Dimensional Changes of Nb_3Sn Conductors During Heat Treatment Using Digital Image Correlation

[1]CEA Paris-Saclay [2]ENS Paris-Saclay

E. Rochepault[1], M. Abdel Hafiz[1,2], H. Felice[1], O. Hubert[2], K. Lavernhe-Taillard[2], C. Lorin[1]

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Objectives

- Develop a new method to visualize deformation field during Heat Treatment cycle (RT – 650 °C – RT)
  → **Adapted to strands, cables, coils**
- Better understand the dimensional changes
  → **Coupling transverse/longitudinal**
- Integrate in tooling design [1]
  → **Minimize coil degradation**

Digital Image Correlation

- Compared to other methods [1-4]:
- ✓ **Valid at 650°C** [5]
- ✓ **Multidirectional** → 3D if stereovision
- ✓ Observe **in-homogenities**
- ✓ Applicable to **different conductors** and geometries

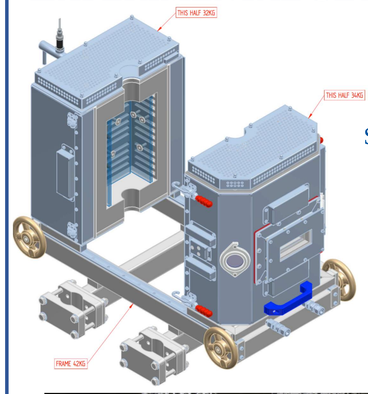
- Displacement field f as a function of time and space:

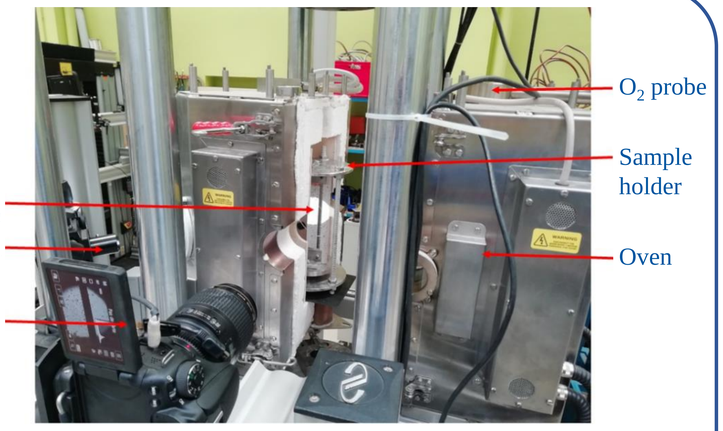
$$f(\vec{x}, t_i) \approx f(\vec{x}, t_0) + \vec{u}(\vec{x}, t_i).\vec{\nabla} f(\vec{x}, t_0)$$

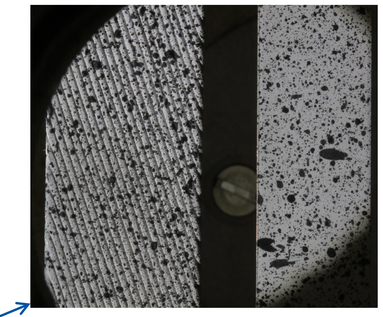
- Need for a **speckle**: max. contrast, no periodicity
  → Boron nitride background
  → + spots of high-temperature black paint

- Correli: **specialized code** developed by LMT

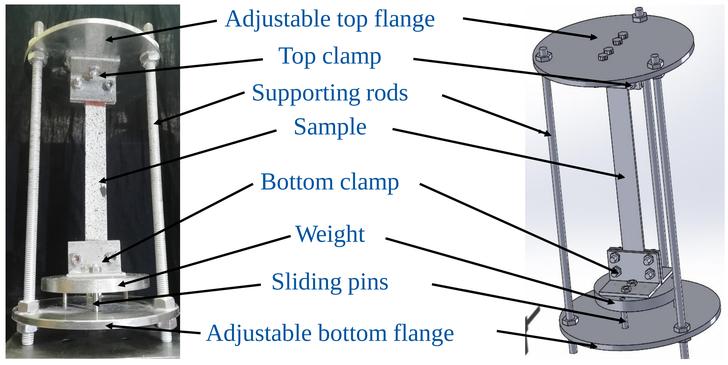
Experimental Setup







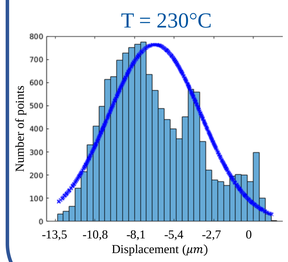
Speckle covering a Rutherford cable and a Cu plate



[1] E. Rochepault et al., IEEE TAS, 2016 [2] D. R. Dietderich et al., ICMC 2007
[3] I. Pong, "Dimensional Changes of Nb3Sn Cables during Heat Treatment", ICMC 2015
[4] M. Michels et al., IEEE TAS, 2019 [5] B. Pan et al., Measurement science and technology 2011

Measured Accuracy

- **At constant T**: all displacements should be 0
  → Measured displacements = accuracy of the method



With Argon flow

[µm]	Average	Std. Dev.
	U_x / U_y	U_x / U_y
230°C	1.6 / 4.4	1.3 / 1.7
415°C	2.5 / -1.6	2.6 / 2.4
650°C	6.0 / 5.3	4.1 / 2.9

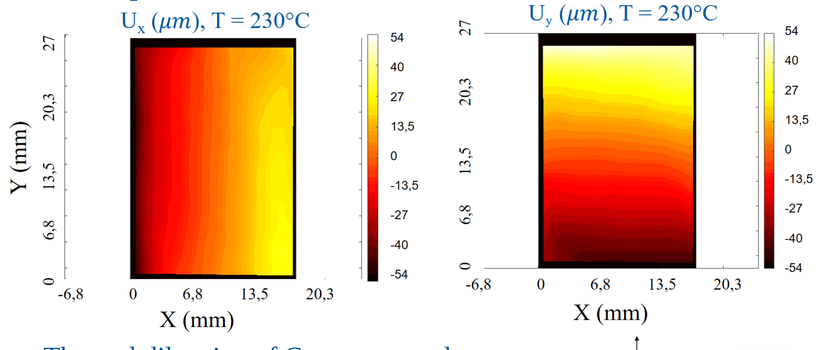
Summary

- **Design of an experimental setup** dedicated to Nb_3Sn Rutherford cables
- Validation of a **speckle adapted to 650°C**
- Measured **accuracy +/-10 µm** ($\pm 5.10^{-4}$)
- **Image quality** guaranteed during HT
- **Calibration of the method** with Cu samples

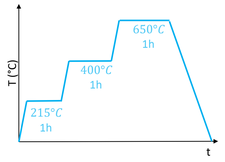
- Improve speckle: **degradation during cool-down**
- Better **characterize temperature field** inside oven
- Ongoing studies on **Nb_3Sn cables**

Calibration on Witness Samples

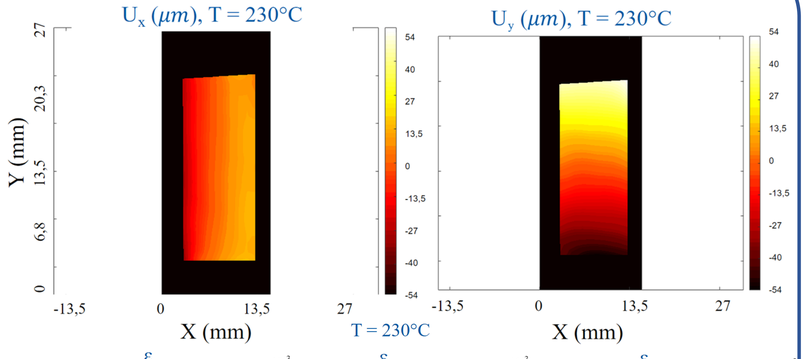
1. Cu plate

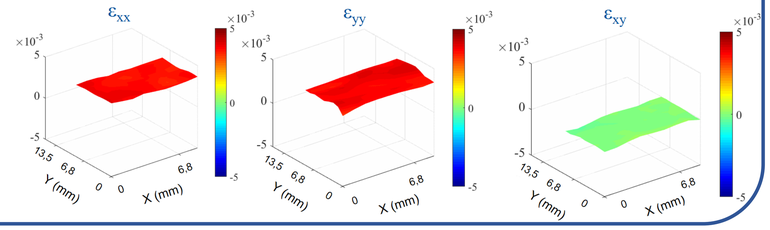


- Thermal dilatation of Cu as expected
- **Homogeneous, isotropic**
- **No shearing mode**



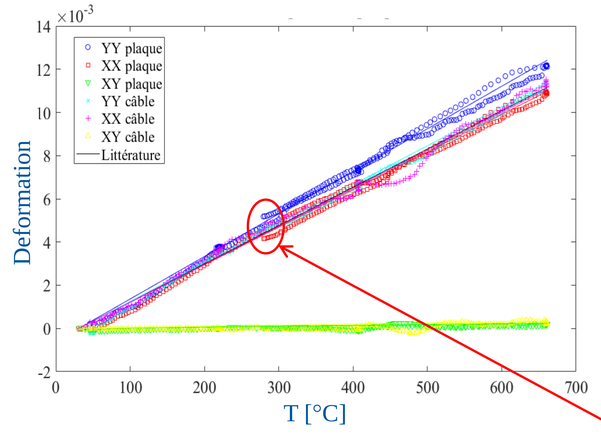
2. Cu Rutherford cable

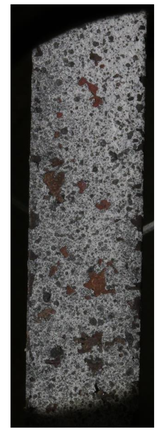




3. Nb_3Sn cable, short HT → ongoing analysis

Results – Cu samples





Degradation of speckle during cool-down

✓ **Behavior matching Cu from literature**