CABLE DESIGN AND R&D FOR NED

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Abstract
This paper presents the work package on conductor development as a part of the Next European Dipole (NED) program supported by EU. The results of a dipole preliminary magnetic design to reach 15 T in the bore are summarised From this preliminary design, a strand and cable specification has been derived to place orders in European industries. The various steps foreseen for the strand development are indicated.

1. INTRODUCTION

The NED project is one of the Joint Research Activities (JRA) accepted by EU in view of developing in Europe high field accelerator magnets [1].

Six institutes have agreed to collaborate to the NED JRA:

- CCLRC-RAL (United Kingdom)
- CEA/DSM/DAPNIA (France)
- CERN/AT (International)
- INFN – Milano/LASA and – Genova (Italy)
- University of Twente (The Netherlands)
- University of Wroclaw (Poland).

The Phase I of NED, which is supported by EU is articulated around three main work packages: (1) Thermal Studies and Quench Protection (TSQP), (2) Conductor Development (CD) and (3) Insulation Development and Implementation (IDI).

The CD work package is coordinated by CERN. The core of the CD work package will be devoted to Nb_3Sn strand and cable development. It includes the preliminary designs of a large-aperture and high-field (up to 15 T) Nb_3Sn dipole magnet in order to derive the Nb_3Sn meaningful strand and cable specifications suitable for large field magnet applications. A technical specification will be written and an order will be placed according to the CERN procedures. The high critical current density of 3000A/mm^2 at 12 T, 4.2K, represents a new technical challenge for the European superconductor industry, which will also invest in this ambitious program. Within the limited funding, it was then decided to concentrate the Nb_3Sn strand fabrication on two routes: the Powder In Tube (PIT) and the Internal Tin Diffusion (ITD).

CERN will make the follow-up of the contract. The characterization measurements will be performed in the associated laboratories:

- Strand critical current measurements (following a standardized protocol) at CEA/Saclay, INFN-Milano/LASA, University of Twente.
- Strand magnetization measurements at INFN-Genova.
- Cable critical current measurements at University of Twente.

2. RESULTS OF THE PRELIMINARY MAGNETIC STUDIES

A preliminary design of a large-aperture (up to 88 mm), high-field (up to 15 T), Nb_3Sn dipole magnet has been made to derive conductor specifications. The design is based on a two layer cable distribution.

2.1 Magnet Overall Structure

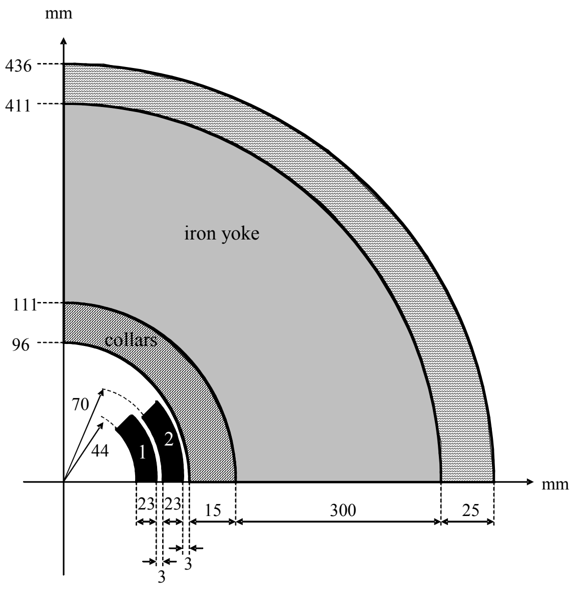

Fig.1.Magnet overall lay-out

Fig.1 shows a schematic magnet overall layout. The coil aperture is 44 mm; there is 3 mm space between the two layers. The iron yoke is separated from the coils by an intermediate spacer (collars) of 25 mm thickness and is surrounded by a 28 mm thick stainless steel shrinking cylinder. The inner layer consists of 4 blocks of conductors while the outer is made of 3. The adjacent blocks are separated by a distance of at least 2 mm. The iron yoke is 350 mm thick.

2.2 Results of an impact study

An impact study of a few variables on the conductor has confirmed that the main parameter influencing the bore field is the overall current density in the coil. The latter is dominated by the critical current density in the non-copper and the insulation thickness. Both have not been considered as a free parameter because they depend so much on the technology, which will be developed in the frame of the NED program. The insulation thickness of 0.2 mm on each side of the cable represents 17% of the total conductor surface.

With a critical current density in the strand non-copper area of 1500 A/mm^2 at 15 T, 4.2 K, the bore field as calculated is 14.4 T at 4.2 K for a maximum quenching field on the conductor of 15 T taking into account a cable degradation of 10 %. To reach 15 T in the aperture, the magnet has to be operated at 1.9.K as shown on the load lines represented in fig.2. The pressure on the broad face of the cable, only due to the magnetic forces amounts to 150MPa.

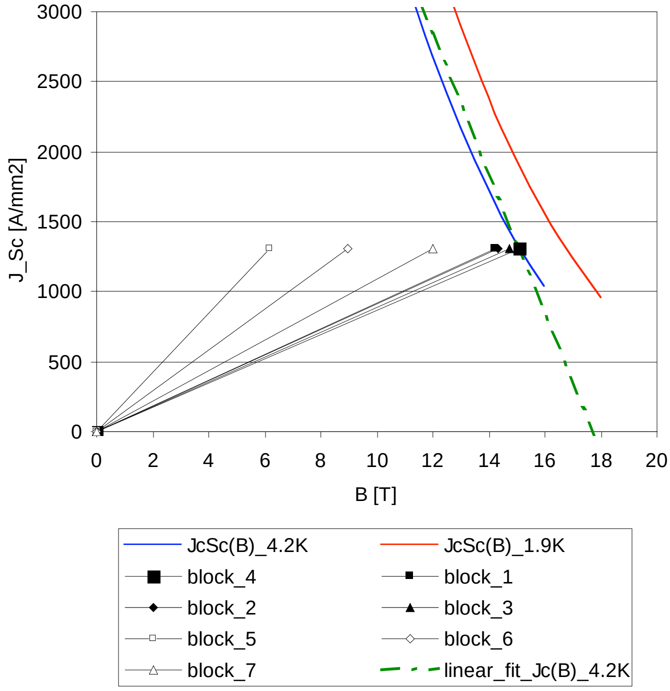

Fig.2.Load Lines

2.3 Overall characteristics of a 88 mm, two layer magnet design

The number of conductors is 19 for the inner layer and 26 for the outer layer. The 2 layers of coil winding use the same cable of 40 strands having a diameter of 1.25 mm

2.3.1 Strand and Cable Characteristics

Table 1 Strand and Cable characteristics

strand diam.	strand number	Cu/ non_Cu	height	width inner	width outer	insulation	Jc_str at 15T, 4.2K	Jc_cab at 15T, 4.2K
[mm]			[mm]	[mm]	[mm]	[mm]	[A/mm^2]	[A/mm^2]
1.25	40	1.25	26	2.175	2.375	0.2	666.67	417.1

2.3.2 Magnet Characteristics

Table 2 Magnet Characteristics

Field [T] / Current [A]	L [mH/m]	Wm [kJ/m]	Max pressure [MPa]	Fx, result. [MN/m]	Overall diameter [mm]
14.42 / 28660	4.4	1810	148	15.8	1004

Calculations with a cable degradation of 10%.

3. STRAND CHARACTERISTICS

Figures 3 and 4 show cross-sections of the strands based on the two foreseen technologies. NED will not make use of a collective barrier in the ITD process.

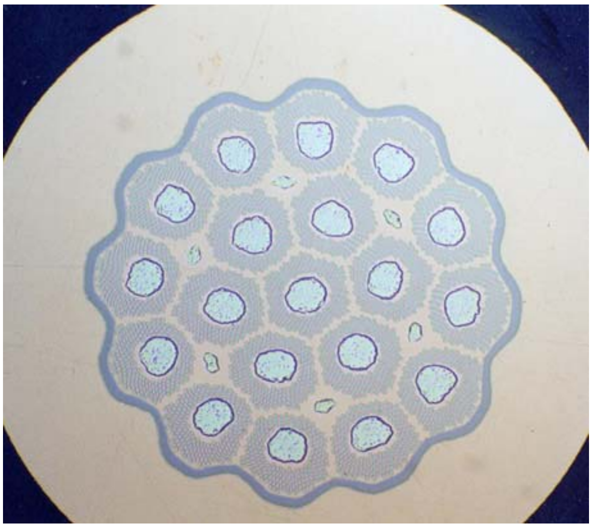

Fig. 3 I T D (ALSTOM)

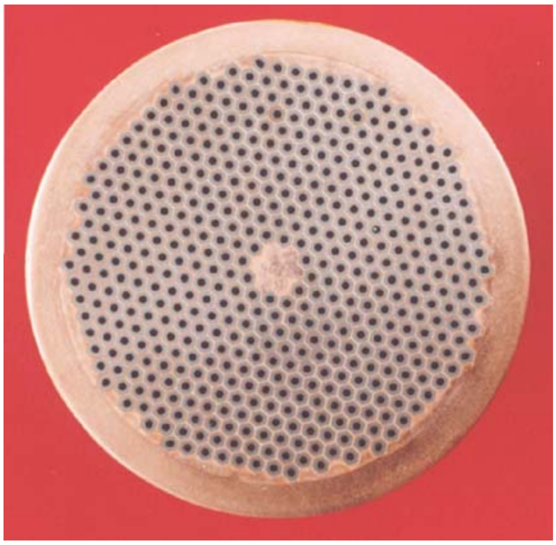

Fig. 4 P I T (SMI)

3.1 Strand Characteristics for NED

The strand specification for NED will be based on a critical current density of 1500 A/mm^2 at 15 T, 4.2 K and 3000 A/mm^2 at 12 T, 4.2 K The effective filament size is smaller or equal to 50 μm. The strand diameter is determined by the maximum cabling capacity of 40 strands.

Table 3.Strand Characteristics

Strand diameter	1.25 mm
Effective Filament diameter according to billet design	< 50.0 μm
Copper to non-copper volume ratio	1.25 ± 0.10
Filament twist pitch after cabling	30 mm
Filament twist direction	right-handed screw
Minimum critical current at 4.222 K	1636 A at 12 T 818 A at 15 T
RRR (after full reaction)	> 200
n-value @ 15 T and 4.2 K	> 30

4. CABLE CHARACTERISTICS(PRELIMINARY)

Table 4 indicates the characteristics of the cable. The dimensions are preliminary and will be decided after cabling tests and measurements of the current degradation.

Table 4. Cable Characteristics

Cable width	26 mm
Cable mid-thickness at 50 MPa	2.275mm
Keystone angle	0.22 degrees
Cable thin edge thickness	2.175 mm
Cable thick edge thickness	2.375 mm
Cable transposition pitch	~180 mm
Number of superconducting strands	40
Critical current at 4.222 K, with field normal to broad face	29440 A at 15 T 58880 A at 12 T
Minimum critical current at 4.222 K of extracted strand	736 A at 15 T 1472 A at 12 T
n-value @ 15 T and 4.222 K	> 20
Residual resistance ratio before reaction after reaction	≥ 70 ≥ 120
Cable transposition direction	left-handed screw thread
Minimum unit length	145 m

5. PROGRAM FOR NED CONDUCTOR

To obtain high a critical current density of 3000 A/mm^2 in a strand of 1.25 mm is very difficult. The firms having a contract have to optimize the raw materials, the Sn and Nb content.
The fabrication process must be suitable for large production. Billets of circa 70 kgs have to be produced and reach piece lengths of strands larger than 1000 m. Many metallurgical tests have to be performed on the strands.

A working group under the leadership of A. den Ouden will make the standardization of the electrical characterization. The follow-up of the contract will foresee several milestones related to payments. The indicative program of development is summarized in Table 5.
The programme requests to make cabling tests with the strands under development to measure the effect of the billet design on cable degradation, if any.

Table 5 .Indicative program of development, fabrication and milestones.

Steps	Date	Description	Milestones
	December 2004		Progress report
1	June 2005	Qualification of initial strand designs	Fabrication/tests of at least 10 kg of strand and relevant cabling tests Progress report
2	December 2005	Qualification of final strand design	Fabrication/tests of at least 10 kg of strand and relevant cabling tests. Progress report
3	June 2006	Total strand production	Fabrication/tests of total strand quantity and cabling tests. Progress report
4	December 2006	Total cable fabrication	Total cable quantity delivery Final report

6. CONCLUSION

The paper gives the general characteristics of the strand and the cable to be developed for the Next European Dipole (NED).The main characteristics are coming from a preliminary magnet design. The main features of the strand are a diameter of 1.25 mm and a current density in the non copper of 3000A/mm^2 at 15 T, 4.2 K. This current density is very ambitious The strand fabrication will be based on Nb_3Sn material following the two routes of Internal Tin and Powder in Tube. Orders will be placed in the European superconductor industries to develop the strand and cable within the next 3 years.

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[1] A. Devred, D.E. Baynham, L. Bottura, M. Chorowski, P. Fabbricatore, D. Leroy, A. den Ouden, J.M. Rifflet, L. Rossi, O. Vincent-Viry and G. Volpini High Field Accelerator Magnet R&D in Europe” Proceedings of the MT18 Conference, 20-24 October 2003, Morioka, Japan