Design and Manufacture of a NbTi Insert Module Relevant for the ITER PF Magnets Conductor

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A NbTi insert coil has been manufactured to give a contribution, through its characterisation, to the discussion about the better layout of the full-size conductor for the Poloidal Field Coils for the ITER machine. The coil has been designed and constructed by ENEA and Ansaldo CRIS, with a conductor provided by Europa Metalli Superconductor and consisting of 36 Ni-coated strands twisted in a three-stage cable, jacketed and compacted in a SS round tube. A self consistent unit has been manufactured assembling the insert module and its mechanical supporting structure, to allow easy installation inside the background magnet of the ENEA test facility where the coil will be tested under representative conditions for the ITER PF magnets. The design and the description of the manufacturing process is presented in this paper, together with an overview of the experimental facility.

INTRODUCTION

A magnet wound with a sub-size NbTi conductor has been realized to study its characteristics in view of the realisation of the full-size conductor for the ITER Poloidal Field Coils.

For this reason ENEA has built up an *ad hoc* experiment, called ASTEX (Advanced Stability Experiment) whose experimental campaign shall start within 2004.

The conductor has been realized by Europa Metalli Superconductor (EMS) with 36 Ni-coated strands twisted in a three-stage cable, while ENEA and Ansaldo CRIS designed and manufactured the module.

The main goal of ASTEX is to study the influence of the current distribution on the conductor properties such as critical current, AC losses and stability. To reach the scope, during conductor cabling, one strand of a triplet has been marked in order to make the sub-stages recognizable at coil ends after winding. Then, when mounting the module in the experimental set-up, both of its terminations have been opened and subdivided into different groups of strands, to feed the magnet with a controlled non-uniformly distributed current by using a system of external resistors.

This paper illustrates the design and the manufacturing of the insert coil and gives also a description of the test facility layout.

CONDUCTOR

Strand

A cross section of the EMS NbTi strand is shown in Fig 1. It is a 0.81mm diameter strand, composed by 54 bundles with 1μm thickness individual barrier and a total number of 6534 filaments, 8mm twist pitch, 6μm diameter and a Cu/non-Cu ratio of 1.9. The strand is Ni coated with 1μm thickness.

A critical current of 398A at 4.2K, 6T background magnetic field, corresponding to a $2.2 \cdot 10^9$ A/m^2 current density and hysteretic losses of 163 kJ/m^3 at 4.2K on a ±3T cycle, have been measured at ENEA [1]. Coupling losses on the strands have been also measured, and results indicate a 6.8μm effective filament diameter and 6.7ms coupling time constant.

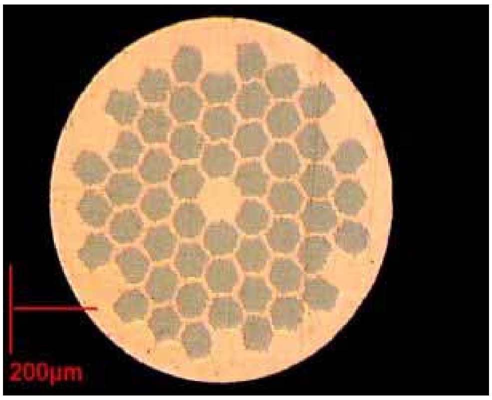

Figure 1 NbTi strand cross-section

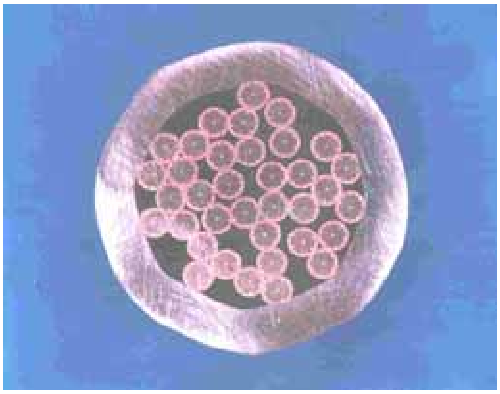
Figure 2 Conductor cross-section

Cabling and Jacketing
The cable layout is a three stages configuration, 36 strands, with the following twist pitches (TP):

stage	specified TP(mm)	measured TP(mm)
3	45±5	42±1
3x3	85±5	83±1
3x3x4	125±5	126±1

All stages have been cabled with a right hand pitch. One strand of one of the twelve triplet has been painted in order to make the sub-stages recognizable at both coil ends after winding. The final cable has been compacted to a circular cross section diameter of about 6.5mm (die diameter).

The jacketing has been carried out by pulling the cable through a straight tube, 120m length, supplied by the FINE TUBE Co UK in an unit coiled length. The jacket was an AISI 304 stainless steel tube 10x8mm. The cable was inserted into the tube by hand and compacted by Turk's head to an average outer diameter of 8.55mm (Fig.2). The void fraction obtained was about 36.1%. An overall 22.5ms coupling time constant of the conductor has been measured by Twente University [2].

MAGNET MANUFACTURING

In Table 1 the main coil and conductor characteristics are reported.

Table 1 Coil and conductor characteristics

Strand type	NbTi
Strand diameter	0.81mm
Cu/noCu ratio	1.9
Ic (6T,4.2K)	398A
RRR	100
Number of strands	36
Conductor diameter (not insulated)	8.55mm
Jacket thickness	1.0mm
Conductor insulation thickness	0.18mm (glass tape, half overlapped)
Layer insulation thickness	0.20mm (glass cloth)
Conductor length	106,60m
Coil axial length	230mm
Coil inner diameter	115mm
Coil outer diameter	249mm
Number of layers	8
Number of turn per layer	23
Total number of turns	184
Outer insulation thickness	4 layers, glass tape, 0.18 mm thick
Voltage taps	n°13 (AISI 304 strip with 0.05mm thickness and 5mm width)
Compensation coil	co-wound insulated copper wire ϕ=0.5mm

The conductor has been insulated by glass tape, 0.18mm thick, hand wrapped half overlapped and wound on a steel mandrel without any pre-bending tool (Fig.3). The interlayer insulation has been obtained by glass cloth with a nominal thickness of 0.20mm. Thirteen voltage taps made by AISI 304 strip (0.05x5mm) have been soft soldered on the conductor jacket and brought out of the winding (Fig. 4) while an insulated copper wire has been co-wound with the conductor to be used for compensating the inductive voltage during field variations.

The impregnation process has been carried out by full immersion of the coil in the epoxy resin under vacuum-pressure cycling. The winding has been previously coated by detaching material then inserted in a mould and filled with resin at 80°C under vacuum, for 24 hours, to guarantee its full penetration.

After that the whole system has been pressurized at 3bar, the temperature has been increased in a first step to 100°C to obtain the gelling of the epoxy and in the second one at 130°C to allow its solidification.

It took one week for the full impregnation cycle.

Figure 3 Module winding

Figure 4 The voltge tap soldered on the jacket and insulation tape

TEST FACILITY

Termination and mechanical supporting structure

Two special boxes have been manufactured to host the opened terminations. The 36 strands have been divided in five groups to feed the magnet with a controlled non-uniformly distributed current: three with 9, one with 6 and the last with 3 strands (Fig.5, 6).

To allow easy installation inside the background magnet of the test facility a mechanical structure supporting the module has been manufactured. The magnet hangs to the top flange by four stainless steel bars and it is thermally insulated from irradiation by four copper screens (Fig.7). Two holes on the top flange host the two groups of five current leads each.

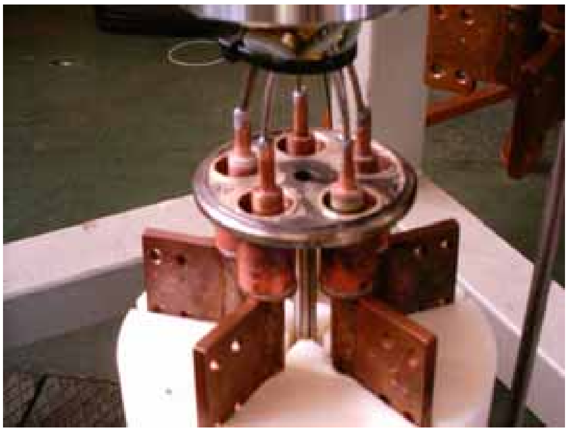

Figure 5 The five termination at one module end

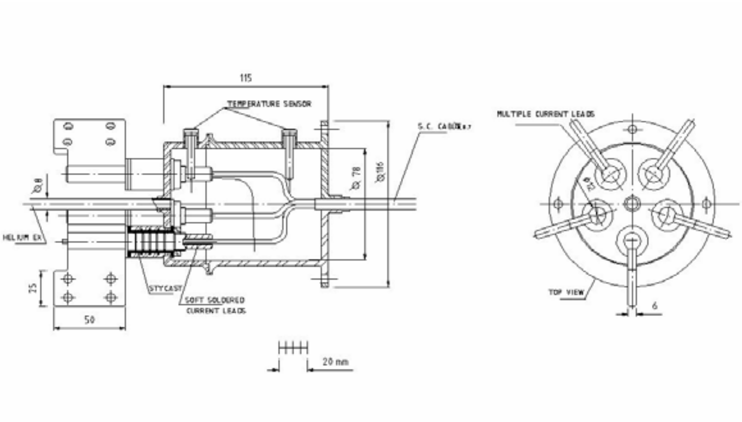

Figure 6 Schematic drawing of termination

Instrumentation

The module has been instrumented as follow:

- 14 fast-response Cernox-type thermometers have been glued on the conductor jacket, after removal of the insulation. Two additional thermometers of the same kind have been installed on each termination box, sensing the inlet and outlet temperature through cold fingers.
- 13 voltage taps have been soldered on the conductor jacket along its length during the winding process. At the 10 module terminations the superconducting strands/sub-bundles have been

brought out of the boxes and voltage taps have been directly soldered on them to measure the inter-bundle transverse resistances, as well as to follow the resistive voltage developing along each of the sub-bundles during DC tests.

- 2 concentric solenoidal pick-up coils have been installed for the magnetic determination of AC losses.
- 2 Micro-Motion Coriolis type flow-meters have been installed at the module inlet and outlet, allowing helium flow measurements over a wide range. The declared response time is 20ms.
- 2 pressure sensors have been mounted at the module inlet and outlet.
- 1 resistive heater will be used to vary and control the helium inlet temperature.

Hydraulic and Electrical Set-up

A Linde 500W@4.2K refrigerator is used to cool down the coil (P_{inlet}=10bar, T_{inlet}=5K) and the background magnet. Two flow-meters located at the module inlet and outlet can work with the helium flowing in both directions, so that counter-flow effects can be observed. Due to this feature, the hydraulic circuit has been designed in such a way that helium flow direction can be reversed in the testing magnet through a 4-valve system. In this way the module stability will be tested in different cooling conditions, in particular varying the quench initiation zone.

Two DC power converters, 6kA and 5kA, will be used to feed the module and the Nb_3Sn background magnet respectively reaching a peak field of about 6T. The 6kA is connected to the module ends by a panel (Fig. 8) manufactured to allow several different resistance configurations in order to obtain the desired unevenly distributed current among the conductor sub-bundles. Ten DCCTs have been mounted to measure the current flowing inside each of the inlet and outlet current leads, as one can see in Fig. 8.

Figure 7 The supporting structure

Figure 8 The resistor panel and the 10 DCCTs

CONCLUSIONS

This NbTi module has been manufactured to qualify the strand for its use in the ITER Poloidal Field Coils also in case of uneven current distribution inside the conductor.

In fact, after having determined stability conditions with uniform transport current, the same runs will be repeated parametrically varying non-uniform current distribution inside the cable. The same kind of measurements will then be repeated after reversing the helium flow. This will cause the transition region to move along the conductor length, owing to the interplay between the self-field profile and the steep temperature profile along the conductor length.

The experimental campaign is foreseen to start in autumn 2004.

REFERENCES

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