

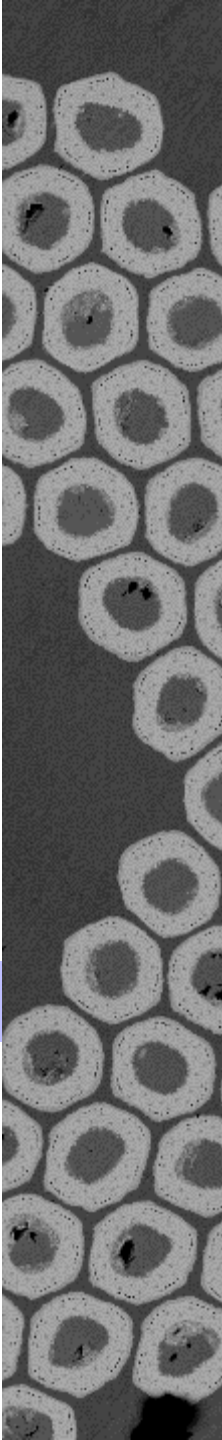
Workshop #2 on

Nb₃Sn technology for accelerator magnets

Pierre MANIL

on behalf of the scientific committee

Paris, 11-12 October 2018



Welcome to Paris

Outline

- Why this workshop *series*?
- Introduction to workshop #2

Outline

- Why this workshop *series*?
- Introduction to workshop #2

Nb₃Sn raises a large variety of questions

- Possible showstoppers:

Cf. workshop^{#1}

- ▶ Heat treatment optimization
- ▶ Brittleness (irreversible degradation...)
- ▶ Series production of strand (unit lengths, procurement strategies)
- ▶ J_c optimization (production methods, Cu/nCu ratio, flux pinning...)
- ▶ Effect of transverse/longitudinal stress/strain
- ▶ Electromagnetic stability (self-field instabilities...)
- ▶ Stress management at the magnet level (**design criteria?**)
- ▶ **Predictivity**: need for *ab initio* approach
- ▶ ...

+ « Side problems »

- ▶ Terminology/concepts not standardized (unhomogeneous literature)
- ▶ Numerical model parameters
- ▶ Difficult *in-situ* observation of the reaction process
- ▶ Heat-treatment-proof tooling
- ▶ Test facilities (need for high field/high pressure)


Intention of the workshop series

- This workshop *series* aims at sharing experience gained worldwide in the field of Nb₃Sn technology for accelerator magnets.
- At the end of the series, the idea is to set-up a **best practice manual** resulting from the discussions having taken place all along the workshops.
- From today, we can evaluate that 3 to 5 workshops could be necessary.
- Workshop^{#1}, held in Madrid last year, has covered:
 - ▶ Mechanical characterization of impregnated conductor
 - ▶ Dimensional changes during heat treatment

Proceedings now available!

Proceedings of workshop^{#1} now available

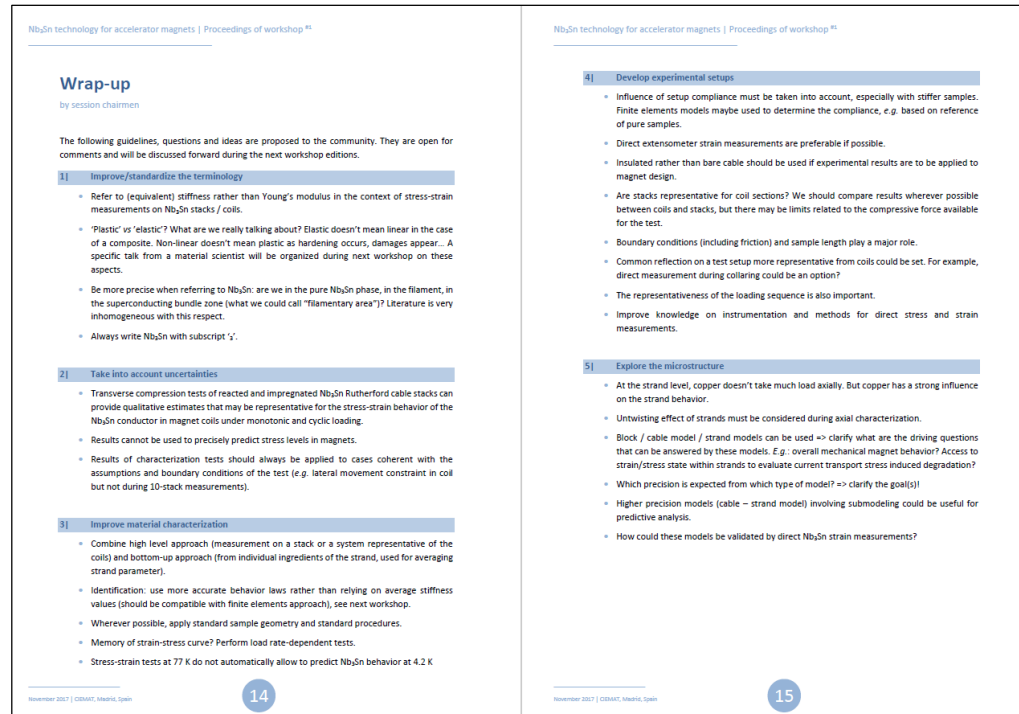
- Short summary of each session, revised by the presenters
- Guidelines from the wrap-up session (open for comments)
- Selected references (by the presenters)
- Professional background of participants



Proceedings of
Workshop^{#1} on
**Nb₃Sn
technology
for accelerator magnets**

16-17 November 2017
CIEMAT, Madrid, Spain

Edited by
Maria Durante, H el ene Felice, Pierre Manil @ CEA Paris-Saclay
Bernardo Bordini, Paolo Ferracin, Friedrich Lackner @ CERN



Nb₃Sn technology for accelerator magnets | Proceedings of workshop^{#1}

Wrap-up

by session chairmen

The following guidelines, questions and ideas are proposed to the community. They are open for comments and will be discussed forward during the next workshop editions.

1] Improve/standardize the terminology

- Refer to [equivalent] stiffness rather than Young's modulus in the context of stress-strain measurements on Nb₃Sn stacks / coils.
- "Plastic" vs "elastic"? What are we really talking about? Elastic doesn't mean linear in the case of a composite. Non-linear doesn't mean plastic as hardening occurs, damages appear... A specific talk from a material scientist will be organized during next workshop on these aspects.
- Be more precise when referring to Nb₃Sn: are we in the pure Nb₃Sn phase, in the filament, in the superconducting bundle zone (what we could call "filamentary area")? Literature is very inhomogeneous with this respect.
- Always write Nb₃Sn with subscript 's'.

2] Take into account uncertainties

- Transverse compression tests of reacted and impregnated Nb₃Sn Rutherford cable stacks can provide qualitative estimates that may be representative for the stress-strain behavior of the Nb₃Sn conductor in magnet coils under monotonic and cyclic loading.
- Results cannot be used to precisely predict stress levels in magnets.
- Results of characterization tests should always be applied to cases coherent with the assumptions and boundary conditions of the test (e.g. lateral movement constraint in coil but not during 10-stack measurements).

3] Improve material characterization

- Combine high level approach (measurement on a stack or a system representative of the coils) and bottom-up approach (from individual ingredients of the strand, used for averaging strand parameter).
- Identification: use more accurate behavior laws rather than relying on average stiffness values (should be compatible with finite elements approach), see next workshop.
- Wherever possible, apply standard sample geometry and standard procedures.
- Memory of strain-stress curve? Perform load rate-dependent tests.
- Stress-strain tests at 77 K do not automatically allow to predict Nb₃Sn behavior at 4.2 K

Nb₃Sn technology for accelerator magnets | Proceedings of workshop^{#1}

4] Develop experimental setups

- Influence of setup compliance must be taken into account, especially with stiffer samples. Finite elements models maybe used to determine the compliance, e.g. based on reference of pure samples.
- Direct extensometer strain measurements are preferable if possible.
- Insulated rather than bare cable should be used if experimental results are to be applied to magnet design.
- Are stacks representative for coil sections? We should compare results wherever possible between coils and stacks, but there may be limits related to the compressive force available for the test.
- Boundary conditions (including friction) and sample length play a major role.
- Common reflection on a test setup more representative from coils could be set. For example, direct measurement during collaring could be an option?
- The representativeness of the loading sequence is also important.
- Improve knowledge on instrumentation and methods for direct stress and strain measurements.

5] Explore the microstructure

- At the strand level, copper doesn't take much load axially. But copper has a strong influence on the strand behavior.
- Untwisting effect of strands must be considered during axial characterization.
- Block / cable model / strand models can be used => clarify what are the driving questions that can be answered by these models. E.g.: overall mechanical magnet behavior? Access to strain/stress state within strands to evaluate current transport stress induced degradation?
- Which precision is expected from which type of model? => clarify the goal(s)
- Higher precision models (cable - strand model) involving submodeling could be useful for predictive analysis.
- How could these models be validated by direct Nb₃Sn strain measurements?

November 2017 | CIEMAT, Madrid, Spain

14

November 2017 | CIEMAT, Madrid, Spain

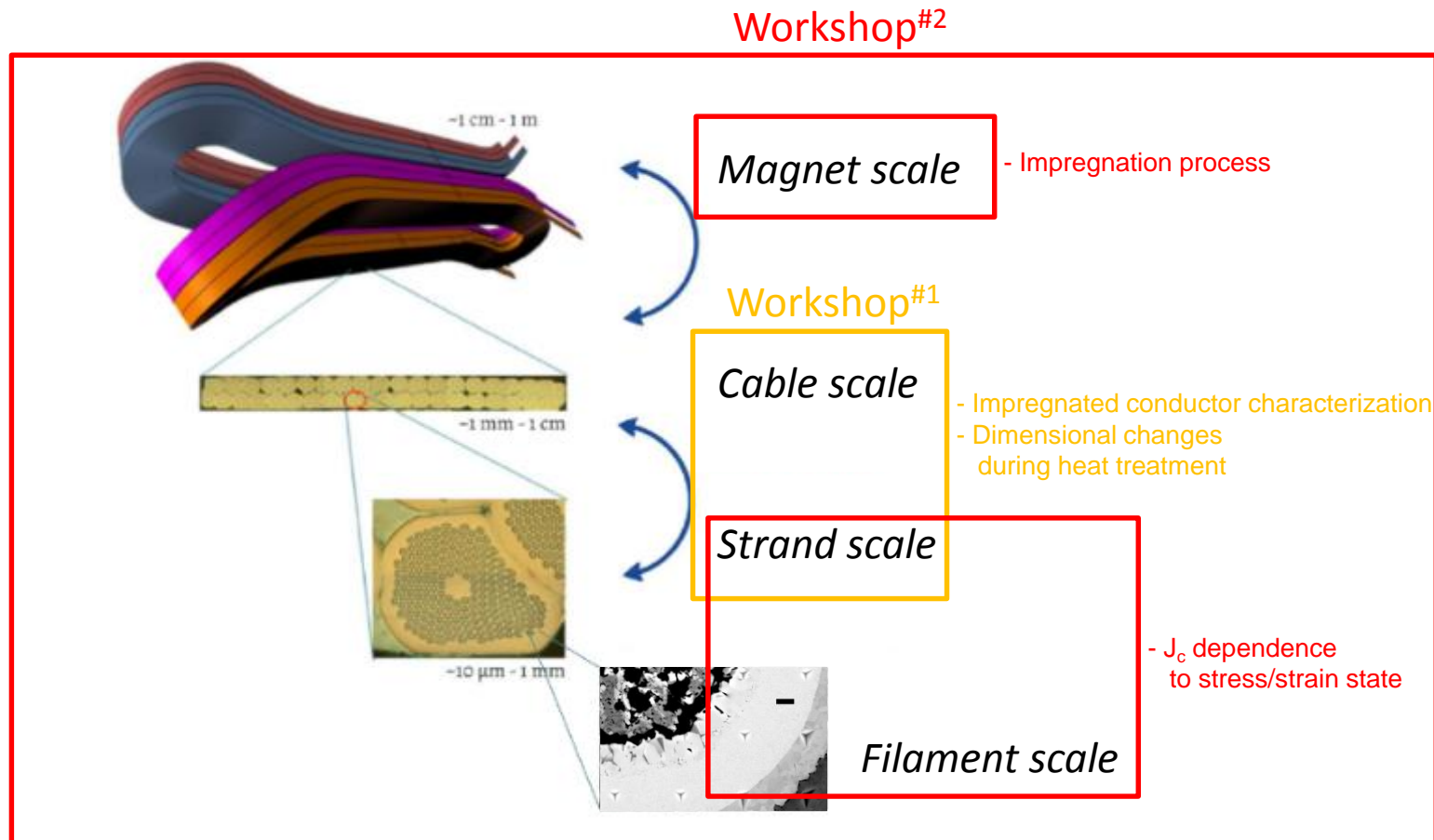
15

Outline

- Why this workshop *series*?
- Introduction to workshop #2

Nb₃Sn raises multiscale questions

- **Macroscopic** behaviour of the magnet is controlled at the **microstructure** level



- Material aspects / Characterization

Agenda

Today 11 October

- **Session #1 | Coil technology – Impregnation process / Influence of process on coil dimensions**
- **Session #2 | Mechanical aspects / characterization**

Tomorrow 12 October

- **Session #3 | Critical current dependence to stress/strain state**
- **Wrap-up session every day**

New! External points of view

- We identified during last workshop that it would be interesting to confront our vision with other views
- 3 speakers ‘out of the accelerator magnets box’ have been invited
 - ▶ **Véronique AUBIN** (material scientist @ CentraleSupélec, France) will discuss the possible contribution of a multi-scale approach to model and characterize our superconductors
 - ▶ **Michel GREDIAC** (material scientist @University of Clermont, France) present the grid method for *in situ* in-plane displacement measurement and its application on a detector magnet conductor
 - ▶ **Luigi MUZZI** (researcher @ENEA Italy) will discuss strain effects on Nb₃Sn cable-in-conduit conductors for fusion magnets
 - ▶ External contribution planned about impregnation has unfortunately been cancelled

64 participants (53 on-site)

CERN 16 CEA 15 INFN 4 CIEMAT 1 ENEA 2 IFJ 1 PSI 1 Twente 1

- + academic newcomers:
- CentraleSupélec
 - University of Clermont
 - Udine university

- + 2 companies
- Bruker
 - Varian



Practical | Organizing committee

- Organization

- ▶ Martine Baldini, Séverine Candau, Sophie Durand, Armelle Le Noa, Natacha Lomet, Florian Paget @ CEA Paris-Saclay
- ▶ On-site support available

- Financial support

- ▶ CEA Paris-Saclay / IRFU (Nicolas ALAMANOS + DACM + DIS)
- ▶ HL-LHC and FCC projects (Lucio ROSSI, Michael BENEDIKT)

- Scientific committee

- ▶ Bernardo Bordini, Paolo Ferracin, Friedrich Lackner @ CERN
- ▶ Maria Durante, Hélène Felice, Pierre Manil @ CEA Paris-Saclay

Practical | Wifi connection

- Espace St Martin is equipped with Wifi network
- Login: ESM-PUBLIC
- Password: wifi.esm

Practical | Catering

- Two coffee breaks per day are planned in the middle of the morning and afternoon sessions.
- Lunches are not provided. Many restaurants are located around Espace St Martin.
A selection of recommended addresses is available in your participant folder.
- The organizers are delighted to invite you to a workshop dinner tonight at 8pm at the restaurant Le Train Bleu.
Registration is mandatory.
Directions will be provided at the end of the afternoon session.

In your workshop folder, you will find...

- Agenda of the workshop
- List of participants
(including professional background, domain of expertise, interest in the workshop topic)
- Proceedings of workshop^{#1}
- Wifi connection details
- Selection of restaurants for lunch (with map)
- Directions to the workshop dinner

Guidelines to the presenters

- Each talk slot is 30' long, firm (+10' for external points of view)
- Besides the scientific results that you wish to present, please keep significant time to present the experimental **setups and procedures**.
- Do not hesitate to present **negative or partial results** if you think they can bring constructive input.
- Please take some time at the end of your talk to conclude on the problems and success encountered and try to draw conclusions (even negative) that could **serve the whole community**.

Guidelines to the attendees

- Ask questions, share your own experience
- Wrap-up sessions (one per day) are an additional opportunity to discuss. Please stay with us for this important session!
- For remote participants:
 - ▶ Vidyo room is accessible on the Indico page of the workshop
 - ▶ **One connection point per Institute is preferable!**
 - ▶ Please **switch off your microphone** when not needed
 - ▶ Chairmen will open the session for distant questions at the end of each talk
 - ▶ Backup option only: questions can be sent by email to the chairmen during the session
- After the workshop: share your comments about the proceedings





Thank you