Nb_3Sn Strand Development in EU: Strand Procurement and R&D for ITER Conductor Optimisation

Alexander Vostner (EFDA CSU - Garching)

Outline:

- Current status of the European strand procurement action
- Scheduled R&D work for the ITER conductor optimisation
- Availability of advanced strands

EU Strand Qualification -

Motivation

- The reduced temperature margin design criteria from ITER-EDA to ITER-FEAT is not supported by the model coil results extrapolation (TF coil more critical, for CS coil $J_c \sim 700$ A/mm^2 sufficient)

- Nb_3Sn strands with high current densities ($J_c \sim 800$ A/mm^2) have already been produced for KSTAR on industrial scale in the USA (IGC) and in Japan (Mitsubishi).

EU Strand Qualification Programme - **Objectives**

- Demonstrate the industrial production of Nb_3Sn strands with performances satisfying the updated ITER requirements: minimum required quantity 100 kg (per supplier)
- Assess candidate suppliers and their manufacturing capabilites, processes and QA procedures
- Produce sufficient amount of strand for cabling and jacketing of prototype lengths to be used for sub size and full size samples of conductors and joints

Tender Nb_3Sn Strand Specification

First Draft

Outer diameter of the strand	**0.81 mm** ±3 μm
Effective filament diameter	< 50 μm (typical)
Strand pitch	< **20 mm**
Hard Cr-coating	2 μm +0.5 μm / –0 μm
Non-Cu critical current density (at 12 T, 4.2 K, 0.1 μV/cm)	Min. guaranteed: **800 A/mm^2** Target value: 1100 A/mm^2
Non-Cu hysteresis losses on a ±3T field cycle (Flux jumping not acceptable)	< **1000 kJ/m^3**
n-value at 12 T and 4.2 K	> 20
nτ time constant	< 5 ms
RRR after reaction heat treatment	> 100
Cu:non-Cu ratio	1.0 ± 0.05
Minimum acceptable length of strand	1.5 km or multiples (target value > 3 km)
Heat treatment cycle	Unified cycle, as proposed by ITER IT

Final Version

Outer diameter of the strand	**0.81 mm** ±3 μm
Strand pitch	< **20 mm**
Hard Cr-coating	2 μm +0.5 μm / –0 μm
Overall critical strand current (at 12 T, 4.2 K, 0.1 μV/cm)	Min. guaranteed: **200 A** Target value: **280 A**
Overall strand hysteresis losses (on a ±3T field cycle)	< 500 kJ/m^3
n-value at 12 T and 4.2 K	> 20
RRR after reaction heat treatment	> 100
Cu:non-Cu ratio	**0.9 – 1.5**
Minimum acceptable length of strand	> 1.5 km

EU Strand Qualification Programme - **Call for Tender**

6 Companies:

- Alstom Power Conversion, France
- Europa Metalli S.p.A., Italy
- Outokumpu Poricopper Oy Superconductors, Finland
- Oxford Instruments, Superconductivity, United Kingdom
- ShapeMetal Innovation BV, The Netherlands
- Vacuumschmelze GmbH & Co. KG, Germany

  (now European Advanced Superconductors)

EU Strand Procurement Action - **Status and Schedule**

- ✓ Preparation work for the call-for-tender action: January 2003
  (Technical specification, definition of the list of relevant companies, ...)
- ✓ Launching of the tender for the strand procurement: February 2003
  (Six companies were addressed)
- ✓ Company reply (all six have replied): April 2003
- ✓ Technical evaluation: July 2003
- ➢ Placing of contracts: September 2003
- ➢ Strand production from six to nine months
  - First strand delivery: December 2003
  - All strand delivery (estimated): June 2004

SCHEDULED R&D ACTIVITIES FOR THE ITER CONDUCTOR OPTIMISATION

R&D Activities for ITER Conductor Optimisation - **Single Strand**

Cross checking of formal qualification

includes: -) field dependence of J_c including n-value at 4.2 K
-) hysteresis losses
-) strand layout (twist pitch, Cu:non-Cu ratio, …)

Full characterisation

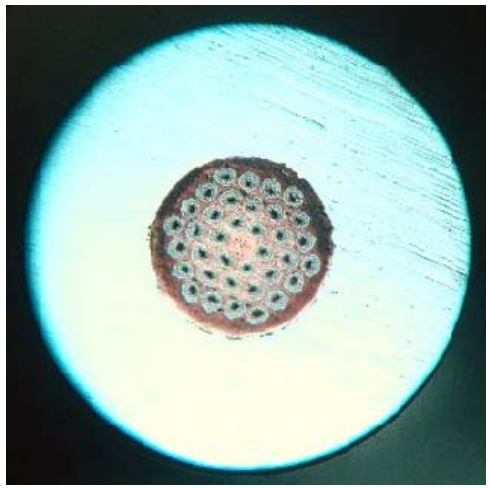
Determination of the field (5 to 15 T), temperature (4.2 to 10 K) and strain (-1.5 to 0.7 %) dependence of J_c and n-value of at least 3 selected strands

Preliminary time schedule:

Launching of the Expression of Interest:	September 2003
Association reply:	October 2003
Placing of contracts:	October 2003
All measurements:	November 2004

R&D Activities for ITER Conductor Optimisation - **Bending Strain on Single Strand**

Assessment of the ratio between the strand twist pitch and the current transfer length of single strands jacketed in stainless steel tubes:



- Jacketed strand from 2.04 mm die
- Available dies for bulk can be used
- Change of jacket thickness due to drawing process negligible

Preliminary time schedule:

Launching of the Expression of Interest:	September 2003
Association reply:	October 2003
Placing of contracts:	October 2003
All measurements:	October 2004

R&D Activities for ITER Conductor Optimisation - **Sub Size Samples**

Parametric study of strand and conductor relevant parameters (void fraction, segregated Cu, twist pitch, current transfer length, ...) on sub cable samples (9, 36, 108 or 144 strands):

- Samples to be measured in a facility were tensile strain can be applied to address the important issues and to get quantification of these effects.
- 2 identical samples for backup
- Single jacketed strands as first step of the parametric study part of test program

Issues \ Cable	3 X 3	3 X 3 X 4	3 X 3 X 3 X 4
Thermal and bending strain	**6** (0, 1 and 2 Cu strands in 1st triplet)	**6** (0,1 and 2 Cu strands in 1st triplet)	
Cable performance			**4** (1 and 2 Cu strands in 1st triplet)*
Void fraction		**4** (25% and 45%)	
Twist pitch		**2** (35/65/110 mm)	
Current transfer	**2** (no Cr coating)		

R&D Activities for ITER Conductor Optimisation - **Sub Size Samples**

Testing of sub size samples to assess the influence of strand production process on residual strain after heat treatment of jacketed conductors:

Cable / Issues	3 X 3 X 4	3 X 3 X 3 X 4
Thermal and bending strain	**2** (reference design)	
Cable performance		**2** (2 Cu strands in 1st triplet)

- 2 identical samples for backup

➢ **Preliminary time schedule**:

Launching of the Expression of Interest:	August 2003
Association reply:	August 2003
Placing of contracts:	September 2003
First measurements:	May 2004
All measurements:	October 2004

R&D Activities for ITER Conductor Optimisation - **Full Size Samples**

- Cabling and jacketing of full size samples from the selected strands according to the chosen ITER conductor design (different conductor layouts due to four different legs)

- Manufacture and testing of full size joint samples at SULTAN facility

- **Preliminary time schedule**:

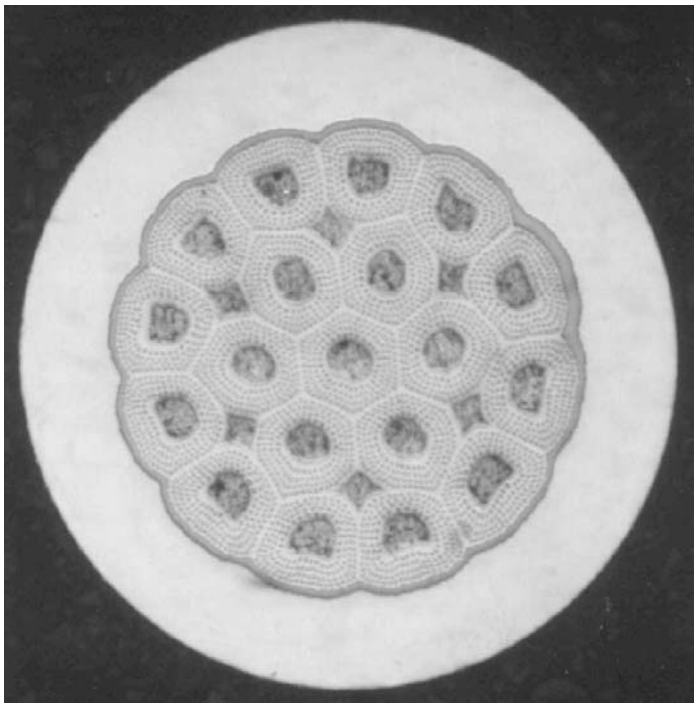
Launching of Expression of Interest for sample manufacture :	September 2003
Association reply:	October 2003
Placing of contracts:	February 2004
Sample manufacture:	October 2004
Testing of FSCS:	End 2004/Beginning 2005

AVAILABILITY OF

ADVANCED Nb_3Sn STRANDS

Available Advanced Nb_3Sn Strands - **Internal-tin**

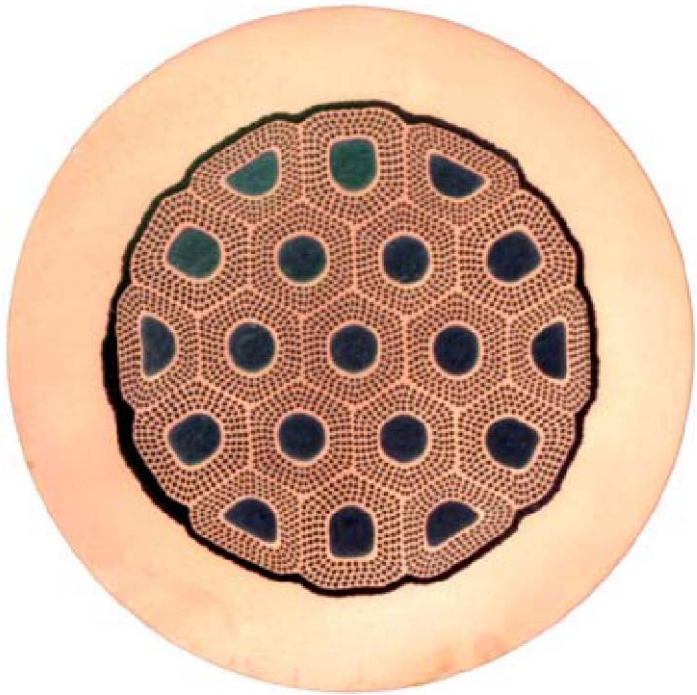
Outokumpu (ASC 2002)



Non-Cu J_c: 850 - 900 A/mm^2

Non-Cu hysteresis losses: < 300 kJ/m^3

Oxford Instruments (EUCAS´03)

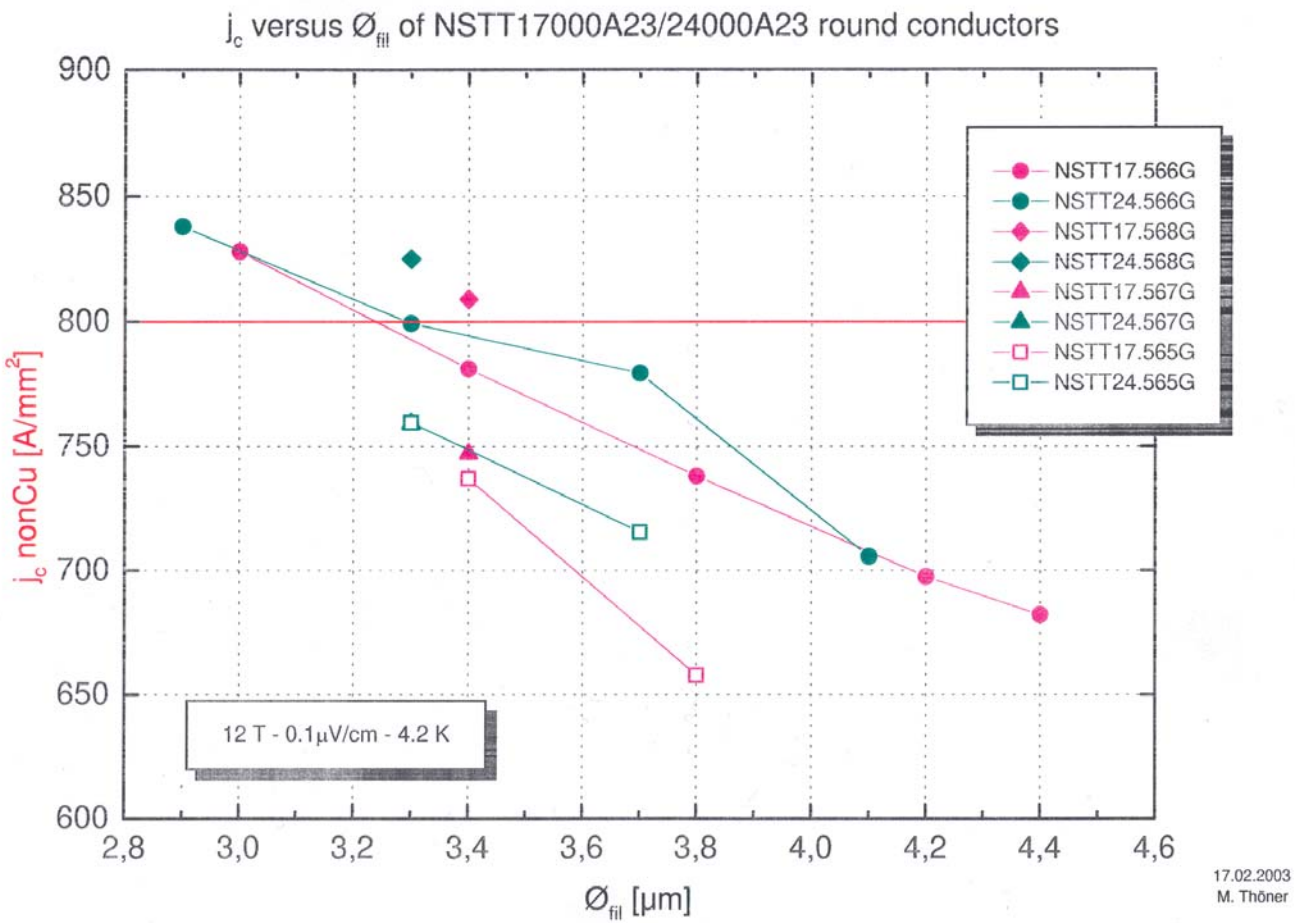


Non-Cu J_c: 1200 A/mm^2

Overall hysteresis losses: < 400 kJ/m^3

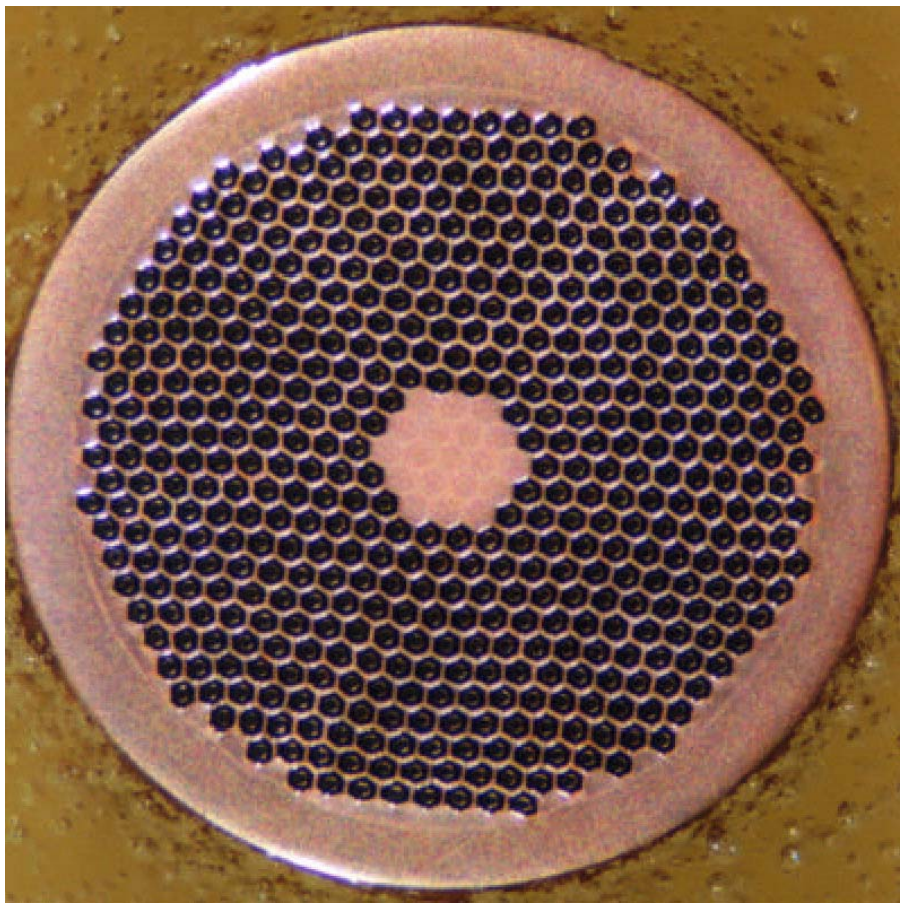
Available Advanced Nb_3Sn Strands - **Bronze**

European Advanced Superconductors



Available Advanced Nb_3Sn Strands - **PIT**

SMI



- Binary type
- 504 filaments
- Heat treatment:
  650 – 675 °C for 30 to 60 hrs
- Price (larger quantities):
  700 €/kg
- Non-Cu J_c: 1300 A/mm^2
- Overall hysteresis losses: 600 kJ/m^3

ITER Superconducting Strand Procurement - **Required Production and Schedule**

NbTi

- Total amount: 245 t
- Scheduled annual production: 90 - 100 t

Existing worldwide production capacity far above the ITER demand

Nb_3Sn

- Total amount (CS and TF coils): 520 t (steel option)
- Required annual production: 175 t (130 t for TF, 45 t for CS)

*Provided that at least 6 companies producing advanced Nb_3Sn strands are available worldwide a production capacity of about **22 t/a** per company would be sufficient to cover the required amount of strand for the TF coils*

CONCLUSIONS

EU Strand Procurement Action

- Our intention to qualify EU companies for higher performance Nb_3Sn strands has been positively accepted by industry: All 6 companies are prepared to design and produce Nb_3Sn strands with enhanced properties

R&D Activities for ITER Conductor Optimisation

- Single strands: All required contracts in pipeline.
- Sub size samples: Contract for testing placed, benchmarking under way, contracts for sample manufacture in pipeline
- Full size samples: Monitoring contracts with Associations under way, industrial contracts

Availability of advanced Nb_3Sn Strands

- Nb_3Sn strands for fusion applications with improved Jc´s and moderate losses are already existing and can be produced in larger quantities