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NEW TESTS ON THE 40 KA NB3SN CEA CONDUCTOR FOR ITER APPLICATIONS

J.L Duchateau[a], D. Bessette[a], B. Blau[b], I. Rohleder[b], G. Vecsey[b], H. Katheder[c]

[a] Association Euratom-CEA sur la Fusion Contrôlée, Centre d'Etudes de Cadarache, F-13108 Saint Paul Lez Durance Cedex, France

[b]EPFL-CRPP Fusion Technology division, 5232 Villigen PSI, Switzerland

[c]The NET Team, Garching, Germany

New tests have been performed on the 40 kA CEA Nb_3Sn conductor in the Sultan III facility. The aim of these tests is to obtain key experimental data on the behaviour of Nb_3Sn conductors for fusion applications under high field and large transport current. The 40 kA Nb_3Sn CEA conductor has a shape and an internal arrangment of the superconducting wires which is very similar to the ITER conductors. These tests are therefore of great interest and bring precious information on ITER conductors designs and margins. The level of the ac losses experienced by these conductors under varying fields influences deeply their design. Till now the ac losses was measured without transport current. In this experiment the influence of Lorenz forces on ac losses is investigated at different background fields and with different transport currents. For this, the basic experiment consists in producing field pulses on the conductor by means of a coil installed in the bore of the Sultan magnet and in recording the integrated voltage obtained on pick-up coils placed on the conductor as a function of time. It is possible by this way to evaluate the conductor time constant as a function of the transport current and of the background field.

1. INTRODUCTION

The 40 kA CEA Nb_3Sn was tested in 1993 in the SULTAN III facility [1]. During these tests the critical current of the conductor at different temperatures and background fields was explored, demonstrating the capability of this conductor to carry high transport current at high field for fusion applications. Other tests were performed at Saclay [2] to measure the ac losses of this conductor but without transport current and at low levels of background field. In these new tests the behaviour in transient pulses has been investigated both in presence of high fields and of transport currents.

2. PRESENTATION OF THE TEST STAND

A pulsed coil pairs made of copper has been recently installed in the SULTAN III facility to produce a sinusoidal magnetic pulse with an amplitude of + - 1 T and about 50 ms duration in the 40 cm long center region of the test conductor. The coils are connected with a 38 mF/1500 V capacitor bank forming an oscillating circuit. The test well with the conductor is placed between the two coils as shown in Fig.1.

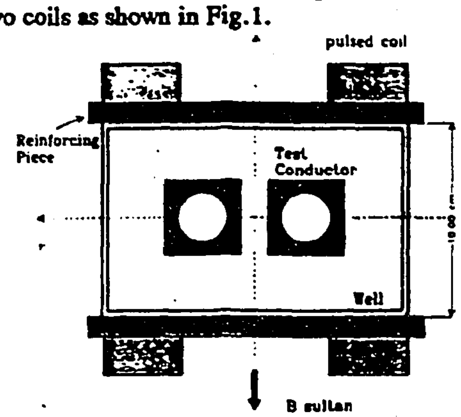

Figure 1. Pulsed coils configuration in SULTAN III test facility

The magnetic axis of the coil pair is in alignment with the SULTAN background field. They are racetrack shaped with a length of 413 mm and a width of 113 mm. Furthermore two iron yokes have been introduced into the magnet bore which allow an increase of the maximum background field in the center region from 11 T to 12 T.

2. IMPORTANCE OF THE INTERNAL GEOMETRY OF THE CABLE AND POSSIBLE INFLUENCE OF LORENZ FORCES

In fusion magnets, the high current conductors have to face important field and current variations due to the fact that these magnets operate in pulse conditions. Furthermore a particular heat load is deposited within typically 0.5 s in case of a plasma disruption. That is the reason why special attention is put to design low losses conductor. The losses due to field variation have two origins :

- the hysteretic losses which are directly proportional to the effective filament diameter.
- the coupling current losses which are proportional *to the so called time constant of the conductor[2].*

This time constant is in strong relation with the electric contact surface between the strands. Parameters such as the local void fraction and the chrome layer deposited on the strands are expected to greatly influence this contact surface. The first conductor to be tested in pulsed operation is the CEA 40 kA Nb_3Sn conductor whose critical properties have already been explored last year. A particular interest exists in proceeding to further tests on this conductor due to the fact that the shape of this conductor is very near the shape which is now chosen for the various conductors of the ITER project [3].

But other tests will be also performed on another conductor : the EM-LMI/Ansaldo conductor previously developped in the Euratom program by the NET team (see in particular [4]).

Both conductors are very similar as far as the diameter, the number of the strands and the twist pitch are concerned, but differ significantly in the geometry of the cable as well as in the effective filament diameter.

3. COUPLING CURRENT LOSSES DURING A *MAGNETIC FIELD PULSE.*

Assuming $\omega\theta << 1$, ω being the field pulsation and θ the time constant of the cable, the equation giving the field B "inside" the conductor is :

$$B + \theta\dot{B} = B_e(t) \quad (1)$$

$B_e(t)$ is the external field variation

The assumption made here is similar to this used in [2] : the time constant of the conductor can be considered as the summation of N time constants, each of them being associated to the contribution of each cabling stage to the total a.c losses, with a dominant contribution of the last but one stage (petal) for the CEA conductor.

with : $B_e(t) = B_0 \sin\omega t$ for $t < \pi/\omega$
and $B_e(t) = 0$ for $t > \pi/\omega$

Equation (1) can be solved for the particular condition of an half sinusoidal field pulse :

$$t < \pi/\omega \quad B(t) = \frac{B_0\omega\theta e^{-t/\theta}}{1+\theta^2\omega^2} + \frac{B_0 \sin(\omega t - \varphi)}{\sqrt{1+\theta^2\omega^2}}$$

$$t > \pi/\omega \quad B(t) = \frac{B_0\omega\theta}{1+\theta^2\omega^2} e^{-t/\theta}(1+e^{\pi/\omega\theta})$$

$tg\varphi = \omega\theta$

The magnetization M(t) of the conductor can be classically defined as : $M = -\theta\dot{B}$

$$t < \pi/\omega \quad M(t) = \frac{B_0\omega\theta e^{-t/\theta}}{1+\theta^2\omega^2} - \frac{B_0 \cos(\omega t - \varphi)}{\sqrt{1+\theta^2\omega^2}}$$

$$t < \pi/\omega \quad M(t) = \frac{B_0\omega\theta}{1+\theta^2\omega^2} e^{-t/\theta}(1+e^{\pi/\omega\theta})$$

In this model, if the time constant is very high ($\theta \to \infty$) then $\varphi \to \pi/2$ and $M(t) = -B_0 \sin\omega t$ which means that no flux enters the sample. The higher the time constant is, the higher is the level of the maximum of the magnetization and the higher the time associated to this maximum. This is pointed out in Table 1 for the the particular pulse duration of the experiment (t=48.5 ms).

Table 1
Influence of the time constant on the value and on the position of the maximum of the magnetization.

Θ (ms)	10	20	30	40	50
$\lvert M/B_0 \rvert$ max.	0.401	0.571	0.665	0.725	0.767
tmax (ms)	14.	17.2	18.8	19.9	20.6

A typical curve is presented in Fig.2.

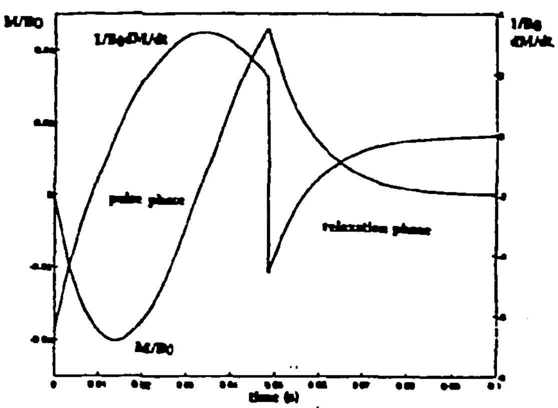

Figure 2 Magnetization of a conductor during a field pulse (duration 48.5ms, θ=10 ms)

4. EXPERIMENTAL RESULTS ON MAGNETIZATION

4.1 Pick-up coils

Each conductor leg is equipped with a 350 mm long pick up coil in the high field region perpendicular to the SULTAN axis. These two saddle shaped coils are directly glued with epoxy onto the conductor jacket as sketched in Fig.3. The number of turns per coil is chosen in such a way that the voltage across the terminals of the coil should not exceed 50 V in order to avoid insulation problem. The classical way of operating to obtain the magnetization of the sample is to balance the pick-up coil P1 or P2 with a so called compensation pick up coil (here Pc1, Pc2 or Pc). The compensation pick up coil must meet two requirements :

- to be placed as far as possible from the conductor not to be influenced by its magnetization.
- to be in the same magnetic conditions as the pick-up coils.

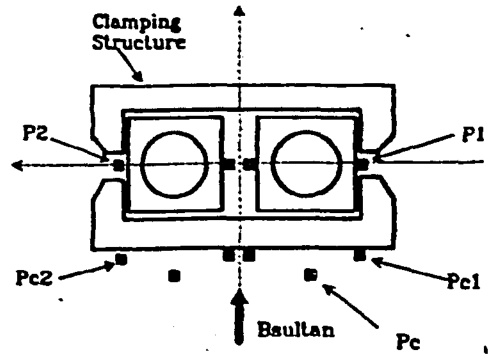

Figure 3 Pick-up coils configuration

4.2 Experimental procedure

It rapidly turned out that it was impossible to balance the pick-up coils with the compensation coils. This was made clear in a test at a temperature greater than 20 K to be sure that the sample is not superconducting. This problem is due to the stainless steel clamps which are placed between the compensation and the pick-up coils and are shielding part of the field variation.

The way of operation was found without using the compensation coils by balancing numerically a "cold shot" on the pick-up coil by a "hot shot" on the same pick-up coil recorded in a previous run.

4.3 experimental results

Experiments have been done at different levels of field : 0T, 4T, 8T and 12 T. Due to temporary operational difficulties of the superconducting transformer, the current in the sample was limited around 20 kA.

The experimental results have been perturbated by the fact that the "hot shot" is not strictly similar to the "cold shot". The diamagnetism of the sample at low temperature affects the field pulse which is

TESTS RESULTS OF SUBSIZE JOINTS BETWEEN NB3SN CABLES AS A FIRST STEP FOR A DESIGN OF JOINTS FOR NET/ITER COILS

D. CIAZYNSKI, P. DECOOL, P. HERTOUT, B. JAGER

Association Euratom-CEA sur la Fusion Contrôlée
Centre d'Etudes de Cadarache, DRFC/STID
F-13108 SAINT-PAUL-LEZ-DURANCE CEDEX, FRANCE

A task for the fabrication and tests of subsize joints between Nb_3Sn cables has been developed at Cadarache within the European Programme, as a necessary step for a design of full scale joints for ITER coils. The first stage (Phase I) of this activity was devoted to basic parametric studies on two main kinds of joint, namely the so-called soldered scarf joint and the overlap (subdivided or not) joint, leading to an optimization of each design from which new samples were fabricated and tested within the second stage of the task (Phase II). The joint samples were made from a cable-in-conduit conductor of reduced size (scale ≈ 1/6), they were tested in helium bath at 4.2 K. The main experimental results concerning D.C. resistance and pulsed magnetic field losses are presented. Performance analysis and theoretical modeling results are also exposed. Flux jump phenomena which were observed experimentally are presented and discussed. Conclusions for the design of a full-size joint are finally drawn.

1. INTRODUCTION

The joints of superconducting cables for ITER coils are special components for which a low resistance needed for cryogenic saving has to be balanced with low losses under pulsed magnetic field needed for stability. When associated with a theoretical modeling, the tests of subsize joints fabricated according to methods relevant to full-size joints can lead to an optimization of a given joint design through a better knowledge of the performances of this type of joint.

2. SAMPLE FABRICATION

The joint samples for Phase I have been fabricated from a square twisted steel jacketed cable provided by ENEA. This cable is composed of 16 pure copper strands and 128 Nb_3Sn composites manufactured by Teledyne Wah Chang (MJR type), 0.78 mm in diameter. The strands are chrome plated. The initial cable void fraction is 40%.

The sample assembly has been already presented in [1]. Two main kinds of joint have been investigated, the soldered scarf joint and the overlap (subdivided or not) joint (see Fig.1) [1,2]. For both types of joint each cable end is cut with its jacket, then jacket is removed and chrome plating is removed chemically from strands over the active length (see Table I).

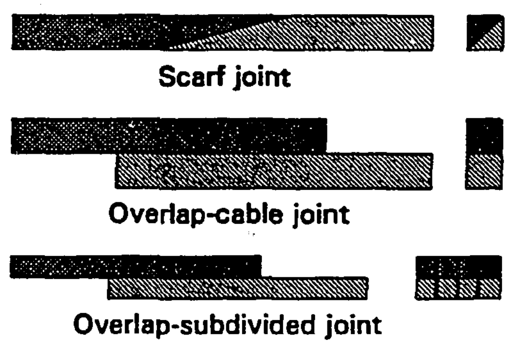

Figure 1. Classification of tested joint

For the scarf joints, the two cable ends are inserted inside a copper tube (cap) until the two facing scarfs (angle 20°) come into contact. The copper cap is then compacted with a press to its final size. The cap can be finally filled with solder.

For the overlap-cable joints, each cable end is inserted inside a copper tube (cap) then compacted to its final square shape with rolling mills. The caps