STATUS OF NED CONDUCTOR DEVELOPMENT

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***Abstract* -This paper presents a brief review of the ongoing Nb_3Sn conductor R&D carried out within the framework of the Next European Dipole (NED) activity and reports on the manufacture of the first prototype of the largest Nb_3Sn Rutherford-type cable ever designed.**

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I. INTRODUCTION

The Next European Dipole (NED) is a Joint Research Activity (JRA) of the Coordinated Accelerator Research in Europe (CARE) project [1], 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 [2] 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 in 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 [3], CEA in France [4], CERN [5], CIEMAT in Spain [6], INFN-Genoa and INFN-Milan in Italy [7]), Twente University in the Netherlands [8] and Wrocław University of Technology in Poland [9]. 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.

II. NED CONDUCTOR DEVELOPMENT

A. 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 formulated by CERN and are aimed at manufacturing the Nb_3Sn Rutherford-type cable for an 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.

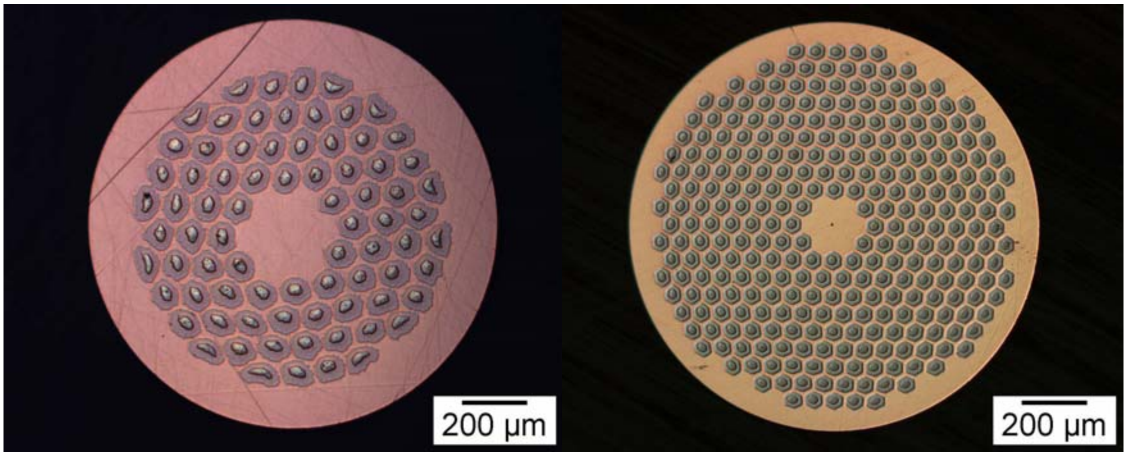

Fig.1. Cross-sectional views of wires developed within the framework of the CARE/NED activity: (a) Internal Tin wire produced by Alstom/MSA (left) and (b) Powder-In-Tube wire developed by SMI (right).

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

Parameter	NED	LARP	ITER
Diameter (mm)	1.250	0.7	0.820
Effective 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

B. 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.

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. 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. 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.

Cross-sectional views of nominal diameter wires developed for NED are respectively shown in Figures 1(a) and 1(b) for Alstom/MSA and SMI companies.

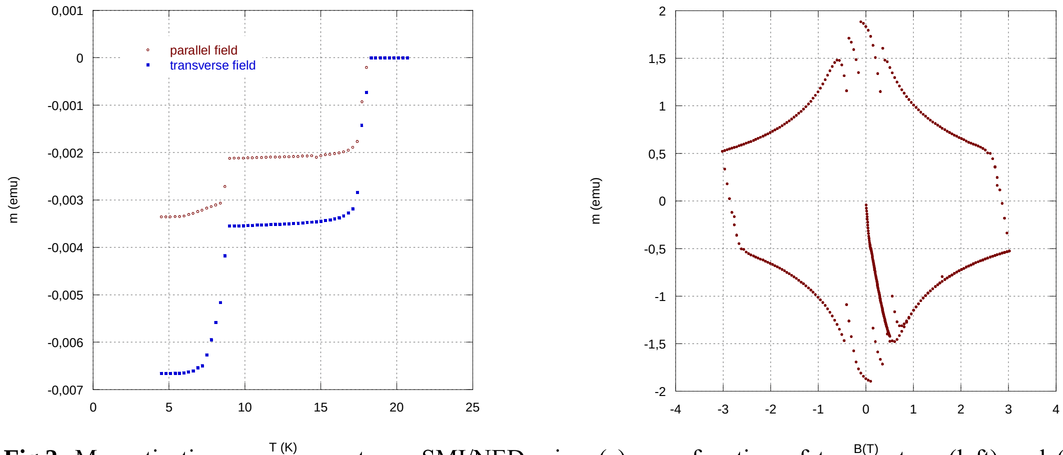

Fig.2. Magnetization measurements on SMI/NED wire: (a) as a function of temperature (left) and (b) as a function of field (right; courtesy of P. Fabbricatore and M. Greco, INFN-Genoa, C. Ferdeghini, INFM-Genoa and U. Gambardella, INFN-Frascati).

C. 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, containing 78 sub-elements with a diameter of 85 µm. The cross-section is shown in Fig. 1(a). This wire achieved a critical current (I_c) of ~740 A at 4.2 K and 12 T, corresponding to a non-copper critical current density (J_c) 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.

At the same time, 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. The cross-section is shown in Fig. 1(b). Magnetization measurements performed as a function of temperature and field are shown in Fig. 2(a) and Fig. 2(b). These measurements 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. 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 the new 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.

Table 2. Salient parameters of Rutherford-type cables produced by LBNL with SMI/NED wire (see Glossary).

Number of strands	40 (∅ 1.25 mm)
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

Fig.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).

III. 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. Meanwhile, CERN is in the process of launching an ambitious high field accelerator magnet R&D program, recently approved and funded by the CERN council (and sometimes referred

* The glossary at the end of this article defines cabling terms.

to as the “White Paper proposal”, from the name of the document where the Director-General expressed the needs to support and improve the CERN accelerator chain). This program calls for the development and the industrialization of a conductor for 13 to 15 T accelerator magnets. The NED collaboration and its results will serve as a base for this new R&D.

ACKNOWLEDGMENT

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REFERENCES

[1] NED Website: http://lt.tnw.utwente.nl/research/HCS/Projects/CARE-NED/

[2] A. Devred et al., “Overview and status of the Next European Dipole (NED) joint research activity”, *Supercond. Sci. Technol*. **19** (2006), No. 3, S67 - S83.

[3] Council for the Central Laboratory of the Research Councils/Rutherford Appleton Laboratory; RAL website: http://www.scitech.ac.uk/About/Struc/Locs/RAL/facs.aspx

[4] Commissariat à l’Energie Atomique ; website: http://www.cea.fr

[5] Organisation Européenne pour la Recherche Nucléaire (formerly Conseil Européen pour la Recherche Nucléaire, acronym retained) ; CERN website: http://public.web.cern.ch/public/

[6] Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas; website: http://www.ciemat.es/

[7] Istituto Nazionale di Fisica Nucleare; website: http://www.infn.it

[8] Twente University website: http://www.utwente.nl/en/

[9] Wrocław University of Technology website: http://www.pwr.wroc.pl/en_main.xml

GLOSSARY

Rutherford-type cable: cable formed by flattening a hollow tubular cable generally made up of several tens of superconducting strands. The Rutherford-type cable cross-section can be either rectangular or, more generally, trapezoidal. In the latter case, the main dimensional cable parameters are the mid-thickness, the width and the keystone angle, as illustrated in Fig. 4.

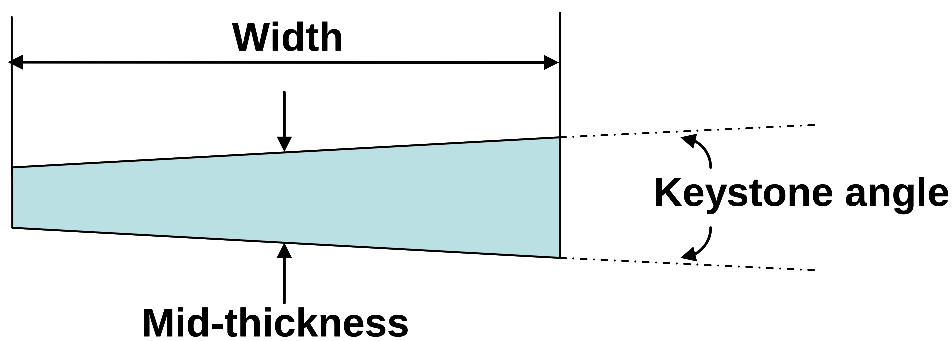

Fig.4. Schematic cross section of a Rutherford-type cable, defining the main dimensional cable parameters mentioned in Table 2.