Measurement of Nb_3Sn strand samples during heat treatment with DILATOMETER at NHMFL

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Motivation

- During the reaction process of a Long Nb_3Sn coil (part of the LARP Long Quadrupole R&D) some issues were found:
  - the total length of the outer and inner coil pole parts changed by different amounts
  - the coil had ~1200 lbs of longitudinal tension
- We need experimental data to model and understand this problem
- Modeling of reaction process requires experimental data of all coil components
  - strand elongation/shrinkage after heat treatment
  - cable elongation/shrinkage after heat treatment
  - coil elongation/shrinkage after heat treatment
- We hope that understanding of coil components behaviour at each steps of heat treatment will allow optimize reaction process, tooling and select the best material for the pole

Parameters and computations for strand test

- Calculations for strand sample preparation
  - Compute max. elongation and radial expansion of strand sample during heat treatment (HT)
  - Compute max. elongation of quartz tube for the temperatures range corresponding to HT temperatures

- Parameters and constraints
  - Strand diameter 0.7 mm
  - Total sample length at max. elongation – 50 mm
  - Available quartz tube inner diameter – 1 mm
    - Available quartz tube outer diameter – 3 mm
  - Temperature range set by nominal LQ coil HT

Computations – samples length

- **Compute max. elongation and radial expansion of strand sample during HT**
- **Compute max. elongation of quartz tube for the temperatures range corresponding to HT temperatures**

⇨ The average CTE of quartz tube is ~5.5E-7 when CTE of Nb_3Sn is 1.2E-5 (factor 20),
⇨ The 47 mm quartz tube will expand by ~18 µm for temperature range of 20-650 °C,
⇨ For the same range of temperature, the Nb_3Sn strand sample expands by ~390 µm,
⇨ The Nb_3Sn strand sample may contract during the first part of the HT (annealing)
⇨The radial expansion of Nb_3Sn strand sample was computed to be 6 µm (d_{strand}= 0.7 mm)

The Nb_3Sn sample length has been chosen to be 1 mm longer than the quartz tube since we do not know precisely strand behavior during HT. We would like to avoid the case that strand length will be shorter than quartz tube length. Also we would like to be below allowed max. sample length in dilatometer.

The lengths choice are:

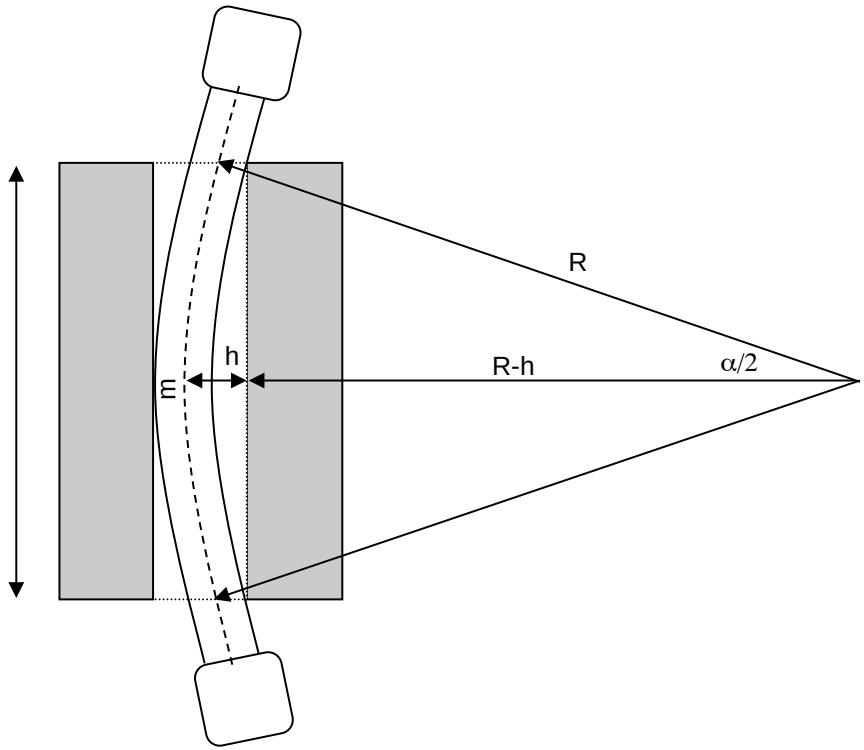
✓ **47 mm of quartz tube**

✓ **48 mm Nb_3Sn strand**

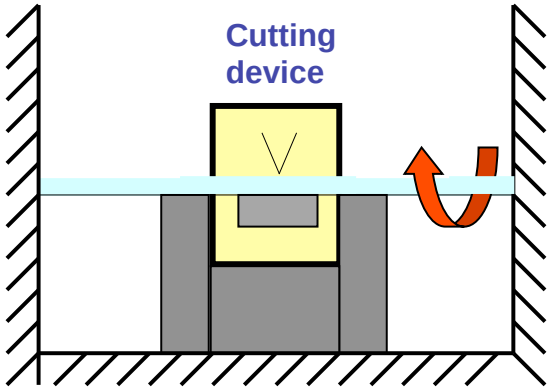
Computations – possible effects

- The ends of the strand are welded to avoid Sn leak from the strand core,
- The diameter of welded ends of the strand sample are larger than strand diameter.
- The max. welded ends diameter was chosen to be < 0.9 mm.
  (From calculations we get radial strand expansion of order of 0.006 mm (d_{strand}=0.7 mm)

⇨ Since $d_{strand} < d_{quartz\ tube}$ (0.7 mm < 1.0 mm)
the strand could bend inside the tube.
⇨ From calculation, the sample length
would shorten by ~5 μm due to the bending effect



Sample preparation



Quartz tube preparation

- ⇨ Small pipe cutting device was used to cut the pipe
- ⇨ Quartz glass (SiO_2) is in amorphous form.
- ⇨ After cutting of required tube length,
  the ends are burnished to obtain flat surface

ideal sample shape

realistic sample shape

- ⇨ Cut a strand sample, longer by 1-2 mm than chosen sample size
- ⇨ Weld the ends of strand
- ⇨ Resize the ends of strands to fit required diameter (< 0.9 mm)
- ⇨ Insert starnd sample inside the quartz tube

Measurements

- Strand sample: Nb_3Sn RRP 54/61 by OST
- Billet #: 9532
- Sample length: 48 mm
- Target heat treatment: see below

⇨ Temperature ramp time to 210°C: 7h 36”
⇨ Heating time at 210°C: 72 h
⇨ Temperature ramp time to 400°C: 7h 36”
⇨ Heating time at 400°C: 48h
⇨ Temperature ramp time to 640°C: 4h 48”
⇨ Heating time at 640°C: 48h
⇨ Cooling time: ~ 48h