CARE NED Work Package 3

Report on Final Strand Production by Powder In Tube Technology

L. Oberli [1]

1) CERN, Switzerland

Abstract

In the framework of the CARE-NED project CERN placed a contract with Shape Metal Innovation (SMI) in the Netherlands to develop a Nb_3Sn strand with a diameter of 1.25 mm to reach a high critical current of 1636 A at 12 T and 4.2 K and to produce the Nb_3Sn strand for a 290 m long superconducting cable consisting of 40 strands. This report describes the final strand production with the PIT technology.

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1. Introduction

In the framework of the CARE-NED project CERN placed a contract with Shape Metal Innovation (SMI) in the Netherlands to develop a Nb_3Sn strand with a diameter of 1.25 mm to reach a high critical current of 1636 A at 12 T and 4.2 K (corresponding to a non-copper critical current density of 3000 A/mm^2 at 12 T and 4.2 K) and to produce the Nb_3Sn strand for a 290 m long superconducting cable consisting of 40 strands.
According to the request of CERN, SMI has started a development program made up of two R&D steps (referred as Step 1 and Step 2) followed by the final production. Step 1 was intended to the development of an initial strand design to reach a high non-copper critical current density. During Step 1, SMI fabricated a few small billets with the aim to increase the non-copper critical current density at 12 T and 4.2 K above 2500 A/mm^2 by powder optimization and by using a Ta barrier. For Step 2, SMI produced two new billets with the final strand design to get a strand of 1.25 mm in diameter with 50 µm filament diameter. SMI succeeded in producing a 1.25 mm strand which achieved a non-copper critical current density of ~ 2500 A/mm^2 at 12 T and 4.2 K with a standard heat treatment of 84 hours at 675 ^{o}C. To qualify this strand for the final strand production, cabling trials were carried out to assess the level of cable degradation. The cabling tests proved the suitability of the SMI strand for cabling and it gave the go-ahead for final strand production.

2. Results of the development program

2.1 Results achieved during Step 1

During Step1, SMI has tried to increase the non-copper critical current density of a Powder-In-Tube strand with 192 filaments to a value above 2500 A/mm^2 at 12 T and 4.2 K. With this number of filaments, the strands produced by SMI during step 1 had to be drawn to a diameter of 1.0 mm to get filaments with a diameter of 50 µm. SMI has produced 2 billets using a tantalum barrier around the niobium tube of each filament and two billets (called B201 and B205) with a modified powder composition without using a tantalum barrier. SMI used Ta barriers coming from two different suppliers. By making use of a Ta barrier around the Nb tube, SMI intended to react completely the Nb tube and to achieve a constant Sn content of 25 at. %. The drawing to a diameter of 1 mm of the two billets using a Ta barrier was not successful due to a large number of breakages starting already at a diameter of 6 mm that were attributed to a poor workability of the Ta barrier. The 2 other billets B201 and B205 did not use a Ta barrier. They were drawn without breakage to a diameter of 1 mm and two unit lengths of 327 m and 320 m were delivered to CERN in fall 2005. Both billets encountered Sn leakage during the heat treatment reaction, even if the Sn content used in the powder of billet B205 was decreased compared to the Sn content in billet B201. A critical current density around 2350 A/mm^2 at 12 T was measured on billet B201, substantially lower than expected due to Sn leakage occurring at the melting point of Sn. A piece length of 20 m of another billet called B179 having also 192 filaments was delivered to CERN. On a sample from billet B179, a critical current density of 2410 A/mm^2 at 12 T and 4.2 K was obtained by SMI.
CERN has investigated the strand behaviour under heavy deformation to evaluate if the strands are indeed capable to sustain the cabling. Samples of the 2 billets B179 and B201 were rolled down at CERN to flatten the strand from 1 mm to 0.85 mm, 0.75 mm, 0.70 mm and 0.65 mm. The filament layout was observed by optical metallography of the cross-section of the samples. Whereas the filament layout of billet B179 when rolled to 0.75 mm was severely deformed showing shear fracture planes crossing the filaments, the filament layout of

billet B201 was able to sustain the high unidirectional deformation due to a larger amount of copper around the filaments.
The results obtained during Step 1 has allowed to move to the second part of the development program for continuing the development of the PIT strand to get a 50 µm filament diameter in a strand of 1.25 mm in diameter.

2.1 Results achieved during Step 2

For Step 2, the decision was taken to continue the development with a design including 288 $(NbTa)_3Sn$ filaments to get a filament diameter of 50 µm in a strand with a diameter of 1.25 mm so as to fulfil the NED specification. The strands for Step 2 were fabricated with the same NbTa tube and the same powder composition as for billet B179 and with a filament layout having more copper around the filaments as applied for billet B201.
A first 3 kg billet B207 was produced by SMI with the final strand design in fall 2005. A high critical current value of 1313 A was measured at 12 T and 4.2 K on the samples of this billet, which corresponds to a non-copper critical current density of 2069 A/mm^2. This lower than anticipated critical current density was attributed to a problem in the powder preparation which underwent by mistake an additional heat treatment. Several strand samples were deformed at CERN to investigate the behaviour of the filaments layout under different levels of deformation to evaluate if this strand with a new strand design is able to sustain unidirectional deformation. The new filament layout of billet B207 was able to sustain well the high unidirectional deformation as observed by optical metallography of the cross section of the samples, confirming the importance to have sufficient copper around the filaments as seen during Step 1. On a sample deformed at a level of 28 %, a RRR value of 80 was measured confirming the good behaviour of the new filament layout under a high level of deformation.
A second billet B215 was launched into fabrication by SMI, keeping the filament layout of billet B207. A strand piece length of 915 m (9.6 kg) was obtained in August 2006 without any breakage. A high critical current of 1397 A was measured at 12 T and 4.2 K, which corresponds to a non-copper critical current density of 2500 A/mm^2. The strand succeeded to sustain the unidirectional deformation test made by rolling. The last step to qualify the strand design before the start of the final production was a cabling test which was done with the strand produced from billet B215.
In December 2006, European Advanced Superconductors EAS acquired the PIT technology of SMI. The transfer of technology associated to administrative matters led to a considerable slowdown of the activity at SMI to finish Step 2. Finally, a 20 meter long cable was fabricated at Berkeley in June 2007 with the available 915 m strand piece length. The cabling tests proved the suitability of the SMI-NED strand for cabling, a moderate degradation between 4 % and 8 % was measured on strands extracted from the cable after a heat treatment at 650 ^{o}C during 120 hours. The go-ahead for final strand production was given to EAS/SMI in August 2007.

3. Final strand production

The total strand production, corresponding to 12.7 km of strand, is done under the responsibility of EAS. The transfer of technology led to delay in the fabrication of the final PIT strand as the equipment of SMI had to be installed in the EAS factory at Hanau. Final strand manufacturing is currently underway and the full strand delivery to CERN has taken a few months delay. A first strand length of 1000 m, B228, produced partly at Hanau by EAS and partly at Enschede by SMI was delivered to CERN in April 2008 into two strand piece lengths of 400 m and 600 m. A second strand, B230 (1650 m), was completely produced at Hanau, except for the final strand drawing to nominal diameter. This strand was delivered to

CERN in July 2008 into 4 strand piece lengths (705 m + 314 m + 305 m + 323 m). When reacted to 120 h at 650 ^{o}C, a critical current density of ~ 2500 A/mm^2 at 12 T and 4.2 K was obtained by EAS on strand B230, very similar to the value obtained on strand B215 with the same heat treatment. Since July 2008, the equipment transfer from SMI to EAS was completed. A third strand, EAS002 was completely produced at Hanau by EAS and was delivered to CERN in October 2008 into 2 strand piece lengths (1440 m + 2357 m). EAS/SMI has completed the final strand production in January 2009 with the fabrication of two strands (respectively 3.5 km and 2.8 km long). However, the last strand fabrication was characterized by numerous breakages, providing too short piece lengths. It was then decided that this strand will be replaced by a new strand to be produced in the coming months.