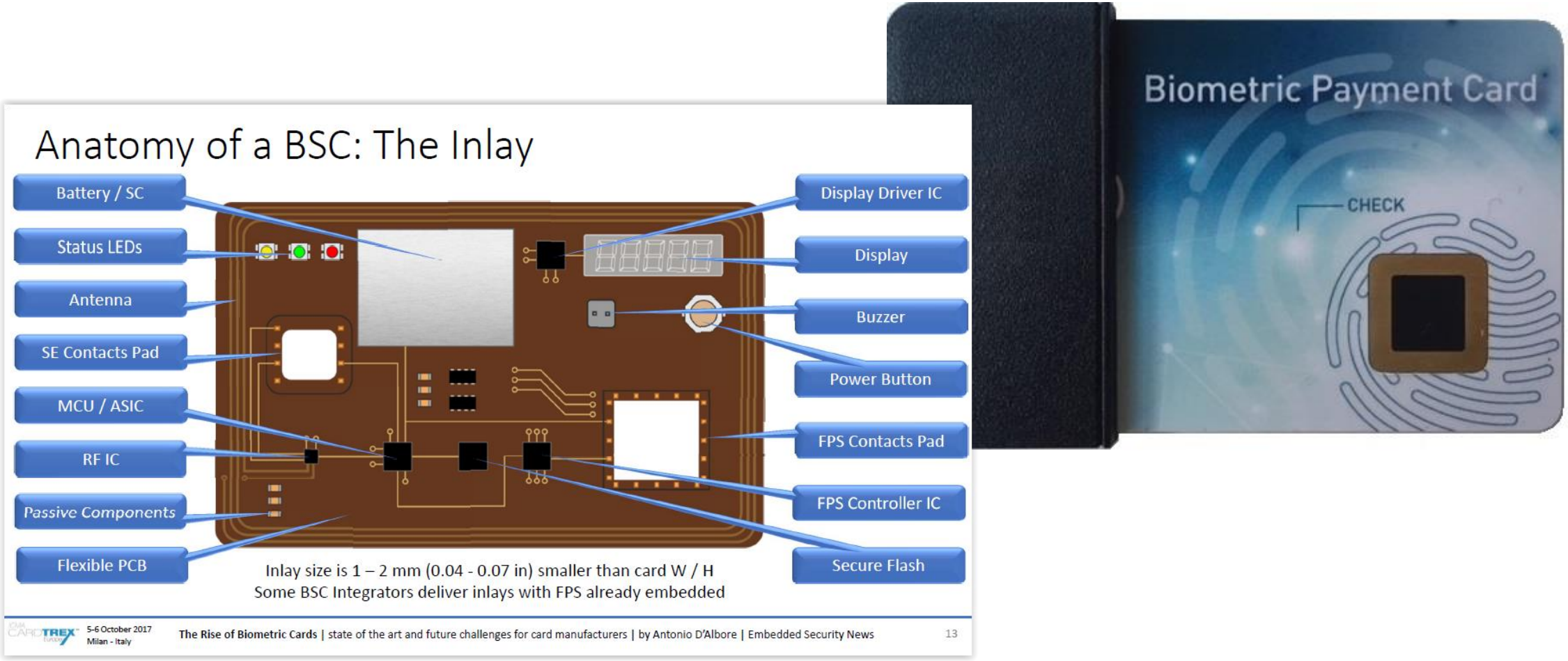
With wireless RFID communication (no battery!)

For Android, IoS & PC

Permanent installations (”coin” sensor is permanently mounted at bolt manufacture)

To be completed 2021

# Generation 3:Wireless ”Coin” sensor module Biometric Card



# Sensitivity to ambient temperature

$$\Delta\ell = \ell_1 \, \alpha \, (t_2 - t_1)$$

Steel has the coefficient of expansion 0. 012 μm per degree and millimeter.

| | | |
|---|---|---|
| $\alpha$ | 0.012 | μm/deg/mm |
| $\ell_1$ | 6 | mm |
| $t1$ | 20 | deg |
| $t_2$ | -20 | deg |
| $\Delta\ell$ | -1.4 | μm |