August 2007

STATUS OF NED CONDUCTOR DEVELOPMENT*

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Abstract
This paper presents a brief status report of the ongoing Nb_3Sn conductor R&D carried out within the framework of the Next European Dipole (NED) activity.

1. INTRODUCTION

The Next European Dipole (NED) is a Joint Research Activity (JRA) of the Coordinated Accelerator Research in Europe (CARE) project, funded under the auspices of EU-FP6 Research Infrastructures. The aim of the NED/JRA is to promote the development of Nb_3Sn accelerator magnet technology in Europe for LHC upgrade and beyond and to complement the vigorous efforts carried out in the USA within the framework of the US-LHC Accelerator Research Program (LARP). NED is articulated around three technical Work Packages: (1) Thermal Studies and Quench Protection (TSQP), (2) Conductor Development (CD) and (3) Insulation Development and Implementation (IDI). The core of the activity is the CD work package which absorbs ~70% of the 979 k€ provided by the EU. In spite of the limited funding, which was capped to 25% of the initial request, NED has been very actively supported by 8 institutes: CCLRC/RAL in the UK, CEA in France, CERN, CIEMAT in Spain, INFN-Genoa and INFN-Milan in Italy, Twente University in The Netherlands and Wroclaw University of Technology in Poland. The overall coordination is ensured by CEA, while CERN is more specifically in charge of coordinating the CD work package. NED was launched in January 2004 and is expected to be completed in the first semester of 2008.

2. NED CONDUCTOR DEVELOPMENT

2.1 Overview

The NED conductor development is carried out through two industrial contracts handled by CERN. The two contractors are: Alstom/MSA, in France, and ShapeMetal Innovation (SMI) in the Netherlands, which has now been acquired by European Advanced Superconductors (EAS) in Germany. The ambitious conductor specifications were derived by CERN and are aimed at manufacturing a Nb_3Sn Rutherford-type cable for a 88-mm-aperture, 13-to-14 –T bore field (~15-T conductor peak field) dipole magnet model. Salient NED wire parameters are summarized in Table 1 and are compared to LARP and ITER wire specifications. An additional requirement is that the billet size should exceed 50 kg in view of industrial production scale-up.

2.2 Conductor Layout

Alstom/MSA and SMI are investigating two different Nb_3Sn wire manufacturing processes: Internal Tin (IT) for Alstom/MSA and Powder-In-Tube (PIT) for SMI.

* This work was supported in part by the European Community–Research Infrastructure Activity under the FP6 "Structuring the European Research Area" program (CARE, contract number RII3-CT-2003-506395).

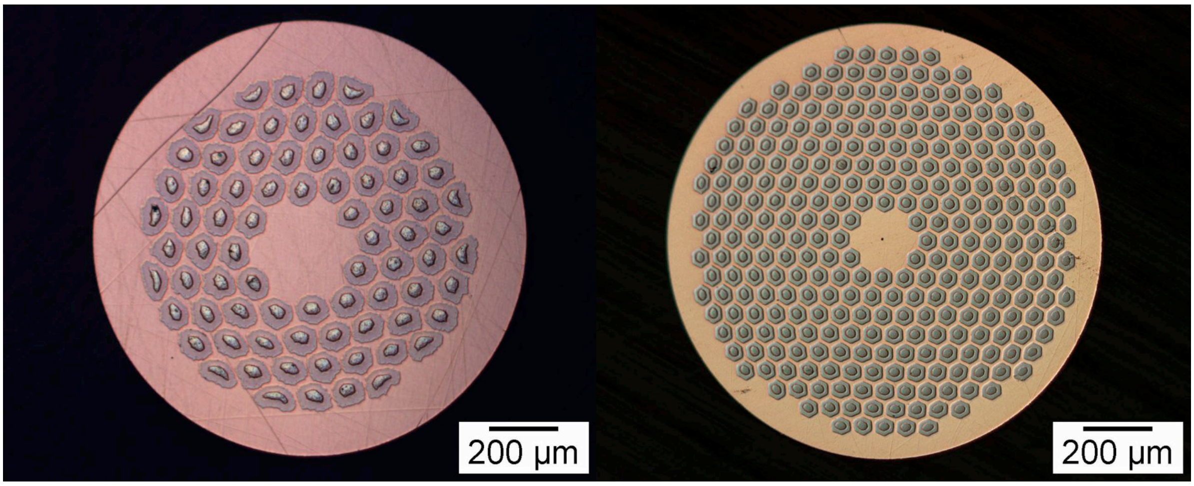

Figure 1. Cross-sectional views of wires developed within the framework of the CARE/NED activity: (a) Internal Tin wire produced by Alstom/MSA (left) and (b) Powder-In-Tube wire developed by SMI (right).

	NED	LARP	ITER
Diameter (mm)	1.250	0.7	0.820
Eff. Filament Diameter (µm)	< 50	< 70	
Cu-to-non-Cu ratio	1.25	1.0	1.0
Non-Cu J_C at 4.2 K and 12 T (A/mm^2)	3000	> 2400	800-900
I_C at 4.2 K and 12 T (A)	1636	> 500	> 210
RRR (after heat treatment)	> 200	> 100	> 100

Table 1. Salient NED wire parameters compared to LARP and ITER wire specifications.

In the Internal Tin process, the final stage billet from which the wire is drawn-down, is made of a few tens of sub-elements embedded in a pure copper matrix, as shown in Figure 1(a). The sub-elements themselves are made up of a few hundreds of Nb or Nb–Ta rods embedded in a copper matrix and arranged in concentric circles around a tin pool. The sub-elements are surrounded by individual Nb or Nb/Ta barriers that prevent tin leakage in the outside copper. The Nb_3Sn phase is precipitated by heat-treating the wire (typically at 660 °C for 50 to 100 hours in a vacuum or in a flow of argon gas). During heat treatment, the tin of the pools diffuses into the copper matrix of the sub-elements, which turns into bronze and reacts with the Nb or Nb–Ta filaments to form Nb_3Sn.

In the Powder-In-Tube process, the final stage billet is made of a few hundreds of tubes embedded in a pure copper matrix, as shown in Figure 1(b). The tubes themselves are made up of Nb or Nb–Ta and are filled up with a highly densified $NbSn_2$ powder mixed with Sn and Cu powders. During heat treatment, the powder reacts with the inner wall of the Nb or Nb–Ta tubes and forms a Nb_3Sn layer which grows outwardly, eventually leaving a small outer sheath of un-reacted Nb or Nb–Ta that prevents tin poisoning of the surrounding copper.

2.3 Recent Results

During the R&D phase of the contract, Alstom/MSA has concentrated in resolving workability issues to produce sub-elements of the desired geometry and to restack them into a final-stage billet. One of the R&D milestones was the production of a 1.25-mm wire, including 78 sub-elements with a diameter of 85 µm (Fig. 1(a)). This wire achieved a critical current of ~740 A at 4.2 K and 12 T, corresponding to a non-copper critical current density of ~1500 A/mm^2, which are the values it was designed to achieve. The next step for Alstom/MSA is to produce a similar wire, but with a non-copper critical current density of 2500 A/mm^2. The new wire is expected in September 2007.

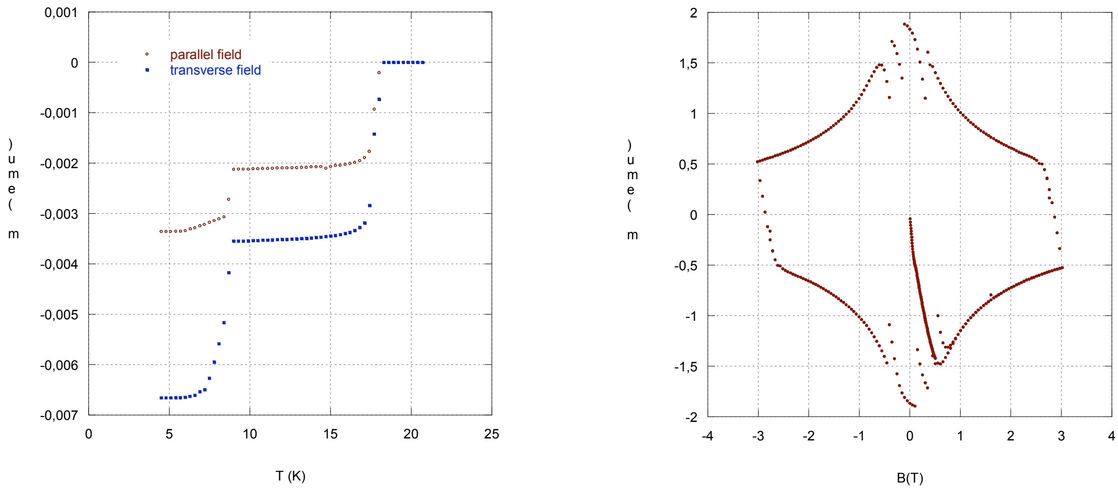

Figure 2: Magnetization measurements on SMI/NED wire: (a) as a function of temperature (left) and (b) as a function of field (right; courtesy of P. Fabbricatore and M. Greco, INFN-Genoa, C. Ferdeghini, INFM-Genoa and U. Gambardella, INFN-Frascati).

In the meantime, SMI has succeeded in producing a 1.26-mm wire, including 288 tubes with a diameter of 50 μm, which achieved a critical current of ~1400 A at 4.2 K and 12 T (corresponding to a non-copper critical current density of ~2500 A/mm^2), thus, fairly close to the target specification (Fig. 1(b)). Furthermore, magnetization measurements performed as a function of temperature (Fig 2(a)) and of field (Fig. 2(b)) have confirmed that the effective filament diameter was ~50 μm (the outer diameter of the shielded volume associated with reacted Nb_3Sn is estimated around 44 μm, while the one associated with the outer sheath of un-reacted Nb is 55 μm). These values are in good agreement with micrographic observations. Finally, it was also verified that the stability current was in excess of 2000 A for field ramps at 0.3 T/min in the 0-to-4 T range. This high stability current value and the limited number of flux jumps observed on Fig. 2(b) demonstrate the wire stability against flux jumps. The high amperage and the fine filament size achieved on the SMI/NED wire are unprecedented at this current density level and set a world record.

The next step for SMI was the production of a large Rutherford-type cable for NED-like magnets so as to assess the level of cabling degradation. Cabling trials were carried out at Lawrence Berkeley National Laboratory (LBNL) at the end of June 2007. The number of strands was 40 and a few parameters like the cable width and the cable mid-thickness were varied as summarized in Table 2. In total, four cable lengths were produced (Fig. 3). The first wire cross-sections near the thin edge of the cable show slight and reasonable shear deformations of the filaments. Critical current measurements on extracted wires are expected in September 2007. If the degradation is small, SMI will be given the go-ahead for final wire and cable production.

Number of strands	40
Finished length (m)	1.8–2.8
Av. Mid-thickness (mm)	2.285–2.317
Av. Width (mm)	26.922–26.988
Av. Keystone angle (^{o})	0.392–0.415
Pitch length (mm)	150–191

Table 2: Salient parameters of Rutherford-type cables produced by LBNL with SMI/NED wire.

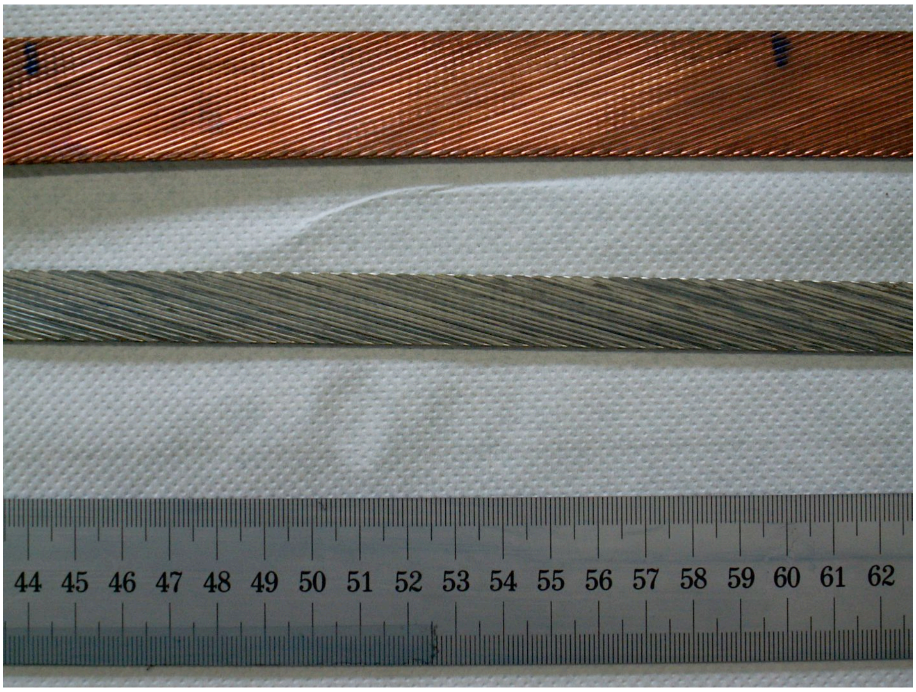

Figure 3: Photo of a 40-strand Rutherford-type cable produced by LBNL with SMI/NED wire (top) compared to a 28-strand LHC inner layer cable (bottom).

3. CONCLUSION

The two Nb_3Sn wire manufacturers contracted by CERN to develop NED conductors have achieved significant progress. One of them is in the final stages of R&D while the other one is ready to start production, pending cabling degradation assessment. A subset of NED partners (CCLRC/RAL, CEA and CERN) has now started the design and manufacture of Short Model Coils enabling the tests of long conductor lengths in a coil environment while the whole collaboration is getting ready to support CERN in the launching of the ambitious high field accelerator magnet R&D program included in the so-called “white paper proposal” recently approved by the CERN council.