11T & Mechanical Measurements

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Outline

1. Goal & Lessons learned
2. Mechanical measurements tools available at CERN
3. 11T Collaring mockup (End of 2017 – 2018)
4. Conclusion

Goal

To give an objective information about :

- **Techniques of mechanical measurements ;**
- **Mechanical measurements related to 11T activities (2012 to 2019);**

Useful links for additional information :

- EDMS#1064933 : Techniques of mechanical measurements for CERN applications and environment, *M. Guinchard, I. Vanenkov, A. Kuzmin.*
- EDMS#1073153 : Caractérisation des mesures de déformation par jauges d'extensomètrie à température cryogénique, A. Bouchardy, M. Guinchard.
- EDMS#1154650 : Analysis for the improvement of the capacitive gauges' performance, *R. Morron Ballester, M. Guinchard.*
- EDMS#1936115 : Mechanical Strain Measurements Based on Fiber Bragg Grating Down to Cryogenic Temperature – Precision and Trueness Determination, *L. Bianchi, M. Guinchard, and all…*

Main tools for mechanical measurements?

	Electrical strain gauges	Capacitive gauges	Optical fiber sensors	Non contact video systems
Principle	Resistive	Capacitive	Bragg	Image processing
Loading cases	All	Compression	All	All
Magnetic effects	Affected	Non affected	Non affected	-
Cryogenic temp.	Affected	Affected	Affected	Only RT

(1) EDMS1073153: Caractérisation des mesures de déformation par jauges d'extensomètrie à temp. cryogénique
(2) EDMS#1936115 : Mechanical Strain Measurements Based on FBG Down to Cryogenic Temperature
(3) http://www.imetrum.com
(4) https://accelconf.web.cern.ch/accelconf/IPAC10/papers/mopeb043.pdf
EDMS#1154650 : Analysis for the improvement of the capacitive gauges' performance

Lessons learned

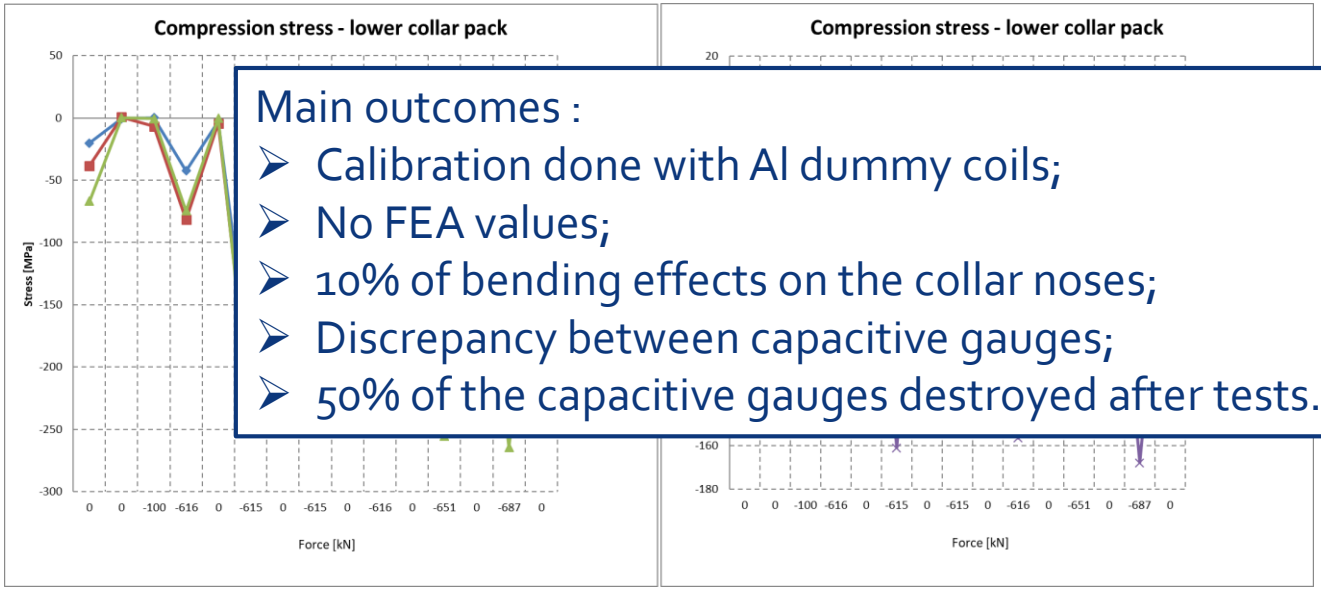
2012 : 11T 150mm mockup

EDMS1221318

Instrumentation : 6 instrumented collars based on strain gauges on the collar noses (without cuts next to the nose);

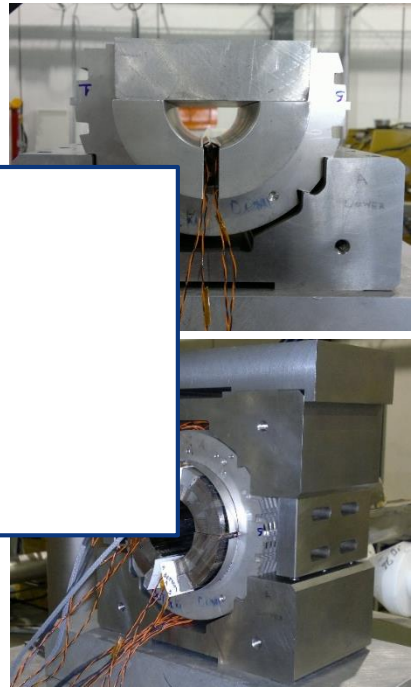
8 Capacitive gauges on the pole wedges;

Fuji Paper.



Main outcomes :

- Calibration done with Al dummy coils;
- No FEA values;
- 10% of bending effects on the collar noses;
- Discrepancy between capacitive gauges;
- 50% of the capacitive gauges destroyed after tests.



Lessons learned

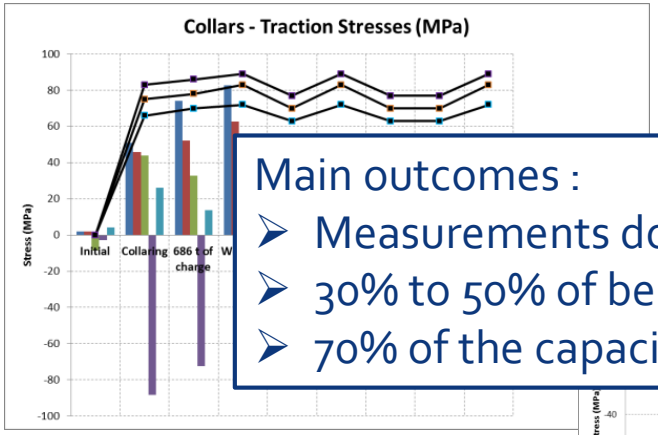
2014 : 11T 2m model

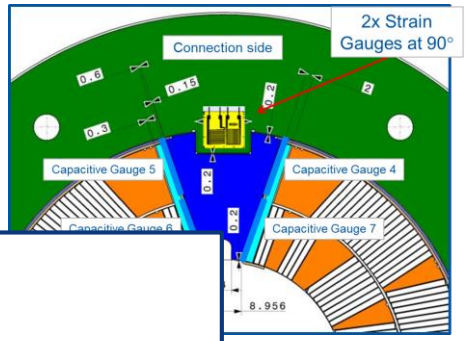
EDMS1352279

Instrumentation : 6 instrumented collars based on strain gauges on the collar noses (without cuts next to the nose);

8 Capacitive gauges on the pole wedges;

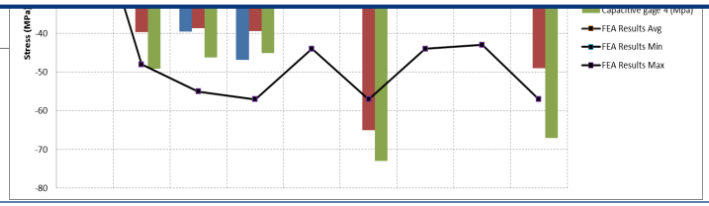
Fuji Paper.

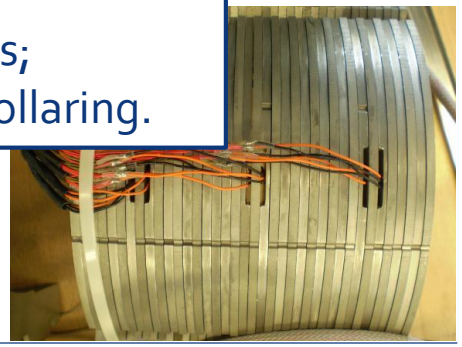




Main outcomes :

- Measurements done down to 4.2K;
- 30% to 50% of bending effects on the collar noses;
- 70% of the capacitive gauges destroyed during collaring.





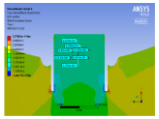
Lessons learned

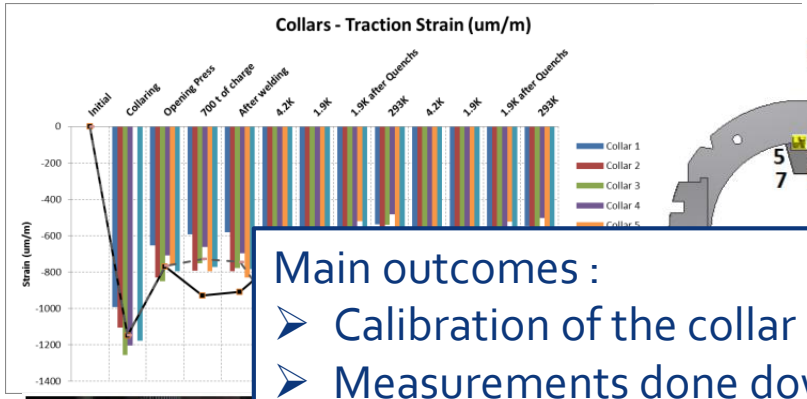
2015 : 11T 2m model

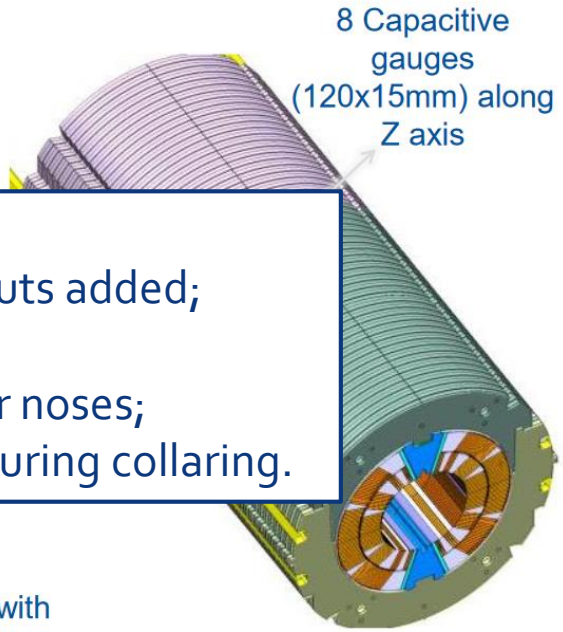
EDMS1387744

Instrumentation : 6 instrumented collars based on strain gauges on the collar noses (with cuts next to the nose);

8 Capacitive gauges on the pole wedges.

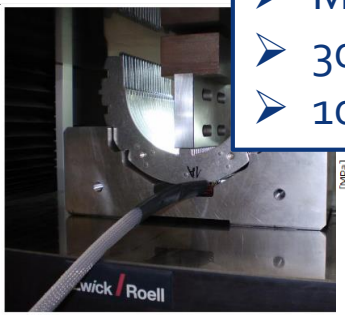


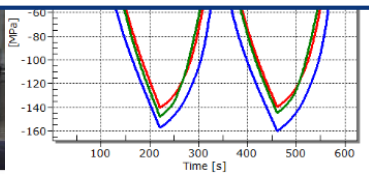


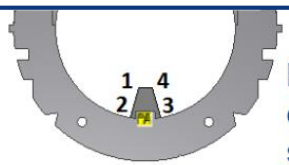


Main outcomes :

- Calibration of the collar noses, additional cuts added;
- Measurements done down to 4.2K
- 30% to 50% of bending effects on the collar noses;
- 100% of the capacitive gauges destroyed during collaring.







Both side equipped with strain gauges

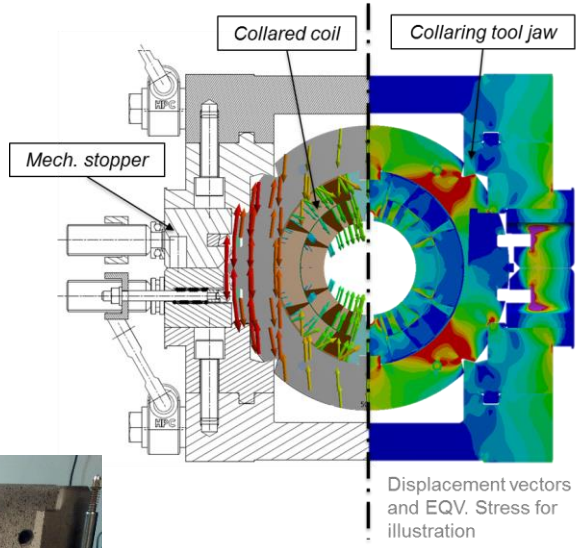
11T Collaring mockup (End of 2017)

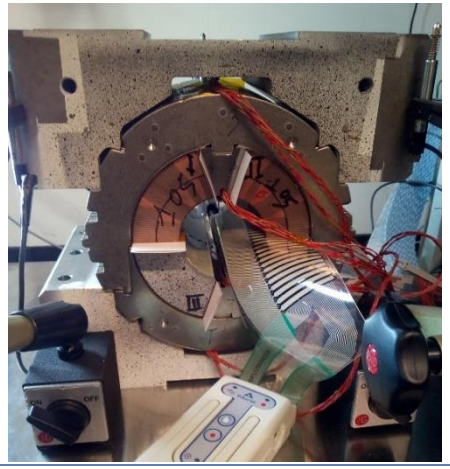
GOAL :

EDMS1886742

By using a 150 mm long collaring mock-up :

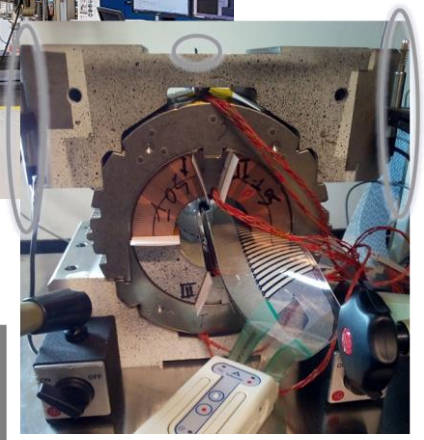
- Study collaring kinematics and mechanics, in particular coil peak stress during collaring
- Define type and location of the instrumentation
- Define shimming and loading scenarios (algorithm) to reduce coil peak stress during collaring in the next models

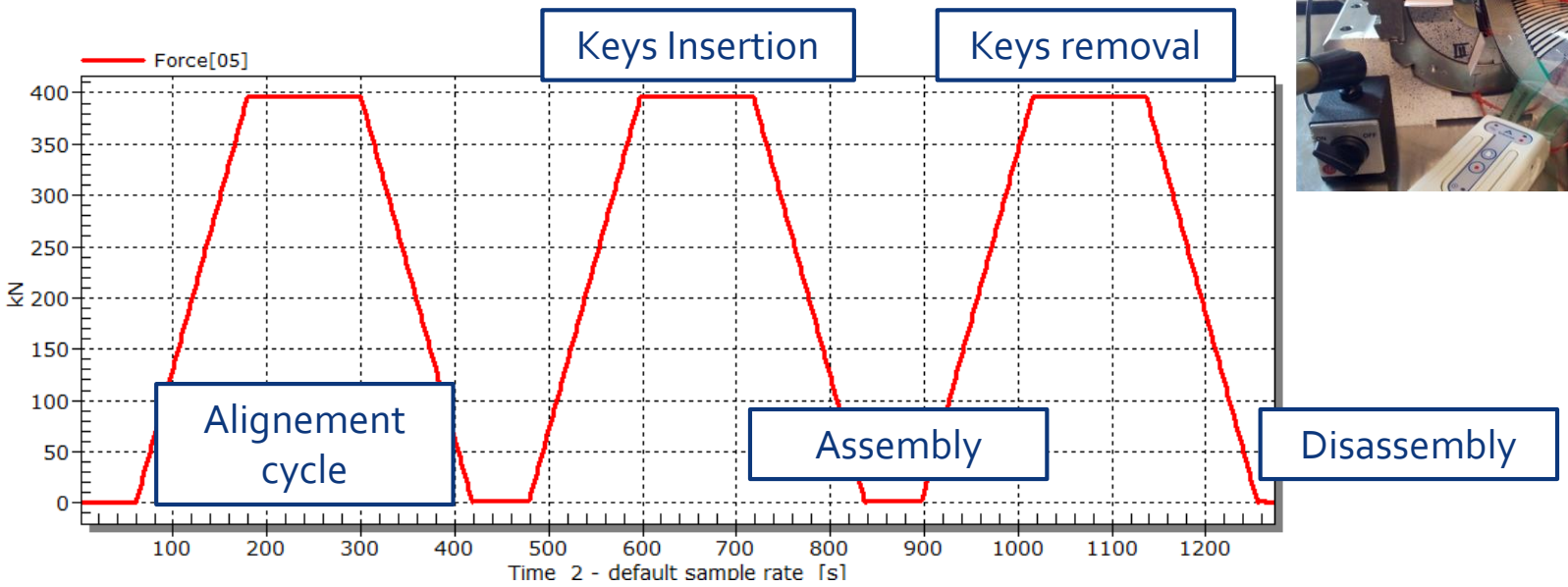




11T Collaring mockup (End of 2017)

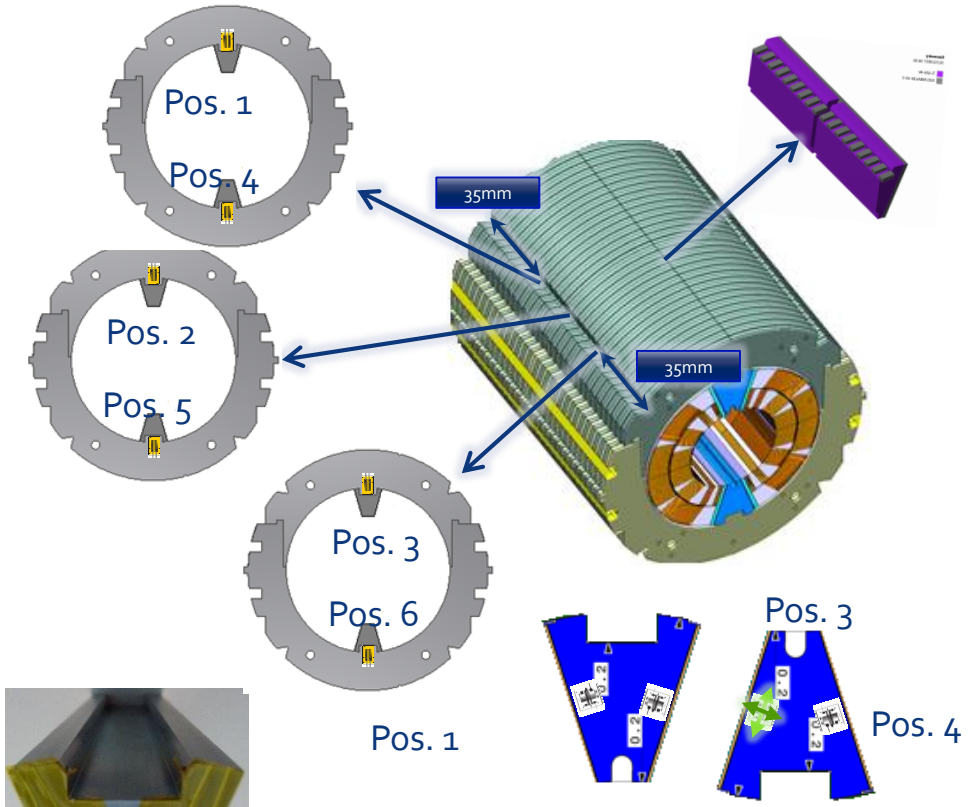
- Universal Testing Machine Z400
- 400 kN max load – ISO Calibration
- Compression plates aligned
- 3 LVDT's in vertical position's
- 1 LVDT in Z position

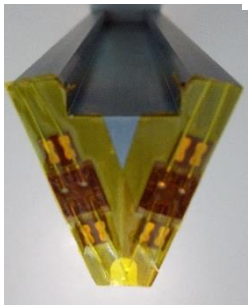




11T Collaring mockup (End of 2017)

- Both side of the 6 collars equipped with strain gauges in half-bridge configuration (Production)
- Bending and compression stress measurements for collars
- Slits with a gap of 500 µm between nose and pole
- Pole wedges equipped with biaxial strain gauges and angel wires

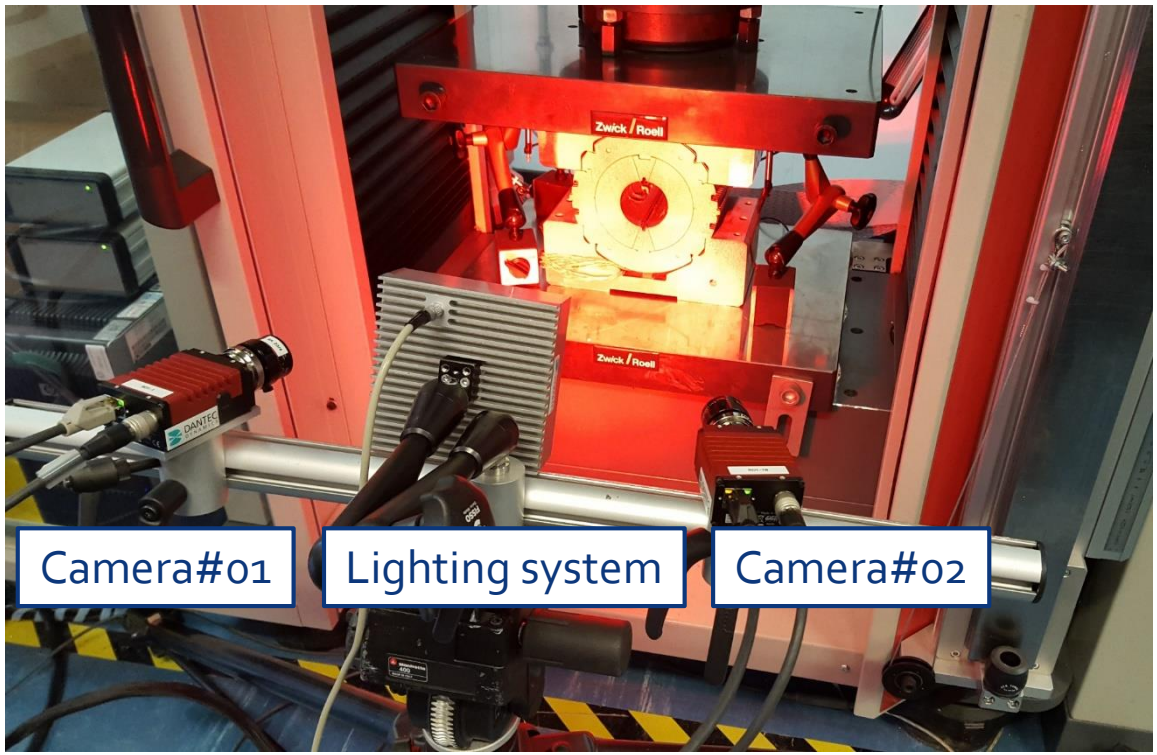




11T Collaring mockup (End of 2017)

- Digital image correlation is an optical method that employs tracking and image registration techniques for accurate 2D and 3D strain measurements.

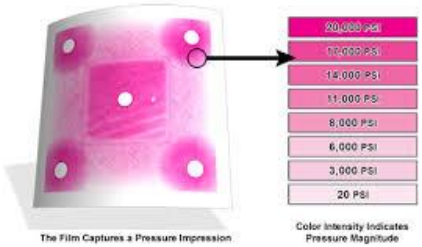
Pattern application
- Aerosol cans
- Airbrush
- Pens / Sponge



11T Collaring mockup (End of 2017)

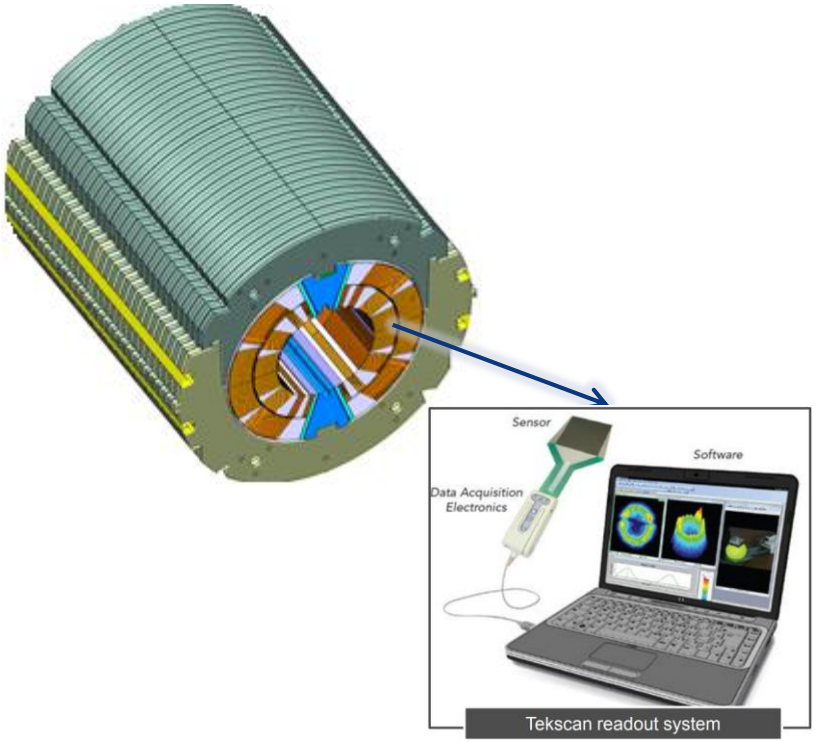
FUJI Paper (Felix)

- Mid-plane
- Poles



Tekscan placed on the Mid-plane

- live read-outs of pressure throughout the collaring process.
- Range 0 to 150 MPa

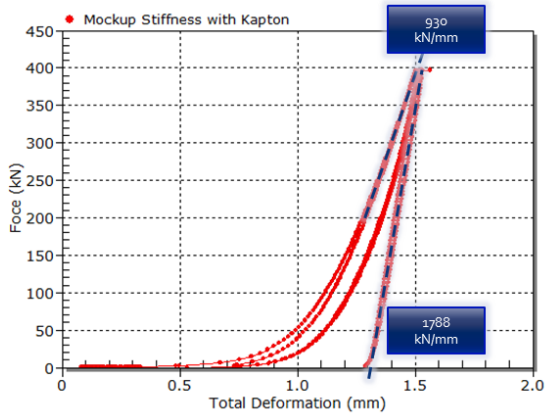


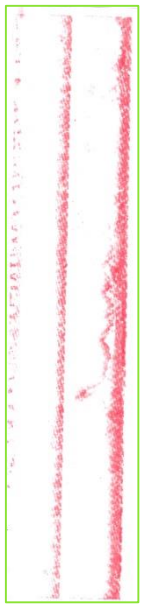
11T Collaring mockup (End of 2017)

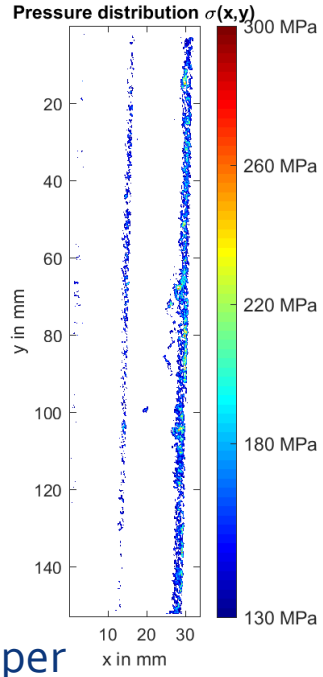
Validation results :

1) Stiffness measurements

2) FUJI Paper vs Tekscan





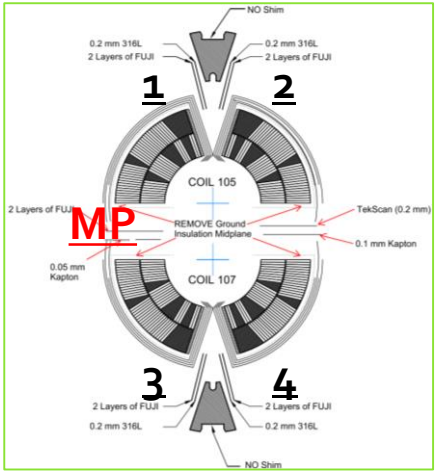


HHS Paper

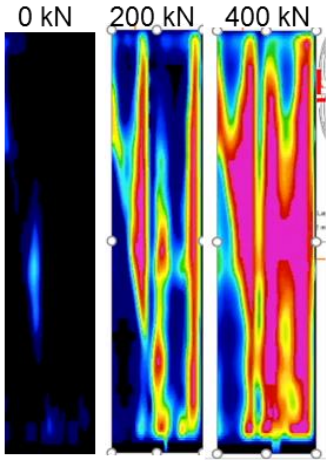
At 400kN, average pressure of 42 MPa

Pressure gradient from 130 Mpa down to 5 MPa on the mid-plane

Good agreement



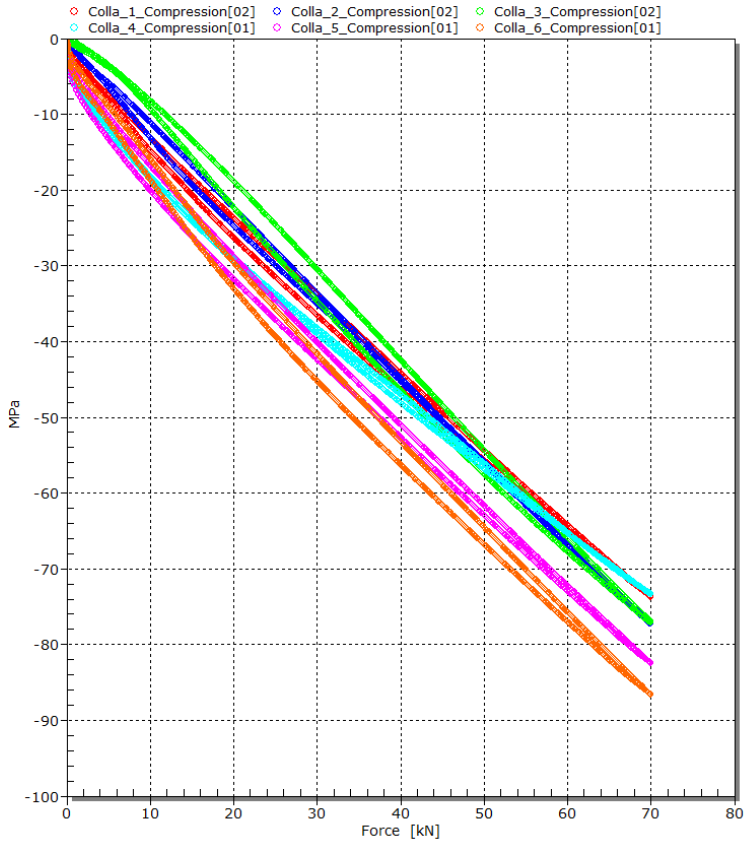
Video 0 kN – 400 kN - 0 kN



11T Collaring mockup (End of 2017)

Validation results :

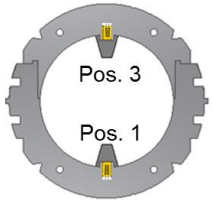
3) Strain gauges response through the pole wedge

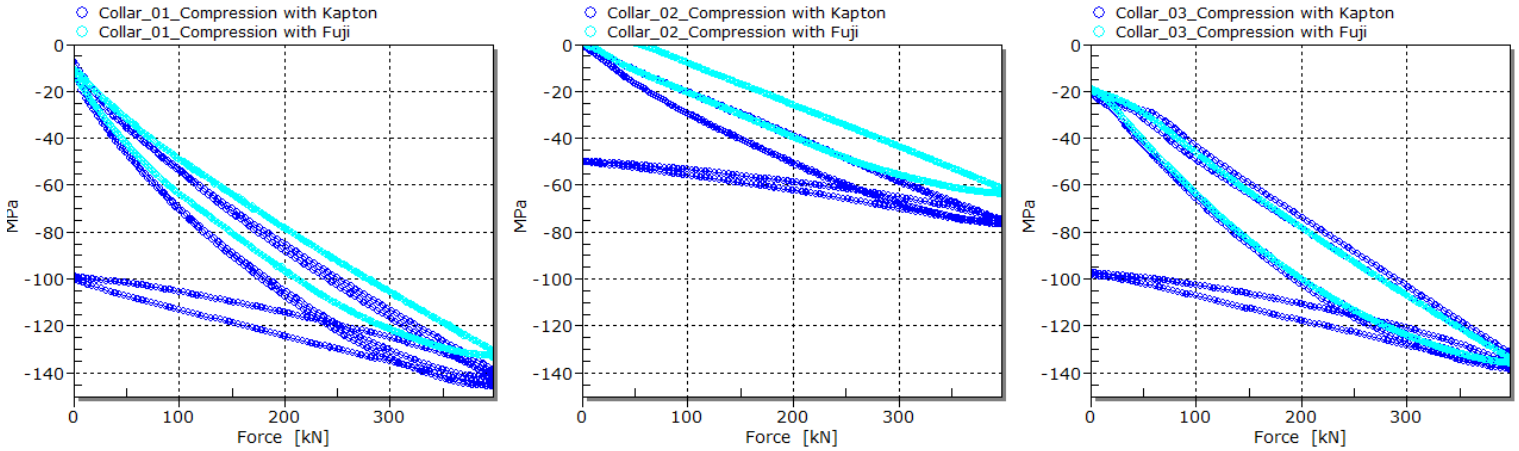


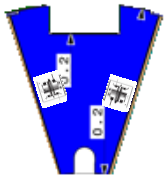
11T Collaring mockup (End of 2017)

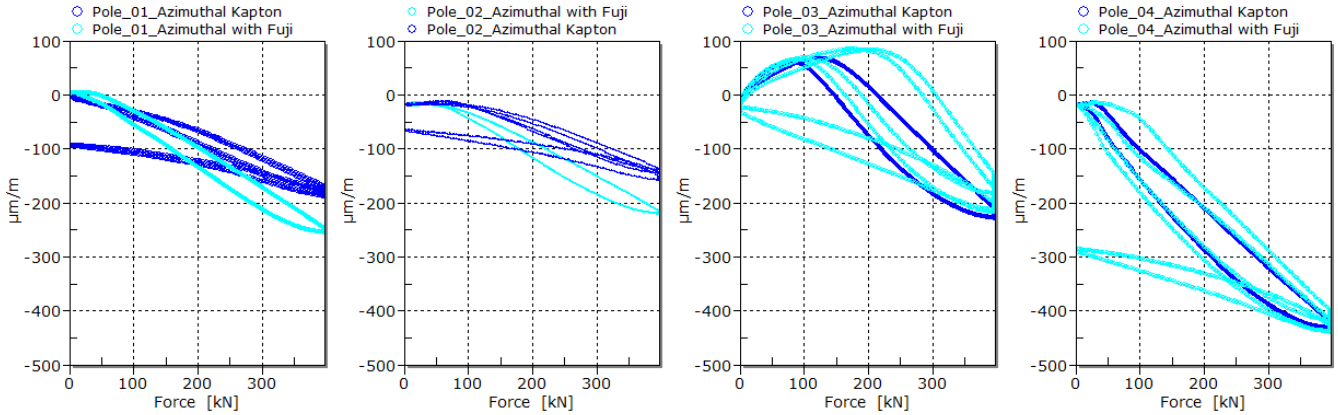
Validation results :

4) FUJI Paper vs Kapton





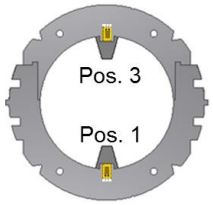


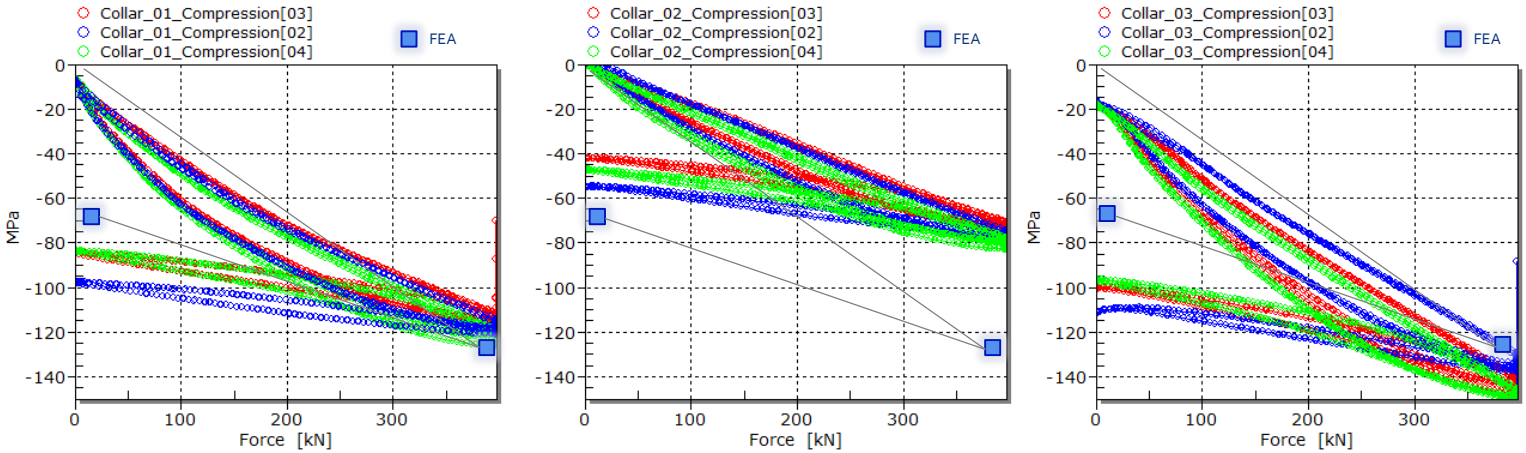


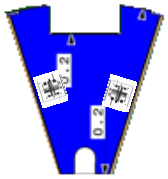
11T Collaring mockup (End of 2017)

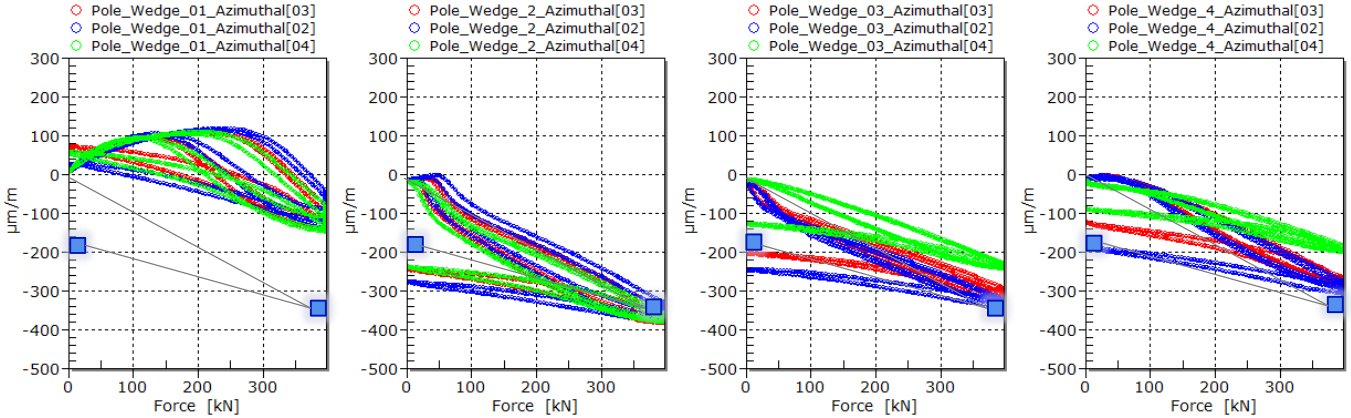
Validation results :

5) Mounting repeatability



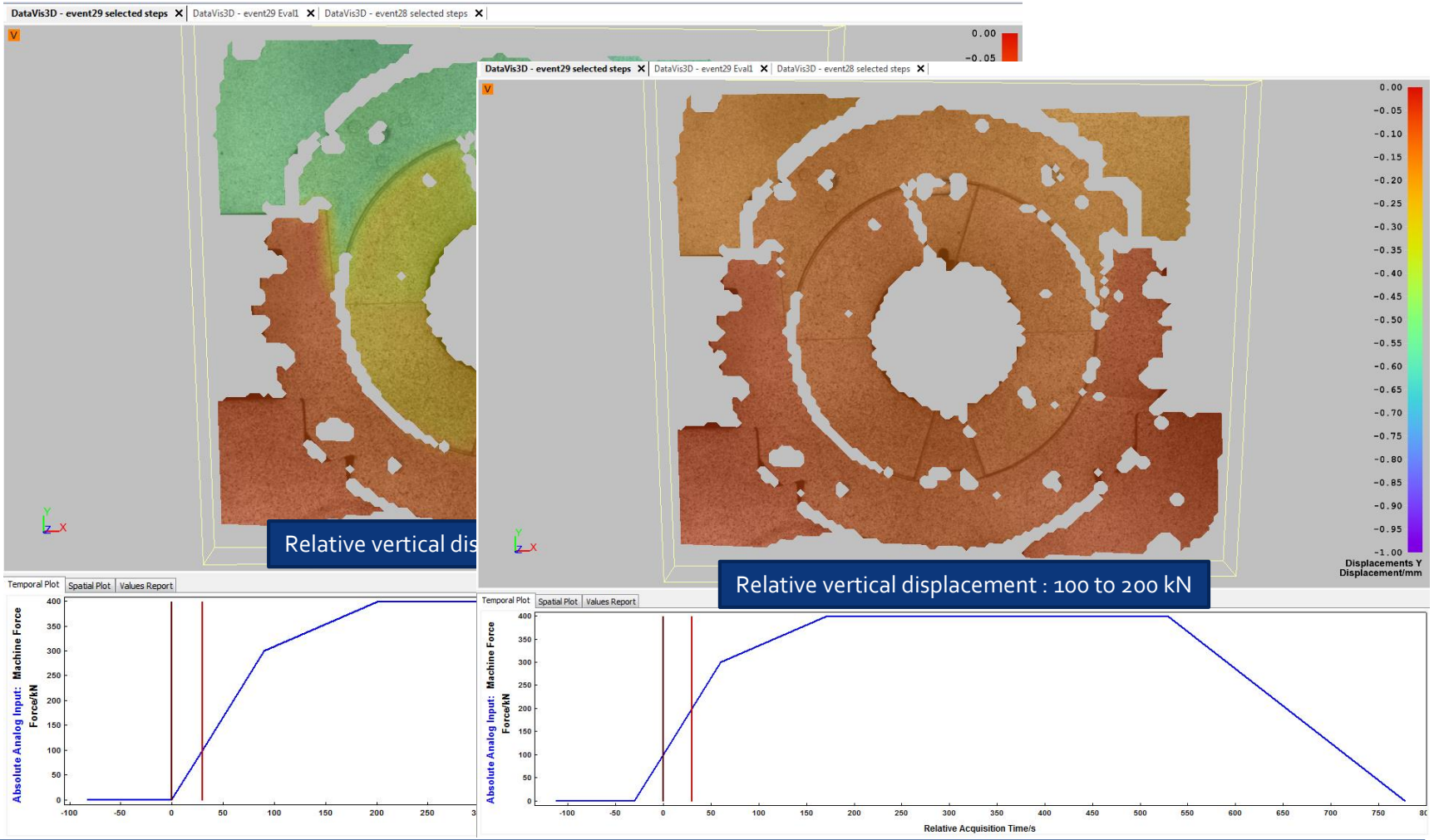






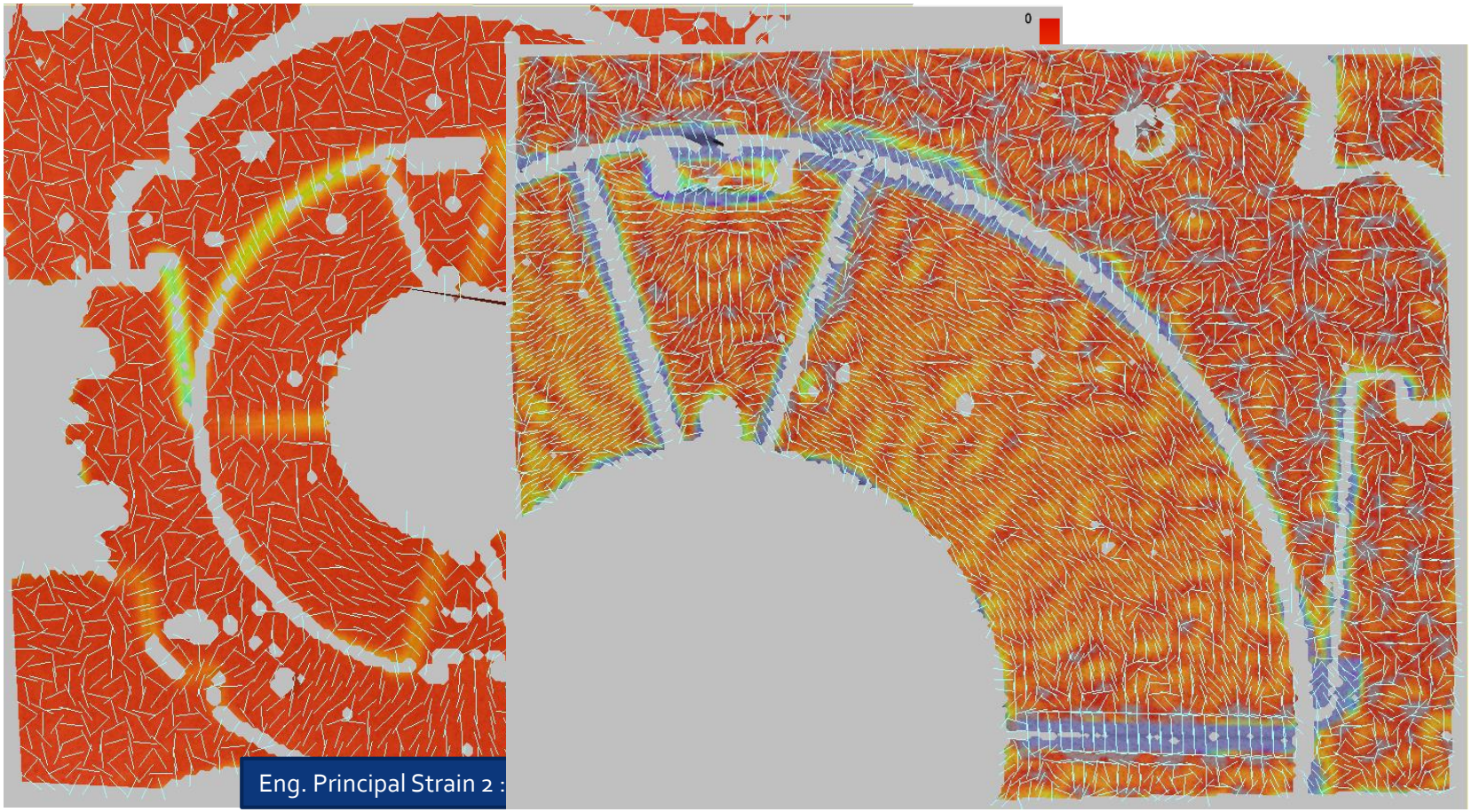
11T Collaring mockup (End of 2017)

- Displacement results :



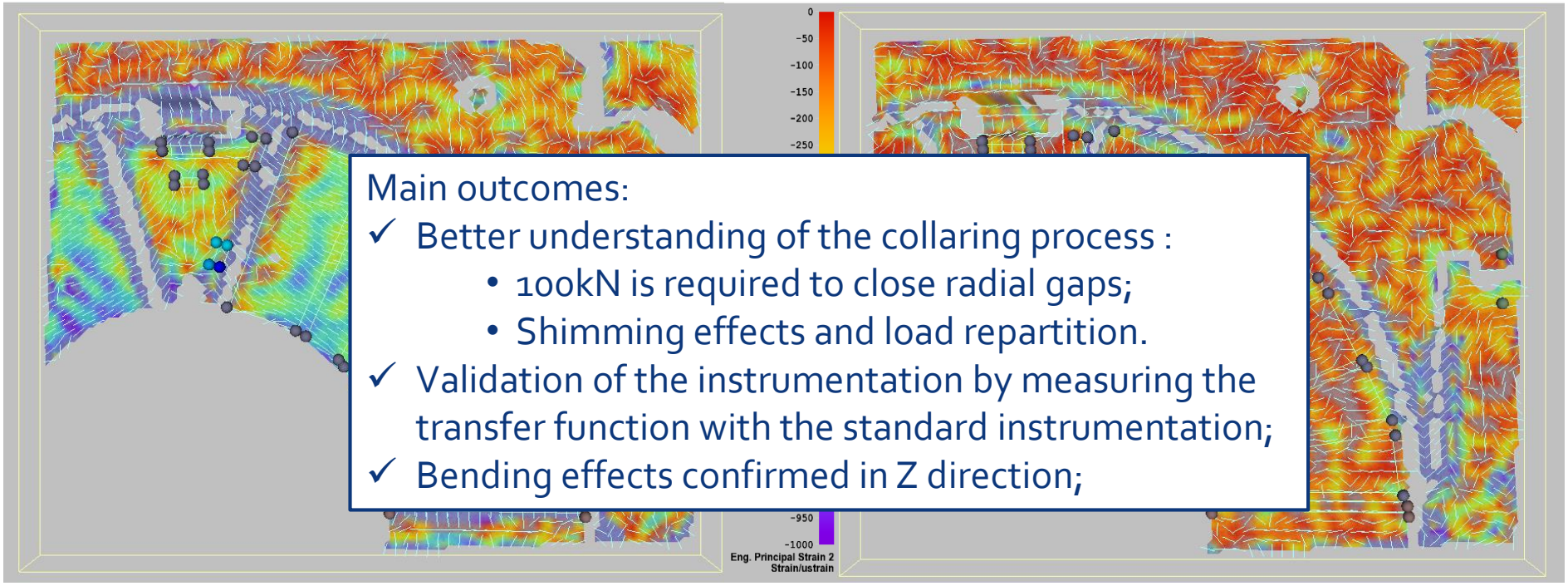
11T Collaring mockup (End of 2017)

- Strain results :



11T Collaring mockup (End of 2017)

- Strain results :



Main outcomes:

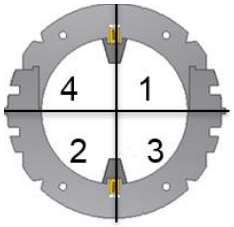
- ✓ Better understanding of the collaring process :
  - 100kN is required to close radial gaps;
  - Shimming effects and load repartition.
- ✓ Validation of the instrumentation by measuring the transfer function with the standard instrumentation;
- ✓ Bending effects confirmed in Z direction;

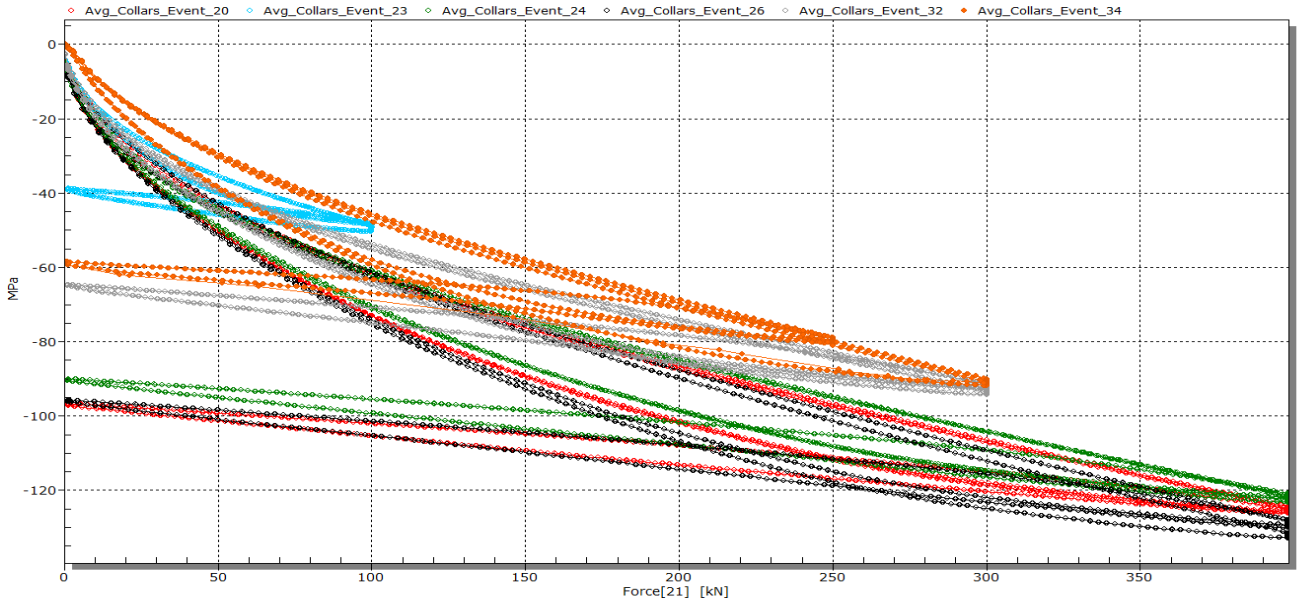
Collaring process : Loading from 1kN up to 400kN	
Polygon 2 - Eng. Principal Strain 2/Mean over surface/ustrain:	-500 ± 80
Polygon 1 - Eng. Principal Strain 2/Mean over surface/ustrain:	-410 ± 70
Polygon 3 - Eng. Principal Strain 2/Mean over surface/ustrain:	-490 ± 90
Polygon 4 - Eng. Principal Strain 2/Mean over surface/ustrain:	-460 ± 100
Polygon 5 - Eng. Principal Strain 2/Mean over surface/ustrain:	-470 ± 100

Collaring process : 400kN to keys in	
Polygon 2 - Eng. Principal Strain 2/Mean over surface/ustrain:	-80 ± 90
Polygon 1 - Eng. Principal Strain 2/Mean over surface/ustrain:	-70 ± 80
Polygon 3 - Eng. Principal Strain 2/Mean over surface/ustrain:	-30 ± 90
Polygon 4 - Eng. Principal Strain 2/Mean over surface/ustrain:	0 ± 100
Polygon 5 - Eng. Principal Strain 2/Mean over surface/ustrain:	-20 ± 110

11T Collaring mockup (End of 2017)

- Stress results :

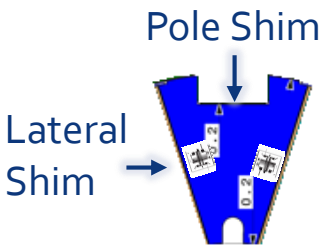


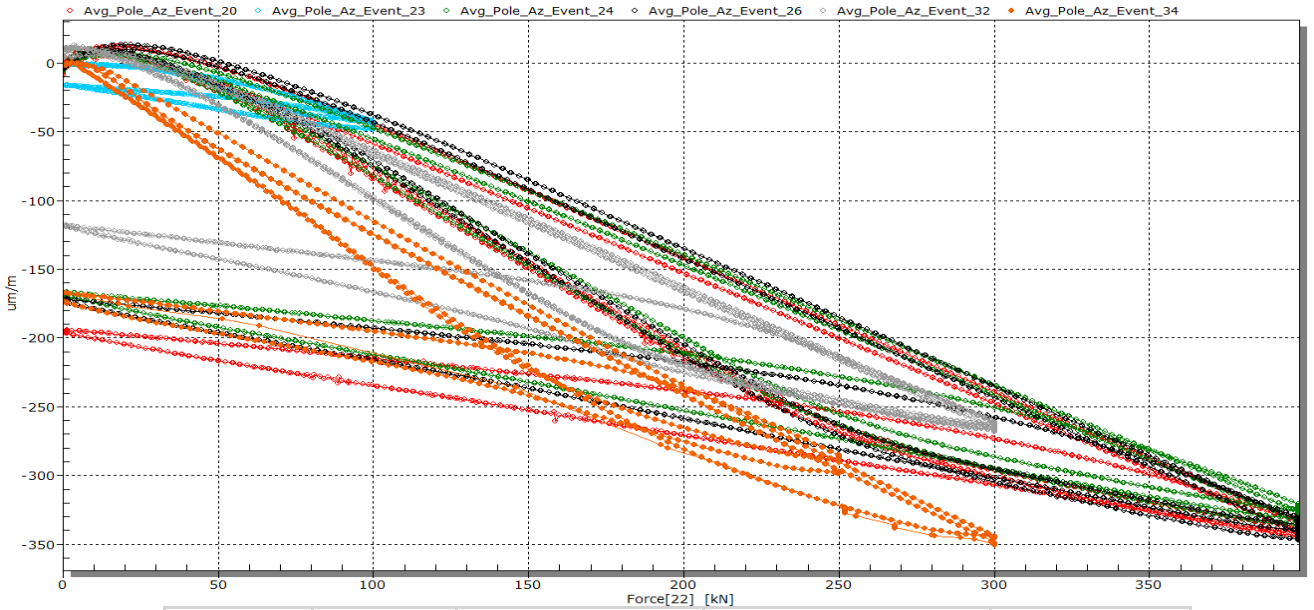


Coil	Curve	Pole shim (µm)	Lateral shim (µm)		Excess (µm)
Al blocks		200	200		150
		200	100		50
		350	100		100
		500	100		150
		200	200		150
CR3		100	0	200	150

11T Collaring mockup (End of 2017)

- Stress results :





Coil	Curve	Pole shim (µm)	Lateral shim (µm)		Excess (µm)
Al blocks		200	200		150
		200	100		50
		350	100		100
		500	100		150
		200	200		150
CR3		100	0	200	150

Conclusion

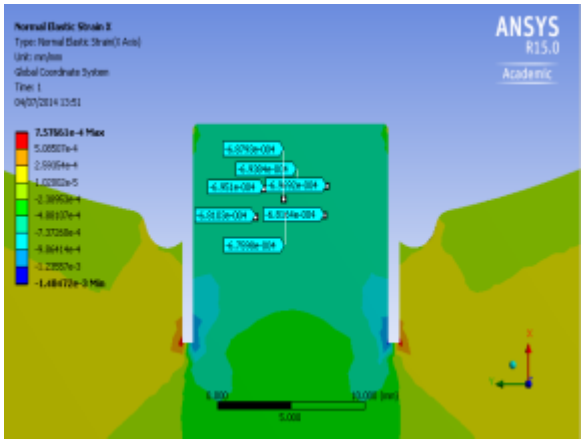
- ✓ Several 11T 150mm Mockups were already measured and huge quantity of data is available, mainly for the last one in 2017/2018;
- ✓ Several measurements devices were tested with the following outcomes :
  - ✓ Electrical strain gauges (ESG) : Nice feedback with a minimum of mechanical effects but the coil azimuthal stress state needs to be extrapolated;
  - ✓ Fuji paper / Tekscan systems gave coherent results but affect a bit the response of the system due to the friction;
  - ✓ Capacitive gauges are not adapted due to the longitudinal motion during collaring steps observed by ESG and DIC. The 100kN to close the gap to access to the strain regime and the stress distribution doesn't help also;
  - ✓ DIC results have shown the overall behavior of the mockup during the collaring process – The transfer function with ESG was also determined and the bending effect measured by the collars was also confirmed.

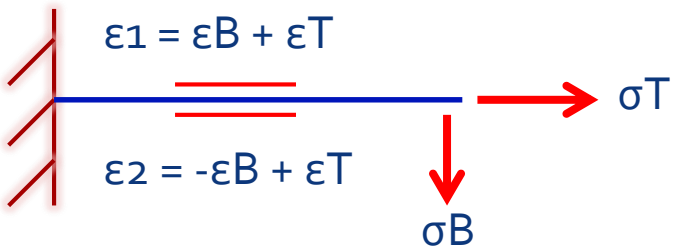
Thank you !
Questions ?

ENGINEERING
DEPARTMENT

Strain gauges for 11T collars

- Cuts next to the nose of the collars were done in order to get more axial stress
- Half bridge configuration
- Poison ratio compensation
- Bending and traction measurements





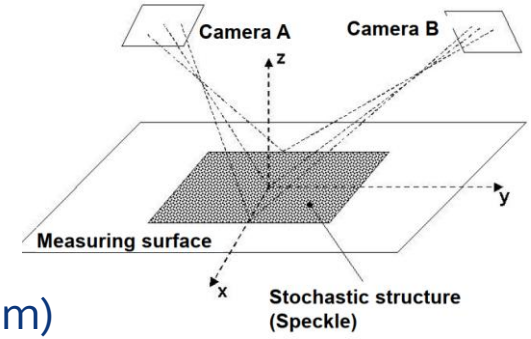
$\varepsilon Traction = (\varepsilon 1 + \varepsilon 2)/2$

$\varepsilon Bending = (\varepsilon 1 - \varepsilon 2)/2$

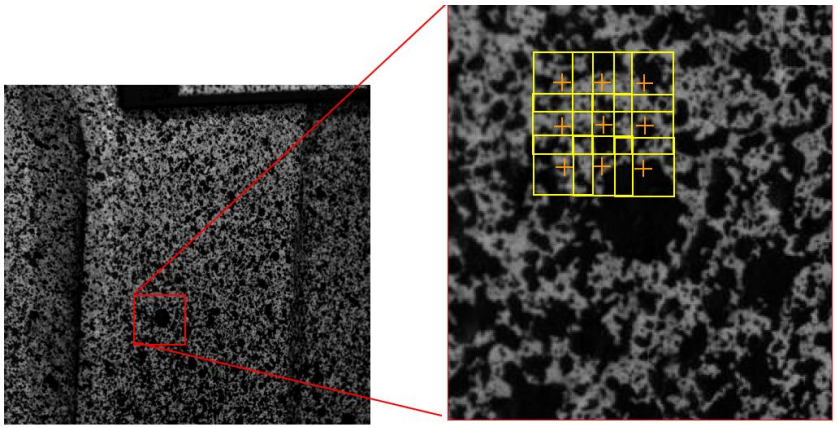
Measurement techniques

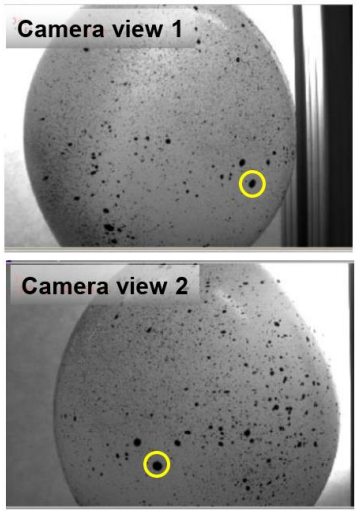
- Goal :

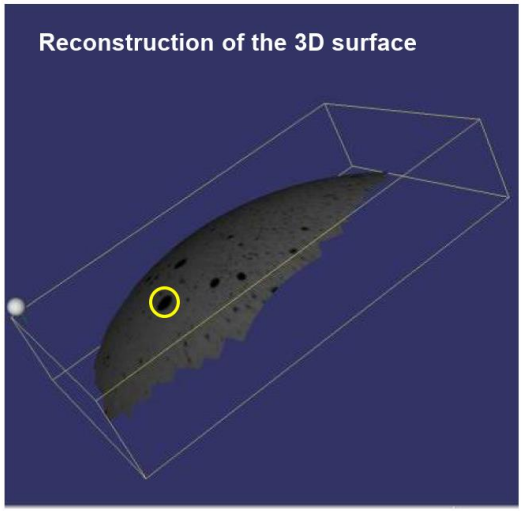
3D Deformation Measurement based on the principle of perspective view (similar to our visual sense)



- How does it work ?:
  - Stochastic pattern on the object
  - View with two cameras from different directions
  - Identification of homologues points (correlation algorithm)
  - Calculation of 3D coordinates

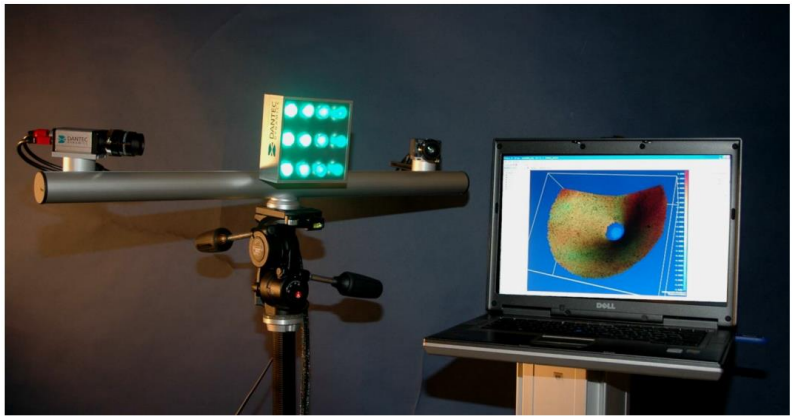






Measurement techniques

- Equipment's
  - Two cameras of 5 mega pixels
  - Fix lenses of x35 or x50
  - Lighting system + support
  - Electronic with 6 input/output channels



- Boundary conditions :
  - Zone of interest : Few cm2 up to one m2 with limited depth of field
  - Strain accuracy : +/- 10 µm/m according to speckle size
  - Temperature range : No limit if visible by human eyes
  - Frequency range : Up to 15 frame/s with the standard camera
  - Surface : Need to be paint (Study ongoing to improve this point)