Measurement Devices for 10 Stacks Mechanical Characterization from RT down to 77 K

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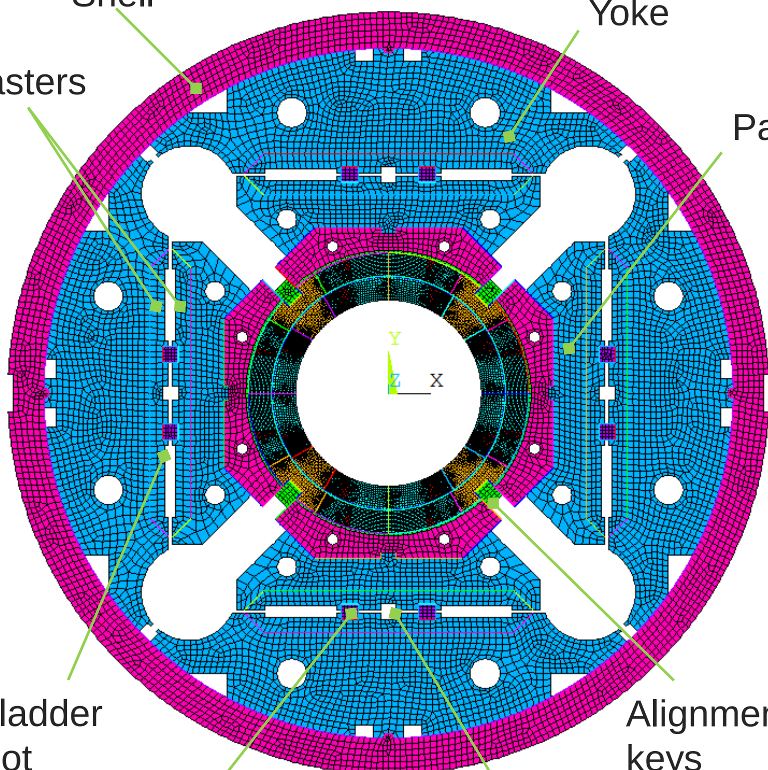
Outline

- Requirements
- Background
- Preliminary Studies
- Test Set-Up
- Validation Campaign
- Results
- Conclusions

Requirements

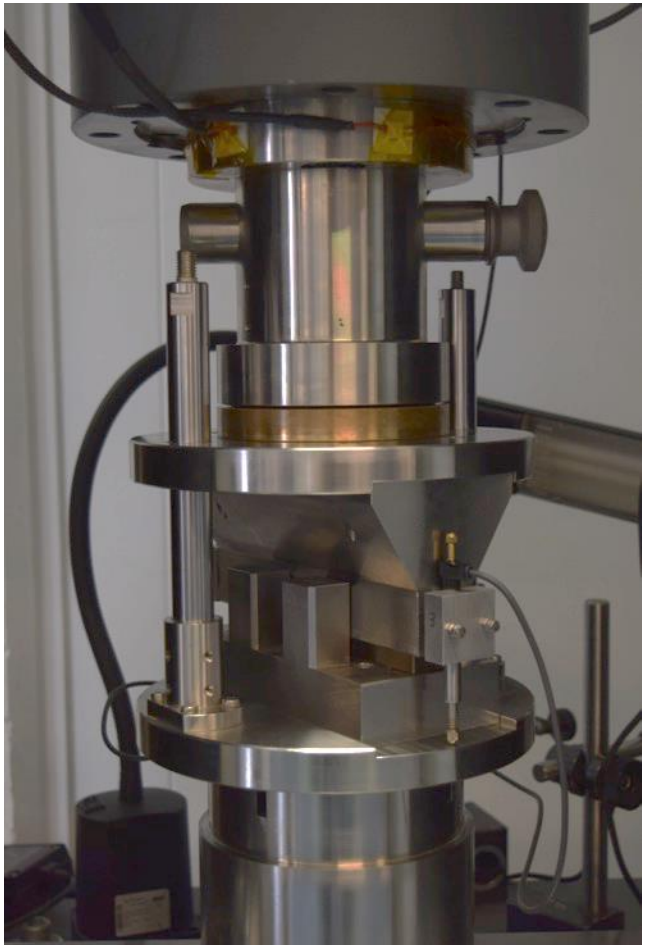
Cross-section MQXF

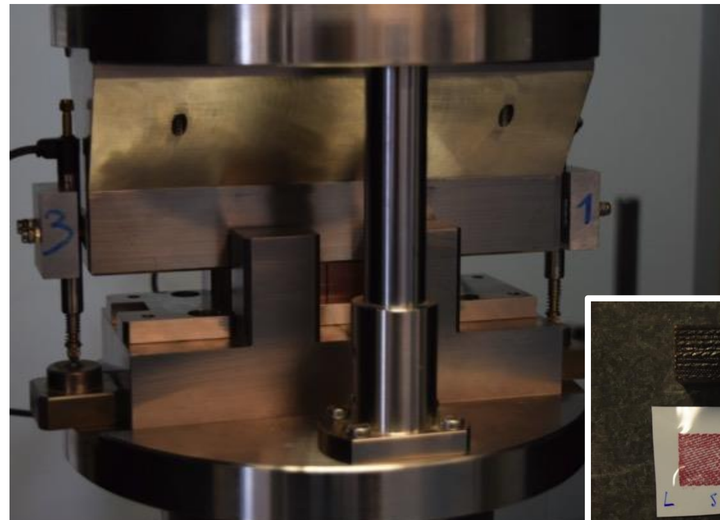


Material	E (GPa)		Poisson's ratio
	293 K	4.3 K	293 K/4.3 K
Coil	44	44	0.3
Stainless steel	193	210	0.28
Iron	213	224	0.28
Aluminum	70	79	0.34
G10	10	10	0.3
Titanium	130	130	0.3
Nitronic 50	210	225	0.28
Aluminum Bronze	110	120	0.3

Background

Measurements at RT and 77 K with capacitive gages calibration set-up in 2015.





OK for a first approximation, but...

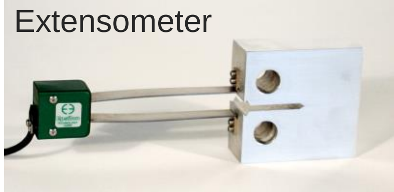
- significant compliance (bigger than the cable deformation)
- difficult operation
- safety matters

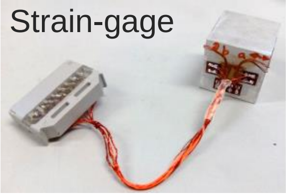
suggest the development of an ad hoc setup for the campaign of tests.

Preliminary studies

In view of future characterization campaigns, preliminary studies combining FEM and experimental testing were launched in order to:

- evaluate the feasibility of upgrading the former capacitive gages calibration tooling;
- determine the most appropriate measurement technique;

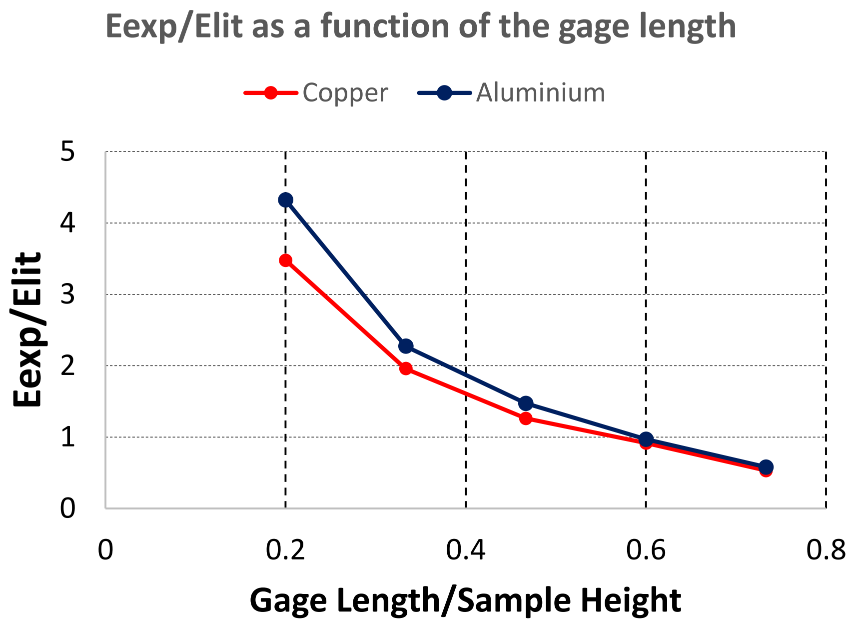


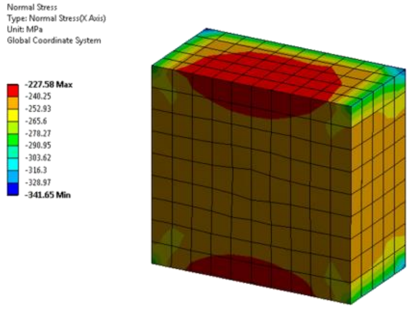


- quantify the deflection of the tooling for the most usual sample sizes, and asses its impact in the measurements;
- determine the compliance of the tooling as a function of the rigidity of the tested material, and hence, if it is possible to apply a correction.

Preliminary Studies – Measurement Technique

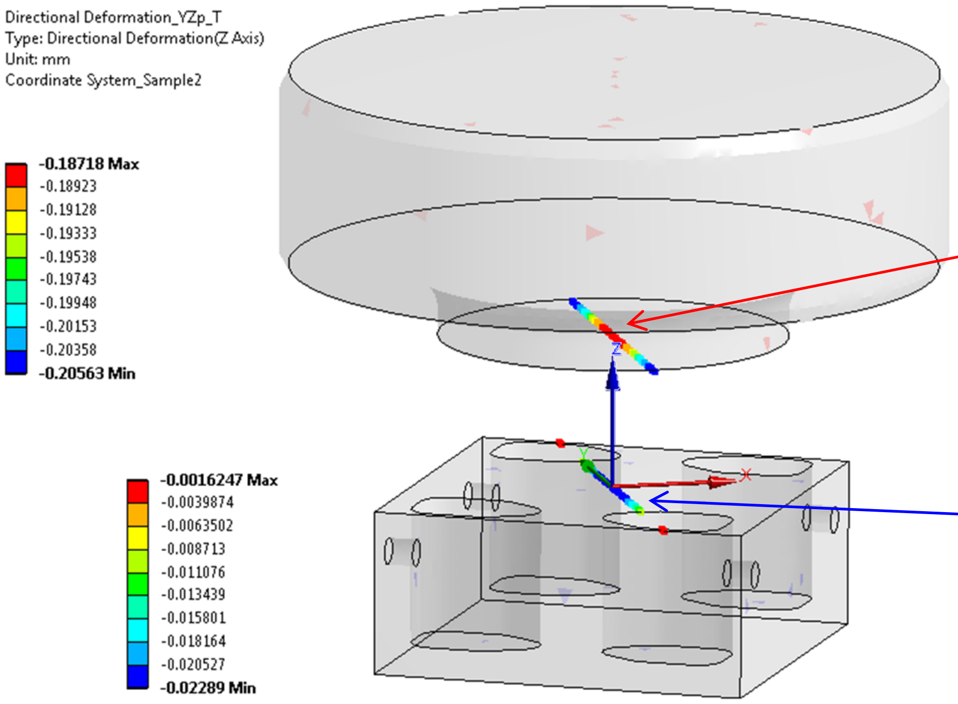
- **Are extensometers an appropriate tool for such measurements?**
- Simulations depict important gradients of strain along the sample volume.
- This behavior has been experimentally verified with a laser extensometer.
- Most of the deformation takes place in the vicinity of the areas in contact with the testing machine.
- LVDT method provides an integrated measurement which partially overcomes this limitation.

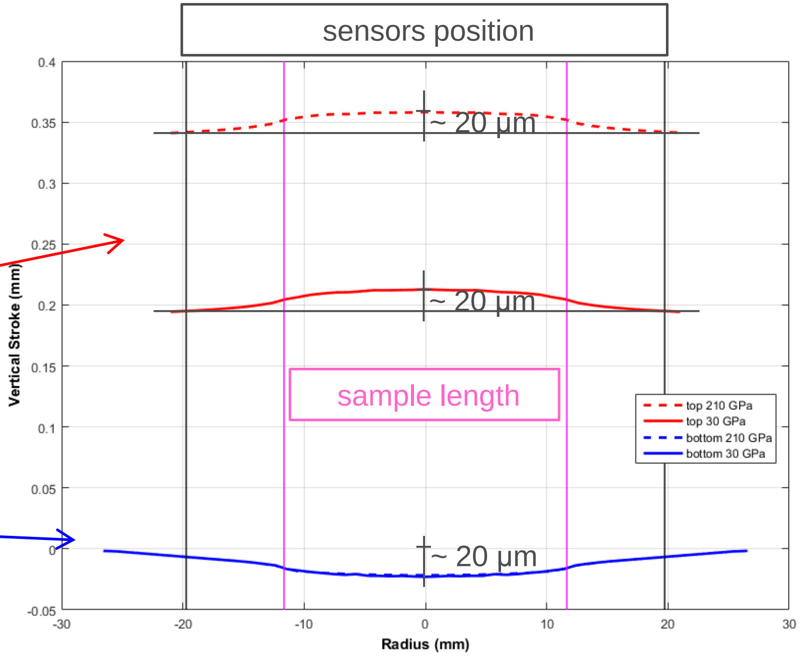




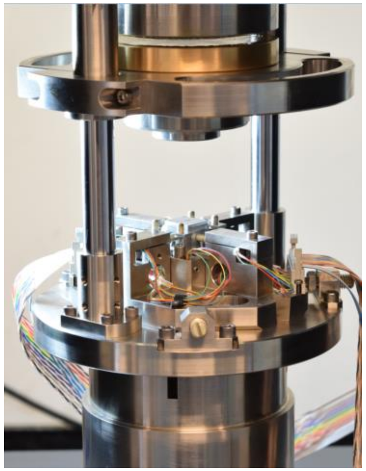
Preliminary Studies - Profiles deformations - 1

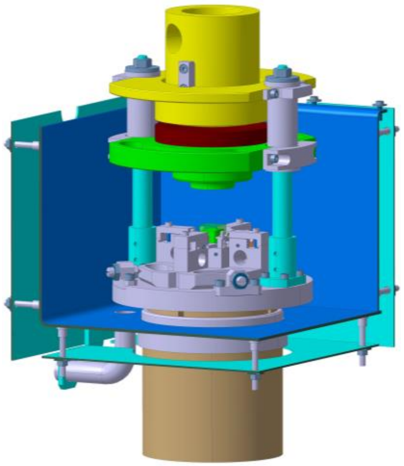
- Expected deformation ~ 230 μm (H=18.9 mm)





Test Set-Up - Overview

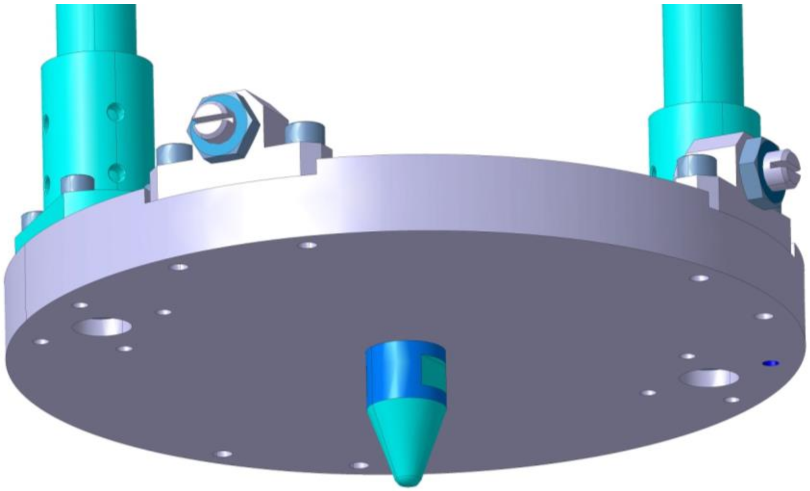


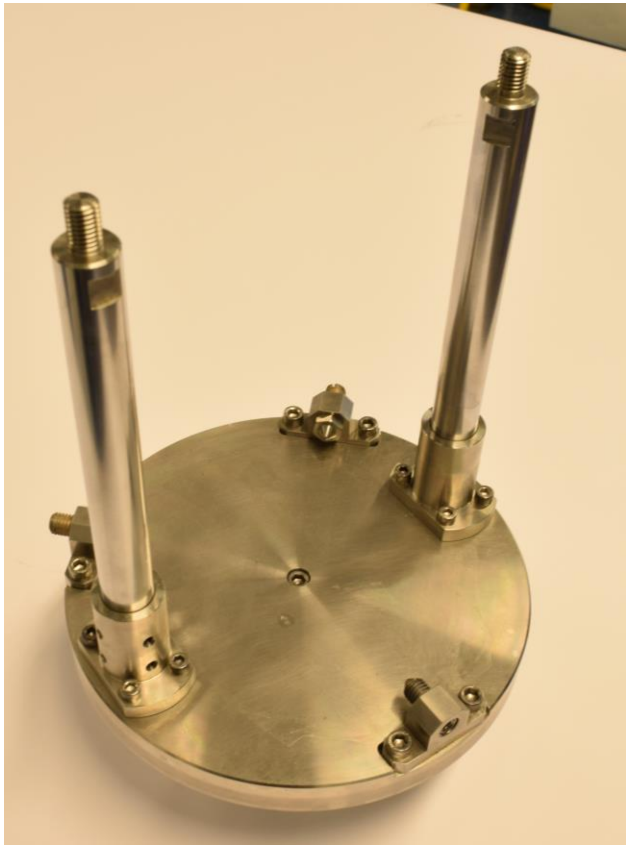


Zwick-Roell 400 kN UTM

Bottom assembly

- Holds the sled
  - Rapid mounting
- Lifts it out of bath
- Centering pin in the bottom



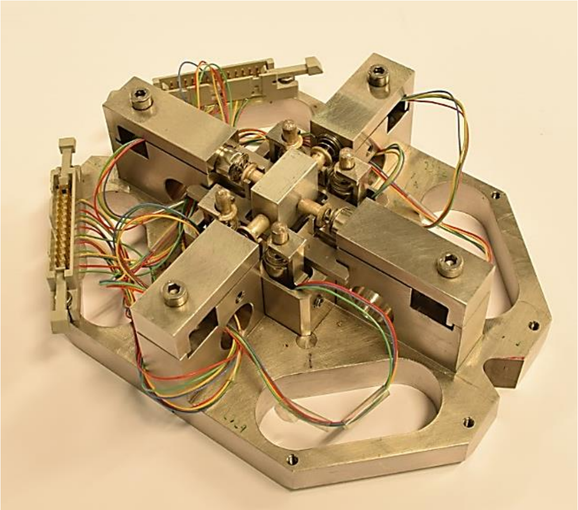


Top assembly

- Ram for press head
  - Removable
- Spherical washer for centering the press
  - Perpendicular contact

Test Set-Up – Removable Measuring Sled

- Sled is prepared away from the testing machine:
  - Easier to position sample and prepare sensors;
  - A set of 2 sleds allows a higher output rate in cryogenic measurements.



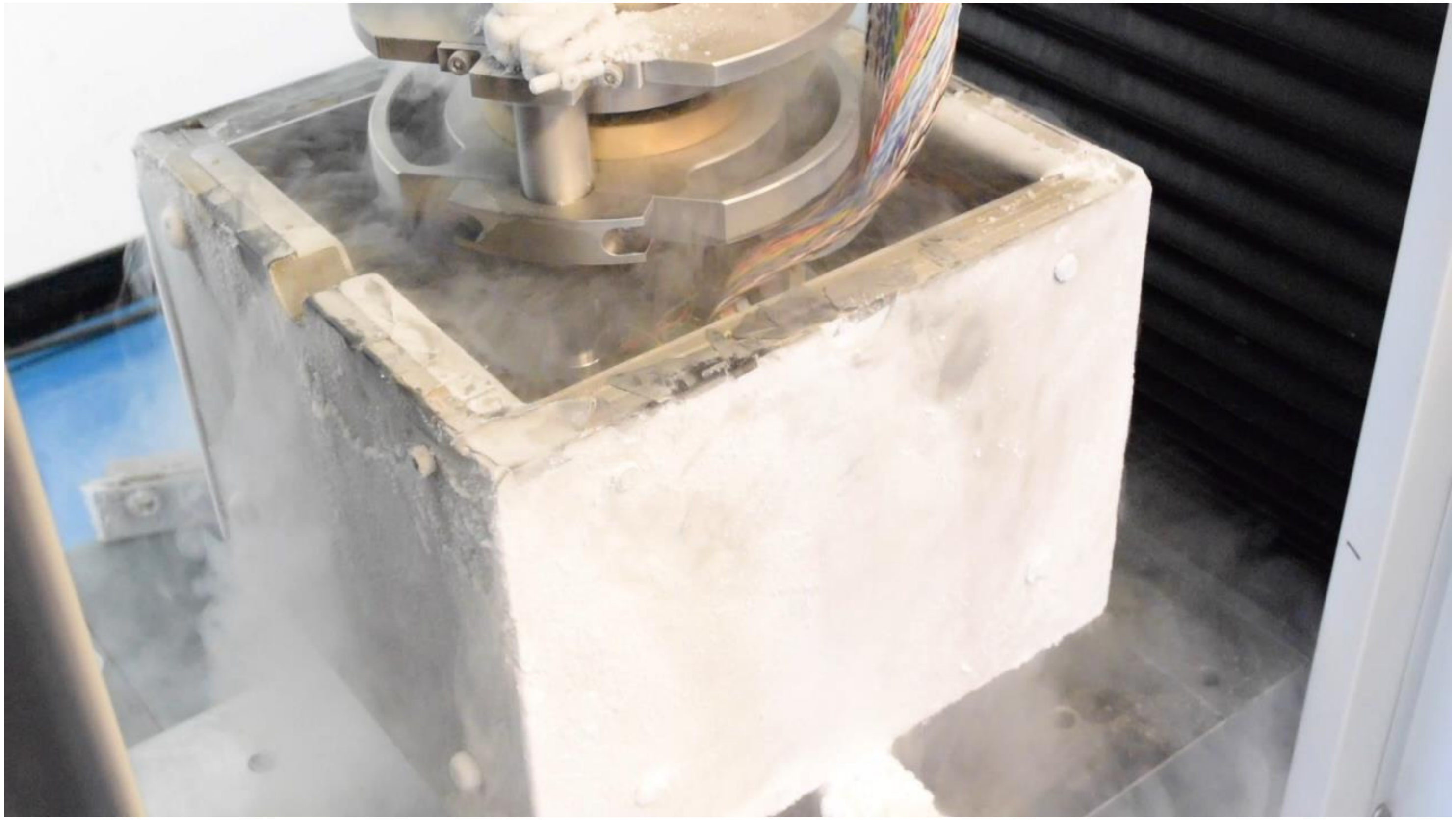
- Centering Mask

- Measuring plate acts as the anvil
- Holds vertical sensors

- Changing the sled allows greater flexibility in terms of possible types of measurements: bending tests, shear tests, custom set-ups, etc.

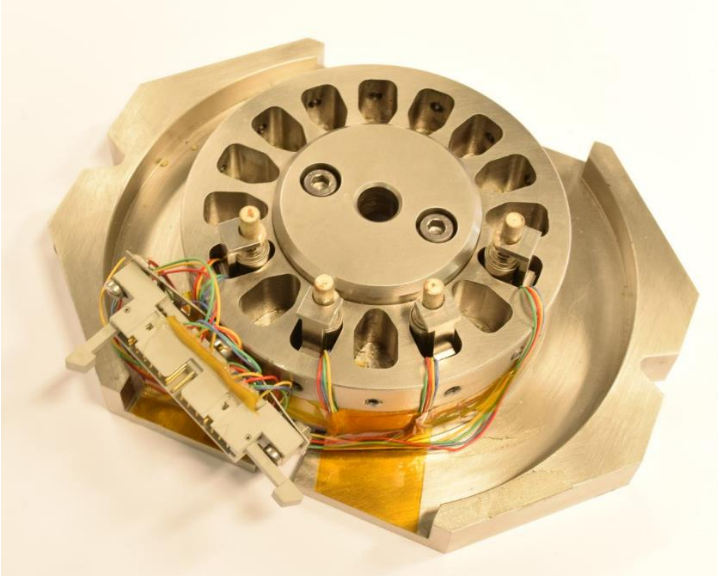
Test Set-Up – Removable Measuring Sled

Sled changing procedure



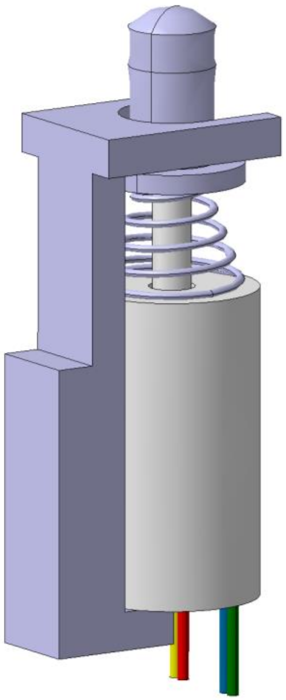
Test Set-Up – Calibration Sled

- Allows the simultaneous calibration of up to 16 sensors.
- Crytical in cryogenic temperatures.

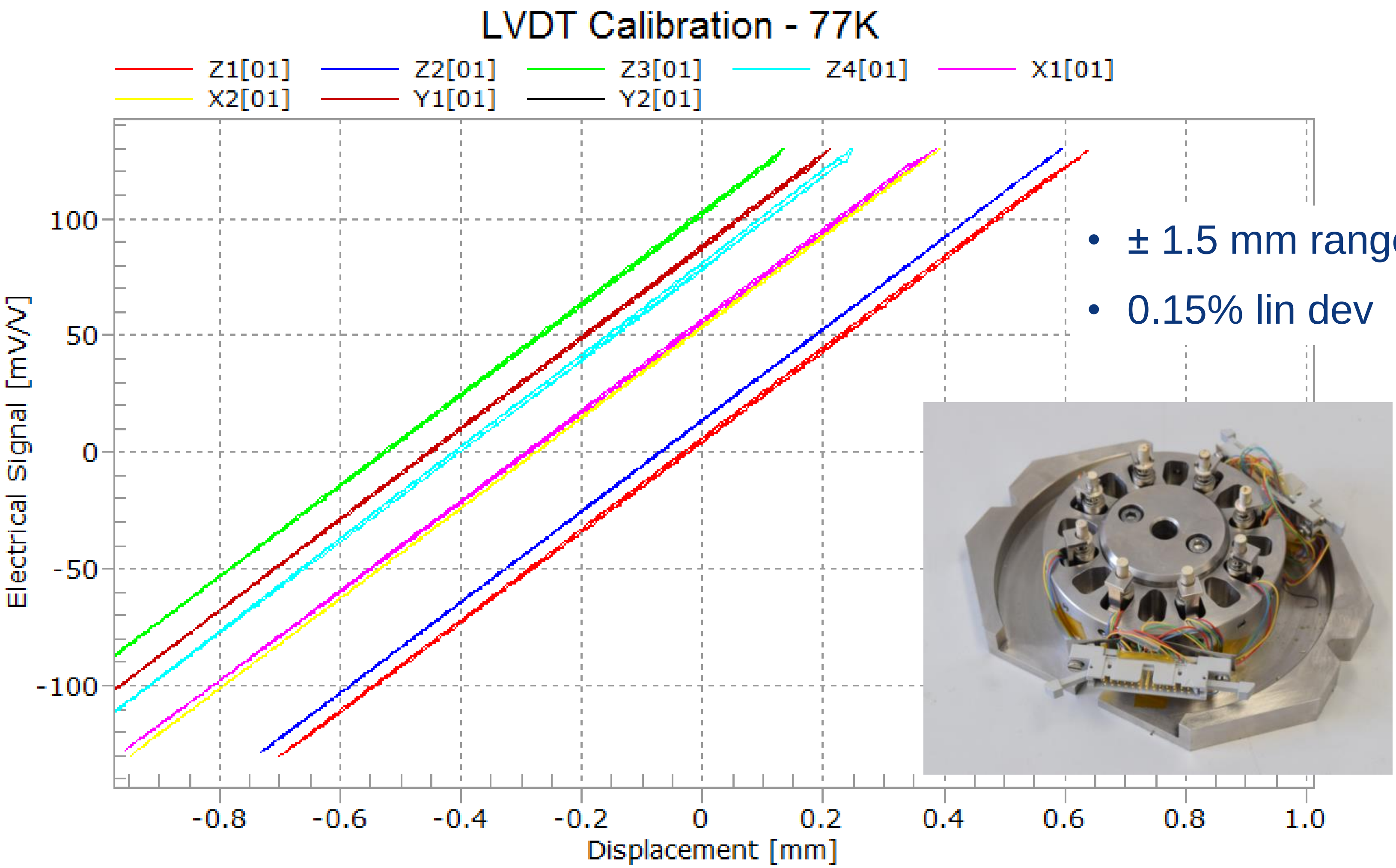


Test Set-Up - Sensors

- Sensorex SX9W03 Miniature LVDT Sensor
- Proved efectiveness at 4k and 77k
- ± 1.5 mm range
- ± 0.15% Linearity deviation
- Forks keeps the sensor together
- Sensor is locked in place by pressing on the fork with a set screw

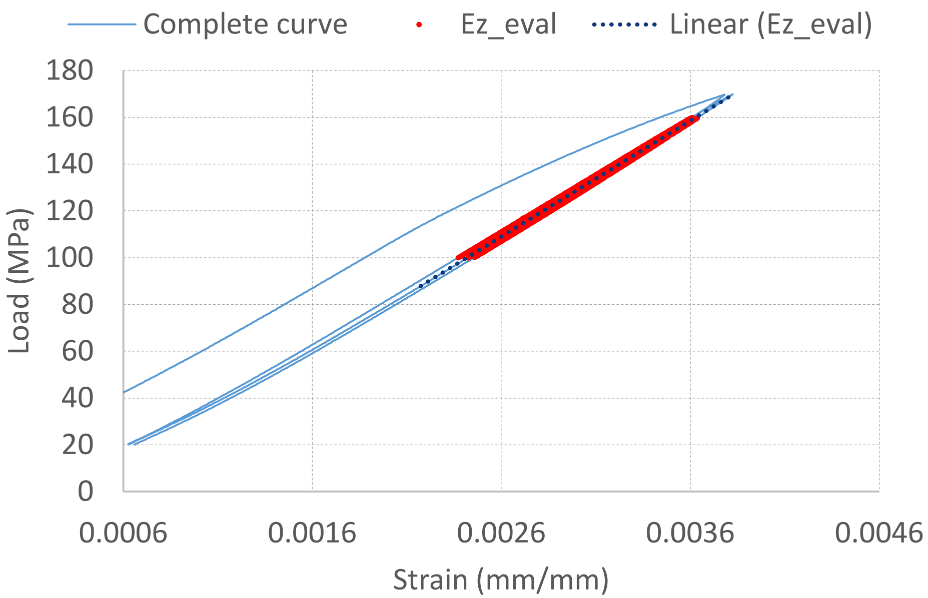


Validation Campaign - LVDTs Calibration



- ± 1.5 mm range
- 0.15% lin dev

Validation Campaign - Tooling Compliance Determination



$$D_{Tool} = \overline{D}_{Exp} - D_{The}{}^{*}$$

$\overline{D}_{Exp}$: AVG experimental deflection

D_{The}: Sample deflection according to E

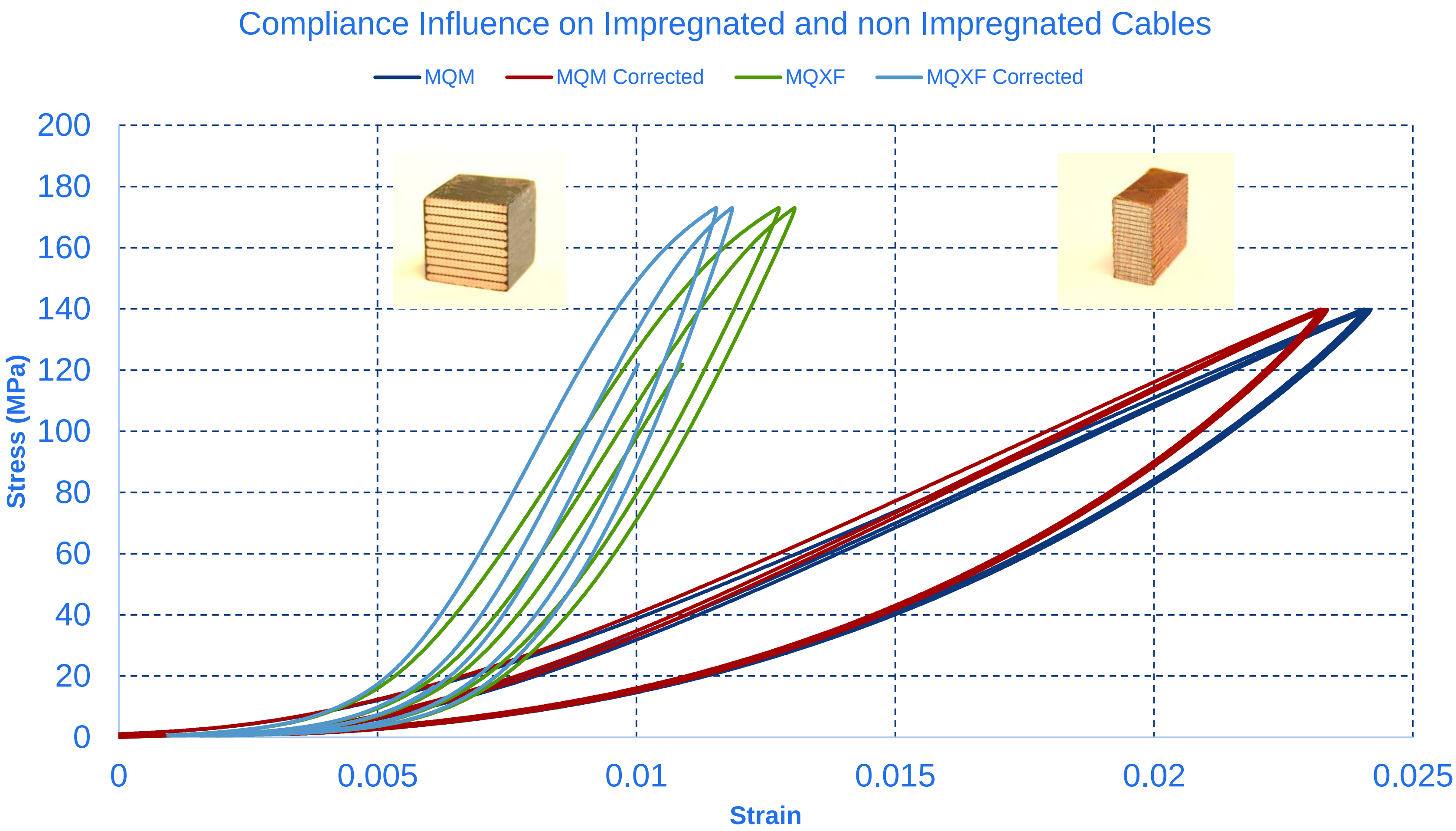
*Considered a region comprised between 100 and 160 MPa to avoid bending and alignment effects.

Deflection (µm/MPa)		
Material	**RT**	**Cryo**
G10	0.085	-
Al	0.091	0.081
Cu	0.098	0.086
AVG (*Corr*)	**0.091**	**0.083**
Max Dev (%)	5	2

Correction equation:

$$D_{Corr} = D_{Exp} - (Corr \times Stress)$$

Results and compliance



Conclusions

- A test rig for compression tests was developed, characterised and validated for stiffness measurements;
- Several test campaigns have been performed so far for 11T and MQXF. A campaign is ongoing for MQM;
- The compliance of the tooling becomes critical when measuring stiffer samples;
- A proper documentation of the tests is of paramount importance for the future exploitation of the data.

Thermal Analysis

- Thermal analysis has not yet extensively explored for the study of the cables.
- Possibility to obtain interesting data both in the high temperatures range (reaction and impregnation) and low temperatures range (thermal contraction).
- The laboratory is already equipped for the determination of :

THERMAL EXPANSION CTE → **THERMAL DIFFUSIVITY a(T)** ← **SPECIFIC HEAT $C_P(T)$**

THERMAL CONDUCTIVITY
$\lambda(T) = a(T) \cdot C_p(T) \cdot \rho(T)$

From RT up to 2000 °C
Solids, powders and liquids

Thank you

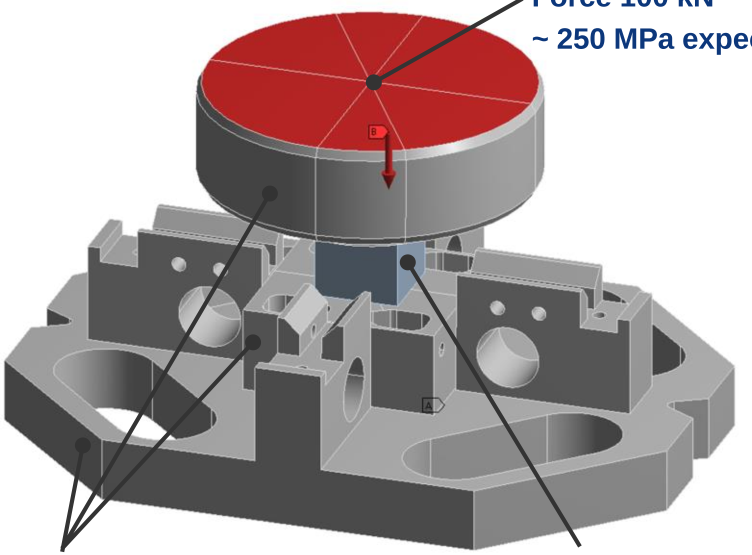
Test Set-Up - Sample Sizes

- Max sample size
  - Length 32mm
  - Width 24mm
  - Height 20mm
- Min sample size
  - Length 15mm
  - Width 10mm
  - Height 15mm
- 11 Tesla sample size
  - Length 20mm
  - Width 15mm
  - Height 15mm
- MQFX sample size
  - Length 20,00mm
  - Width 18,70mm
  - Height 18,85mm

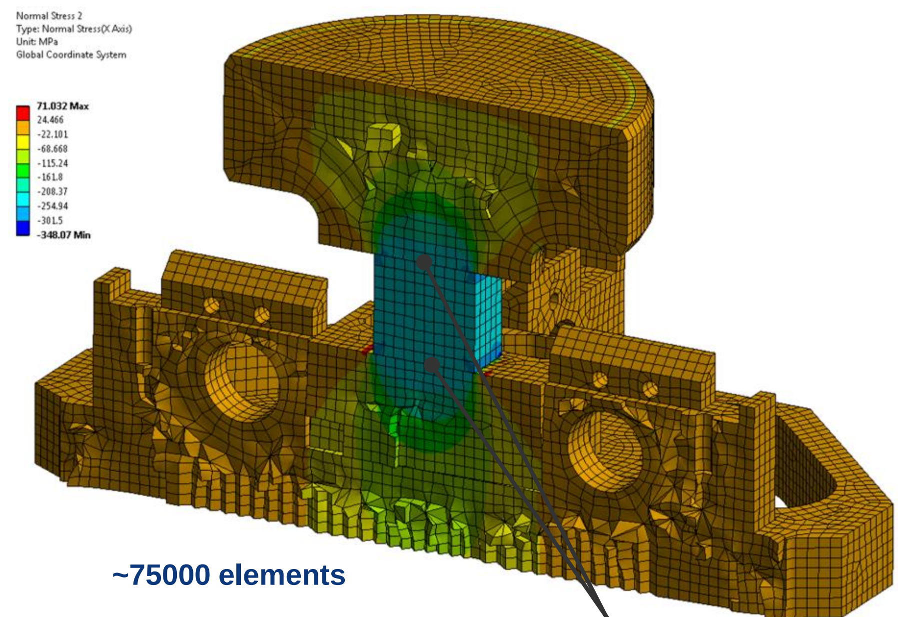
- Max Volume = 32*24*20=15360 [mm^3]
- Min Volume = 34*20*15=10200 [mm^3]

Preliminary Studies - FE analysis

- **FE model**



Force 100 kN
~ 250 MPa expected



~75000 elements

340L Stainless Steel:

- ***ρ*=7.9 kg/dm³**
- ***E*=210 GPa**
- **σ_y=175 MPa**

Sample:

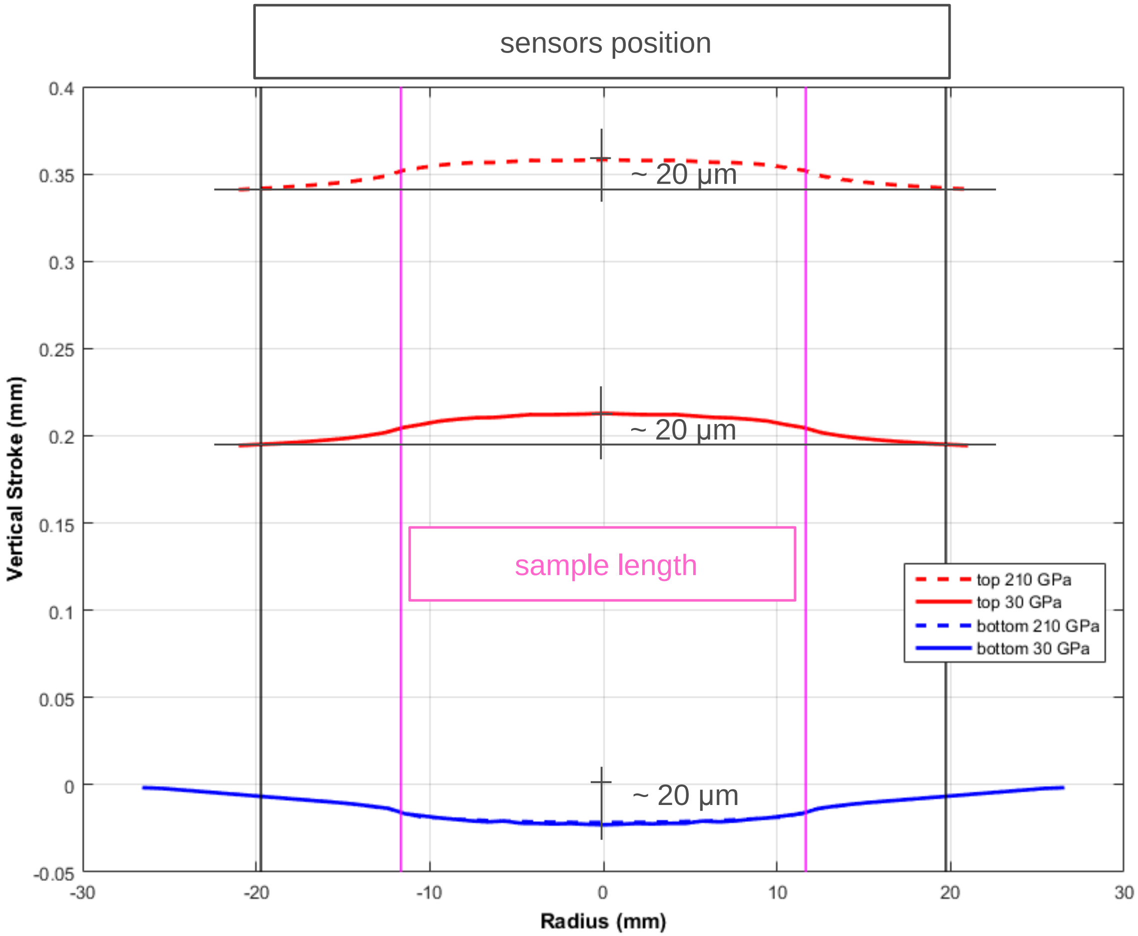
- ***ρ*=5.0 kg/dm³**
- ***E*=30 GPa**

Sample size:

- **L=20 mm**
- **W=20 mm**
- **H=18.9 mm**

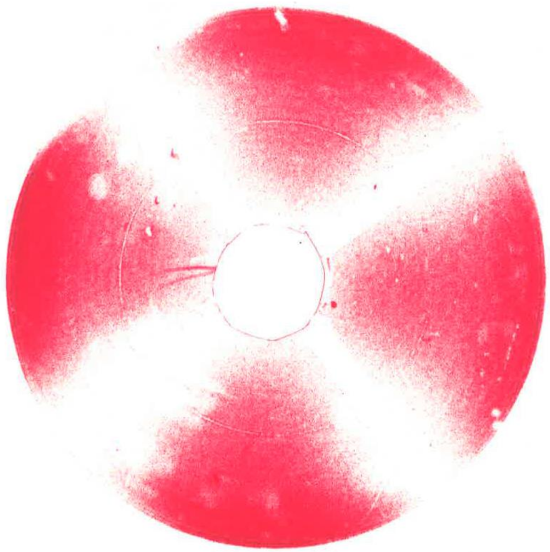
Frictional contacts (0.1)

Preliminary Studies - Profiles deformations - 2

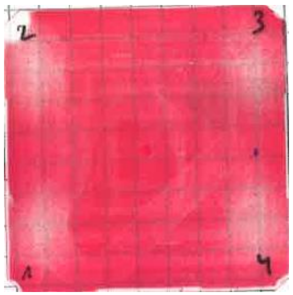


Validation Campaign - Pressure distribution

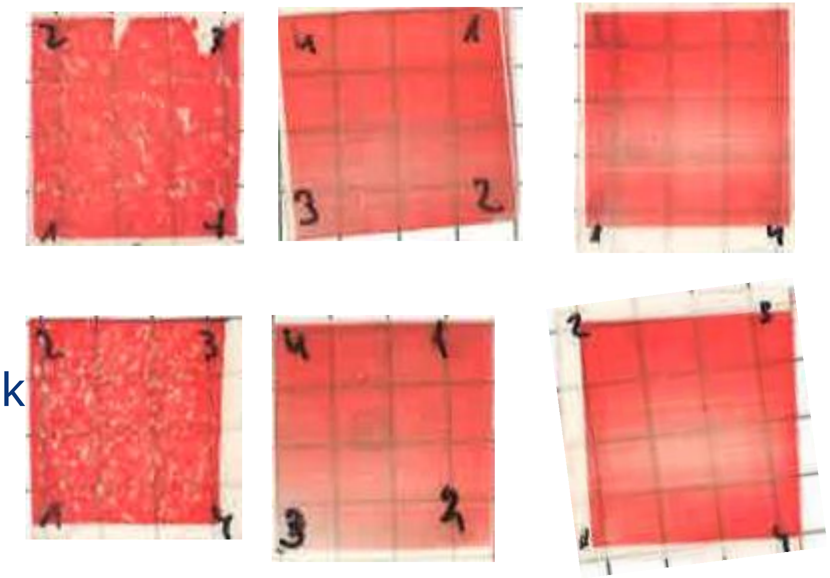
Base-Tooling



Sled-Supporting Block



	G10	Al	Cu
Pusher-Sample			
Sample-S. Block			



- No particular issues on low rigidity samples
- Sample geometry is very relevant for Cu

Validation Campaign - Characterization of the tooling

Test conditions:

- Preload: 20 MPa
- Load rate: 3 MPa/s
- Load program: 3 loading-unloading

Sample Geometries:

- MQXF: Ho=18.7 L=19.98 W=18.85
- 11T: Ho=15 L=15 W=15

	Room Temperature						77K	
	Pressure distribution tests	3 samples 0º, +180º sample	Dismount-Clean	LVDT Calibration	3 samples 0º, +180º sample	Specific Tests	LVDT Calibration	3 samples 0º, +180º sample
G10								
Al								
Cu								

Study of the tooling compliance, repeatability and reproducibility of the measurements.

Validation Campaign – Uncertainty Determination

Uncertainty Budget

Sources of uncertainty	Measurement		Uncertainties				
	Measurement affected	Units	Meas. Uncertainty %	Type	Distribution	Divisor	ci
Loadcell	F	N	0.50%	B	Normal	2	$\frac{H_0}{A_0 \Delta H}$
LVDTs	ε	m	0.3%	B	Normal	2	$\frac{\Delta P H_0}{A_0 \Delta L^2}$
Micrometer Lo	Ho	m	negl	B	Rectangular	1.73205 1	$\frac{\Delta P}{A_0 \Delta H}$
Micrometer Area	A		0.2%		Rectangular	1.73205 1	$\frac{\Delta P H_0}{{A_0}^2 \Delta H}$

$$U_{E_m} = \sqrt{\left(\frac{\partial E}{\partial \Delta P}\right)^2 {U_{\Delta P}}^2 + \left(\frac{\partial E}{\partial H_0}\right)^2 {U_{Ho}}^2 + \left(\frac{\partial E}{\partial \Delta H}\right)^2 {U_{\Delta H}}^2 + \left(\frac{\partial E}{\partial A_0}\right)^2 {U_{A_0}}^2}$$

$$U_{E_m} = \sqrt{\left(\frac{H_0}{A_0 \Delta H}\right)^2 {U_{\Delta P}}^2 + \left(\frac{\Delta P H_0}{A_0 \Delta L^2}\right)^2 {U_{H_0}}^2 + \left(\frac{\Delta P}{A_0 \Delta H}\right)^2 {U_{\Delta l}}^2 + \left(\frac{\Delta P H_0}{{A_0}^2 \Delta H}\right)^2 {U_{A_0}}^2}$$

Where:
ΔP= load increment in the segment considered
A_0= cross section
ΔL= extension increment in the section considered
H_0= gauge length

This leads to an expanded uncertainty of 4 GPa with k=2*

*for the usual sample geometries