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SUPERCONDUCTING SOLENOIDS FOR NUCLEAR PHYSICS AT ORSAY

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Résumé - Deux systèmes utilisant de grands solénoïdes supraconducteurs sont décrits. Le premier, SOLENO, est composé de deux aimants (3T, 600 KJ chacun) et remplacera un triplet de lentilles magnétiques. Pour le moment un seul aimant est en fonctionnement. Le deuxième système, CRYEBIS II, avec un solénoïde fournissant 5T, est construit en double exemplaire pour deux sources d'ions lourds : une pour notre laboratoire et l'autre pour l'INSTITUT DE PHYSIQUE ATOMIQUE/STOCKHOLM (Suède). Ce système utilise un interrupteur supraconducteur pour court-circuiter le courant sur l'aimant.

Abstract - Two systems using large superconducting solenoids are described. The first, SOLENO, is composed of two magnets (3T, 600 KJ each) and will replace a standard triplet of magnetic lenses; for the moment only the first magnet has gone into operation. The second system, a 5T solenoid, CRYEBIS II, is built in duplicate and will be used on heavy ion sources: one for our laboratory and the other one for the RESEARCH INSTITUTE OF PHYSICS/STOCKHOLM (Sweden). This system employs a superconducting switch to short-circuit the current on the magnet.

INTRODUCTION

For our laboratory, the first approach to superconductivity was design and construction, in a joint collaboration between CEN/SACLAY and IPN/ORSAY, of a large superconducting solenoid SUPER SOLO, an essential component of a heavy ion source CRYEBIS I /1/ for the synchrotron SATURNE II at SACLAY.

The SOLENO project was born in 1979 /2/ when the physicists wanted to replace a standard triplet of focussing magnets with a device of improved performance (azimuthal symmetry, large solid angle, good magnetic rigidity) which proved to be superconductive.

Shortly after, our laboratory started the CRYEBIS II project /3/ for atomic and nuclear physics research, a system roughly similar to CRYEBIS I, where as the superconducting solenoid produces now 5T compared to 3T for CRYEBIS I. In a contract with the RESEARCH INSTITUTE OF PHYSICS/STOCKHOLM, a duplicate is now built for this institute.

The design and the winding of these magnets has been accomplished with the precious aid of CEN/SACLAY.

SOLENO

The SOLENO SPECTROMETER (Fig. 1) is composed of 2 same superconducting magnets and intended for detection of charged particles around zero degrees. The main characteristics are:
- a large solid angle (100 msr)
- an azimuthal symmetry around the beam axis
- a good acceptance of particles with large rigidity (0.81 T x m)
- a low geometrical aberration
- the magnetic shield allows the object and image zone free.
- the system is compatible with the accelerators of IPN/ORSAY, GRENOBLE and GANIL
- the second coil will extend the experimental capabilities (Time of flight experiments).

1 - Magnet Characteristics (for 1 coil)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coil inside diameter</td>
<td>0.486 m</td>
</tr>
<tr>
<td>Coil outside diameter</td>
<td>0.52 m</td>
</tr>
<tr>
<td>Coil length</td>
<td>0.75 m</td>
</tr>
<tr>
<td>Number of layers</td>
<td>12 layers</td>
</tr>
<tr>
<td>Total number of turns</td>
<td>5902 turns</td>
</tr>
<tr>
<td>Stainless steel hoop's stress</td>
<td>1 layer</td>
</tr>
<tr>
<td>Operational current</td>
<td>375 A</td>
</tr>
<tr>
<td>Central field</td>
<td>3.10 T</td>
</tr>
<tr>
<td>Inductance</td>
<td>8.75 H</td>
</tr>
<tr>
<td>Stored energy</td>
<td>600 KJ</td>
</tr>
<tr>
<td>Weight of wire</td>
<td>100 daN</td>
</tr>
<tr>
<td>Total length</td>
<td>9300 m</td>
</tr>
</tbody>
</table>

The winding is vacuum-grease impregnated. The stainless-steel mandrel serves also as an internal helium wall.

2 - Wire Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper/Sc ratio</td>
<td>2/1</td>
</tr>
<tr>
<td>Sc filaments</td>
<td>47 microns</td>
</tr>
<tr>
<td>number</td>
<td>276</td>
</tr>
<tr>
<td>twist pitch</td>
<td>25 mm</td>
</tr>
<tr>
<td>Superconductor</td>
<td>Niobium 46.5 pc-Titanium</td>
</tr>
<tr>
<td>Critical current</td>
<td>800 A</td>
</tr>
</tbody>
</table>
3 - Coil protection (Fig. 2)

Threshold of the quench detector: 0.2 V and 0.05 s
Current Breaker delay time: 0.15 s
Maximum temperature rise: 100°K

Only 15% of the total energy is dumped into the protection resistance.

4 - Cryostat-cryogenics (Fig. 3)
The main dimensions of the vacuum tank are a warm aperture of 0.36 m, an external diameter of 0.85 m and a total length of 0.984 m. According to the design, the coil centre is shifted of 15 mm with regard to the centre of external magnetic shield, which is splitted in order to conserve the azimuthal symmetry. When the coil is energized, this shift involves important magnetic axial forces which attain under certain conditions 17,000 daN. So, the coil tank is shocked by 3 fiberglass reinforced epoxy thrust-blocks on each side. Each thrust block accepts a 6,000 daN compressive strength.

The current leads consists of a bundle of 35 twister copper braids (0.127 x 1.6 x 570 mm) fitted into a stainless steel tube ($\phi_t = 9$ mm). The optimal working point is obtained between 300 and 350 A with heat losses about 2.1 mW/A. The helium gas flow through each lead is about 0.5 m$^3$/h with generates a pressure drop about 0.3 KPa (3 mbar).

5 - Testing and Operation

Cool down : initial cool down delay with LN2 : 8 hours
cool down and fill up with LHe : 5 hours

Consumption : 40 $\ell$ of LN2 and 150 $\ell$ of LHe

Normal running : The total consumption of LHe including transfers is about 5$\ell$/hours. The magnetic measurements had shown that the field quality closed to expectations. Displacement of the magnetic axis towards the geometric axis under operational conditions is possible through an adjustment of the suspension rods and controlled with a X-Y semiconductor detector.

CRYEBIS II

CRYEBIS II (Fig. 4) will be used as a testing bench for accelerators ion source and as a source for atomic physics experiments. The goal of the project is to obtain fully stripper ions from 18$^+$Ar to 54$^+$Xe. It will be working insulated from the ground (50 KV) and with a fixed magnetic field, which authorizes the use of a superconducting switch to trap the current allowing minimized helium consumption, less influence of the external noise.

1 - Magnet Characteristics

- Coil inside diameter: 0.12 m
- Coil outside diameter: 0.18 m
- Coil length: 1.6 m
- Number of layers: 24 layers
- Total number of turns: 18 260 turns
- Stainless steel hoop's stress: 1 layer with rectangular wire 2 x 3.5 mm
Operational current 350 A
Central field 5 T
Inductance 4 H
Stored energy 250 KJ
Weight of Wire 140 daN
Total length 9000 m in 4 pieces

The winding is vacuum-greased impregnated.
The 3 solders in the winding are made with tin-lead (50/50).
The working intensity has been chosen as the maximum possible with respect of the
magnetic disturbances generated by current leads and soldered joints between the
coil and its switch. The total disturbance on the axis is lower than $10^{-4} \times B_{\text{max}}$.

2 - Magnet Wire Characteristics

<table>
<thead>
<tr>
<th>Supplier</th>
<th>IMI and AIRCO for the swedish duplicate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions bare</td>
<td>2. x 1. mm</td>
</tr>
<tr>
<td>Dimensions insulated (formvar)</td>
<td>2.1 x 1.1 mm</td>
</tr>
<tr>
<td>Copper/Sc ratio</td>
<td>2/1</td>
</tr>
<tr>
<td>Sc filaments : diameter</td>
<td>47 microns</td>
</tr>
<tr>
<td>number</td>
<td>361</td>
</tr>
<tr>
<td>twist pitch</td>
<td>25 mm</td>
</tr>
<tr>
<td>Superconductor</td>
<td>Niobium 46 pc – Titanium</td>
</tr>
<tr>
<td>Critical current at 4.2 K and 5 T</td>
<td>870 A</td>
</tr>
</tbody>
</table>

3 - Switch Characteristics

The superconducting switch is a small aselfic solenoid wound on a fiberglass mandrel.
The winding is impregnated with on epoxy resin 253 SCOTCHCAST; (external diameter
50 mm, length 500 mm). The winding is done with a 36 strands (VAC FKN 60/0.2 mm,
CU-Ni Supra = 1.4) Copper-Nickel cable ($\phi = 1.8$ mm) with a critical current of
2000 A at 0 T and 4.2 K. We observed a reduction of a factor 2, for the critical
current, for the straight single wire supplied compared to the same wire integrated
into the 36 strands cable.

4 - Coil Protection (Fig. 5)

The quench detector is the same as the SOLENO one; it triggers the current breaker
and the discharge of a capacity (20 $\mu$F under 400 V) into the aselfic switch which
instantly flips into normal state; 56% of the energy stored is dumped into the
protection resistance (1.4 $\Omega$) while the coil heats up to 75°K.

5 - Cryostat and Cryogenics (Fig. 6)

Low LHe consumption, thus maximum autonomy for a given storage capacity and easy
convenient operation of the whole cryosystem were the basic aims of the design.
Coil and guard vessels are each surrounded with a dual copper radiation shield main-
tened at respectively 80°K and 20°K with a cryogenerator (CTI model 1050). The
current leads which serves only to energize the magnet are largely underoptimized.
each is made with 1 brass tube ($\phi = 12 \times 1 \text{ mm}; \text{ length } = 600 \text{ mm}$). The temperature of the coil LHe bath may be lowered to $2.2^\circ\text{K}$ by pumping on LHe contained in a small volume ($\phi 50 \text{ mm}, L 1500 \text{ mm}$) completely immersed in the depth of the solenoid reservoir.

REFERENCES

