



**HAL**  
open science

# DESIGN STUDY OF A THIN, SUPERCONDUCTING SOLENOID

J. Zellweger, G. Vécsey, H.-Ch. Walter, J. Crawford, P. Reeve

► **To cite this version:**

J. Zellweger, G. Vécsey, H.-Ch. Walter, J. Crawford, P. Reeve. DESIGN STUDY OF A THIN, SUPERCONDUCTING SOLENOID. Journal de Physique Colloques, 1984, 45 (C1), pp.C1-351-C1-356. 10.1051/jphyscol:1984172 . jpa-00223728

**HAL Id: jpa-00223728**

**<https://hal.science/jpa-00223728>**

Submitted on 4 Feb 2008

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

## DESIGN STUDY OF A THIN, SUPERCONDUCTING SOLENOID

J. Zellweger, G. Vécsey, H.-Ch. Walter, J. Crawford and P.A. Reeve\*

*Swiss Institute for Nuclear Research, CH-5234 Villigen, Switzerland*

\*TRIUMF, University of B.C., Vancouver V6T 2A3, Canada

**Résumé** - Une étude de construction d'un spectromètre cylindrique avec un diamètre de 1,3 m et une longueur de 1,3 m est présentée. Le champ magnétique de 1,7 T est produit par une bobine supraconductrice. Une homogénéité de  $\pm 1\%$  est demandée. L'épaisseur totale de la bobine, chambre à vide incluse, est limitée à 0,6 de la longueur de radiation des photons. On a étudié deux solutions : d'abord une bobine composée d'un supraconducteur de Nb-Ti stabilisé avec aluminium ensuite un solénoïde transformateur avec un bobinage primaire supraconducteur et un secondaire normal en aluminium. Dans les deux cas la bobine est refroidie indirectement par écoulement forcé d'hélium supercritique à une pression de 10 bar et une température de 4,5 K, une technologie qui est bien établie en SIN.

**Abstract** - A design study for a thin 1.7 T superconducting solenoid spectrometer of 1.3 m diameter and 1.3 m length is presented. A field homogeneity of  $\pm 1\%$  is required. The overall material thickness of coil and vacuum chamber is limited to 0.6 photon radiation length. Two versions were studied: A single layer coil wound with Al-stabilized Nb-Ti-superconductor and transformer solenoid with a superconducting primary winding a a normal conducting secondary winding made out of Al. In both cases the coil is cooled indirectly by forced flow of supercritical He at 10bar and 4.5 K - a technology developed at SIN.

## I - INTRODUCTION

For the study of flavour changing muon decays and other rare muon and pion reactions a large, superconducting photon transparent magnetic solenoid spectrometer of high field is needed. Detailed information of the experiments and of the spectrometer assembly is given in Ref. /1/. Magnet design aspects are reported in Chapter 2.

The basic design data for the SIN solenoid is listed:

- a) A homogeneous magnetic field of up to 1.7T  $1\%$  must be reached in a cylindrical volume of 1.2m diameter and 1m length.
- b) The coil assembly consisting of vacuum chamber, thermal shields and superconducting coil must be transparent for photons. The material thickness must not exceed 0.6 radiation length.
- c) The geometry is fixed by  
Coil dimensions: diameter: 1.3 m; length: 1.3 m  
Cryostat length: 1.3 m

A cross sectional view of coil and cryostat including iron yoke and pole plates is given in Fig. 1a,b. The shape of the iron parts are mainly defined by primary beam, various sensors access to measurements and so on.

Similar thin, transparent superconducting solenoids have been built in France: Cello /3/, in USA: PEP /4/, in Geneva: ISR /5/.

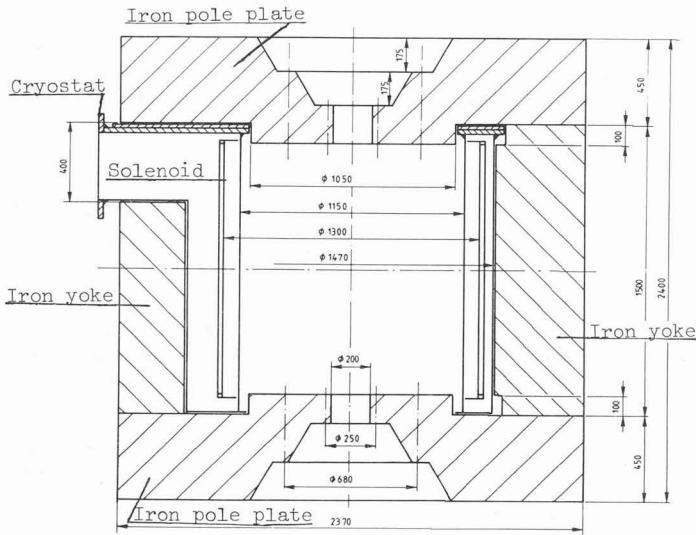


Figure 1a:

Cross sectional view of solenoid, cryostat and iron yokes and mirror plates.

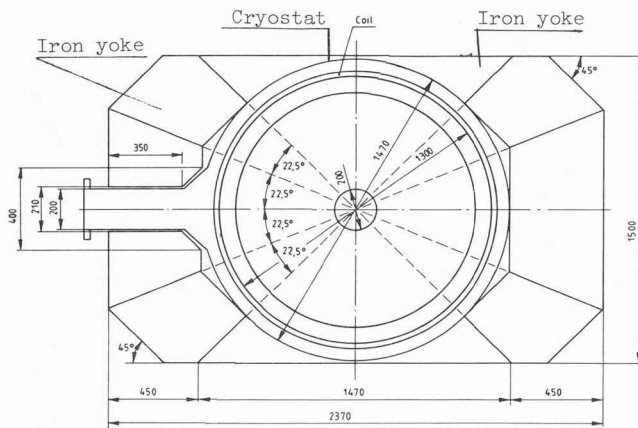


Figure 1b:

Cross sectional view of solenoid cryostat and iron.

II - MAGNET PARAMETERS AT STATIONARY CONDITION

For the given coil dimensions and the desired B-field the following data summarized in Table 1 - were calculated based upon the model of perfect mirrors.

TABLE 1 - Main Parameters of the Coil

Comment	Data
Main parameters: B-field on conductor Magnetic energy Amp. turns	B = 1.7 T E = 2.0 MJ NI = 1.76 Mega-A
Forces : attracting force: coil-iron decentering force in axial direction per 1cm axial displacement centering torque due to a 1°C rotation relative to the main axis	F < 150 to dF/dz < 22.5 to dM/d (PhI) = 3.4 to 1°C
Pressure : Magnetic pressure on winding	p = 11.5 kp/cm

Refined computer calculations limited the decentering force to 12 to/cm. In addition In addition the inhomogeneity due to the non ideally shaped iron parts was studied more carefully. Details are reported in Ref 6.

III - CONDUCTOR DESIGN

A) General Features:

Basically two conductor concepts were studied, which fulfill the transparency requirement. Furtheron, we assume that the radial force is taken by the cooling tube. Therefore, no additional reinforcement material in the conductor is necessary.

Version 1: A monolithic Nb-Ti filament conductor with copper matrix in metallic contact with high purity aluminium conductor similar to the CELLO design was studied. The best solution is a Nb-Ti conductor coextruded with aluminium. (see:Fig. 2a)

Version 2: The coil winding consists of a superconducting Nb-Ti primary winding and a normal conducting, high purity aluminium secondary winding. The latter acts as a transformer winding and is used for the energy dump following a quench. Conductor of both windings are shown in Fig. 2b. A similar design is used in the TPC-coil (USA). Contrary to their design the secondary winding is not shorted but connected to an external resistor outside the vacuum chamber. The discharge time is kept reasonably low to be able to use commercial power switches instead of SCR's as in the TPC-version.

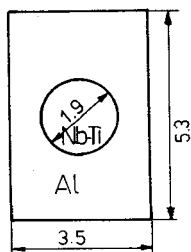


Figure 2a:  
Version A conductor

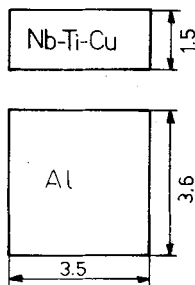


Figure 2b:  
Version B conductor

B) Conductor and its operating parameters:

The operating current of the 1.7T solenoid was chosen to be 2500A at a maximum temperature of 5.5K. The critical current should be above 2750A at this temperature. The filament diameter is fixed to appr. 30µm and the twist pitch is 1cm. For quench conditions the discharge time was set to 2 sec for version A) and 0.2 sec for version B) (superconductor). The hot spot temperature should not exceed 100K. Relevant discharge circuits are shown in Fig. 3a,b. Quench boundary conditions for the conductor are listed in Table 2, whereas important conductor parameters are listed in Table 3.

TABLE 2 - Quench Boundary Conditions for Conductor Design

Comment	VERSION A	VERSION B	
		primary circuit	secondary circuit
nominal current	2500 A	2500 A	2500 A
diode cascade (forward voltage)	---	~1000 V	~10 V
inductance (L)	0.64 H	0.64 H	0.64 H
mutual inductance(M)	---	~0.63 H	~0.63 H
Resistance (R)	0.32 Ohm	---	0.32 Ohm
quench detection time	<200 msec	<50 msec	
power-switch turn-off time	~50 msec	~50 msec	
current turn-off time	2000 msec	200 msec	2000 msec

TABLE 3 - Important Conductor Parameters

Ta	Version A	Version B	
		primary conductor	secondary conductor
nominal current	2500 A	2500 A	2500 A (after quench)
max.ambient temperature	5.5 K	5.5 K	(5.5K)
magn. field	1.7 T	1.7 T	(1.7T)
critical current (2T, 5.5K)	2750 A	2750 A	2750 A
overall current density of conductor	146 A/mm <sup>2</sup>	460 A/mm <sup>2</sup>	200 A/mm <sup>2</sup>
current density of stabilizing material	160 A/mm <sup>2</sup>	600 A/mm <sup>2</sup>	200 A/mm <sup>2</sup>
RRR-Cu	100	80	---
RRR-Alu	250	---	300
Al-Cu (Nb-Ti) ratio	18-1.3-1.0	0.4.16-1.0	1.0-0.-0
conductor area	17.5 mm <sup>2</sup>	5.4 mm <sup>2</sup>	12.5 mm <sup>2</sup>
max. conductor temp.	<75 K	<75 K	≈ 75 K
hot spot temperature	100 K	100 K	---

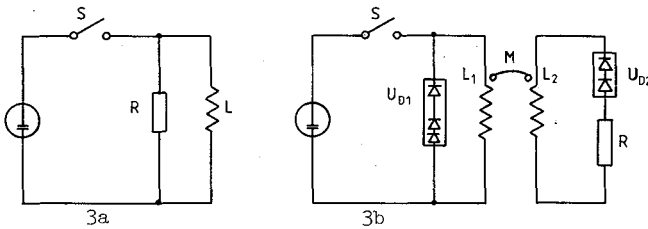


Figure 3:

Schematic diagram of the discharge circuit  
 Rotation: R=Resistor,  
 L=Inductance  
 M=Mutual Inductance,  
 S=Power Switch,  $U_D$ =Diode forward Voltage,  
 ( $U_{D1}$  =800V,  $U_{D2}$  10V)

IV - COIL DESIGN

A) Description:

A 4mm thick aluminium tube of 1.3m diameter with two end rings welded on each side supports the insulated primary or secondary winding as seen in Fig. 4. The insulated cooling tube - a total of ten cooling circuits - is wound on top of the winding. The aluminium former, the cooling tubes and the conductor layers are vacuum impregnated to improve the insulation and guarantee heat exchange due to local temperature gradients. The quadratic cooling tube must withstand 150bar in case of a quench. Its dimensions are 12x12 mm and its inner diameter is 10 mm. The solenoid is positioned and aligned azimuthally, radially and longitudinally relative to the vacuum-chamber and "Iron-Mirrors" by appropriate rods, which act on the end rings.

B) Cooling concept:

According to the cooling concept used in the muon channels /7/ and seen in Fig. 5 the solenoid and its suspension represent separate thermal loads, which are subdivided into 10 solenoid and two suspension cooling circuits. Supercritical helium at 4.5K and 10 bar leaving a helium bath heat exchanger is circulated between cooling circuits and bath heat exchangers. Finally, the supercritical helium having passed all cooling circuit is expanded into the helium bath by a Joule Thompson valve. In the cold state all circuits are connected in series. Massflow control is done with the Joule Thompson valve by keeping the helium bath level constant. The bath temperature is also kept constant by bath pressure control. The expected thermal load is 65W. The current leads, which are helium vapor cooled, are an additional load. Accounting 0.5 gm/sec for the leads, the total He-massflow is 4.8 gm/sec. The thermal heat shields, at about 90K, are also helium cooled. The expected heat load is 1000W.

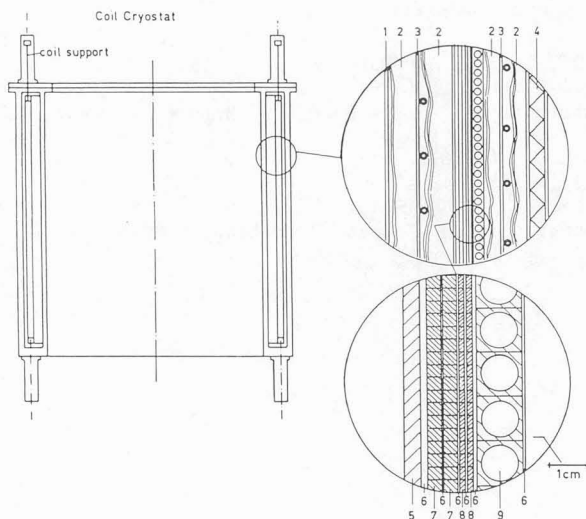


Figure 4:

Cross section through the cryostat and the coil (version B):  
 (1) Inner cryostat wall,  
 (2) Vacuum with superinsulation  
 (3) Nitrogen shield,  
 (4) Outer honeycomb cryostat wall,  
 (5) Coil support cylinder,  
 (6) Glass mesh insulation  
 (7) Pure Al secondary winding,  
 (8) Cu-Nb-Ti superconductor winding  
 (9) Cooling tubes

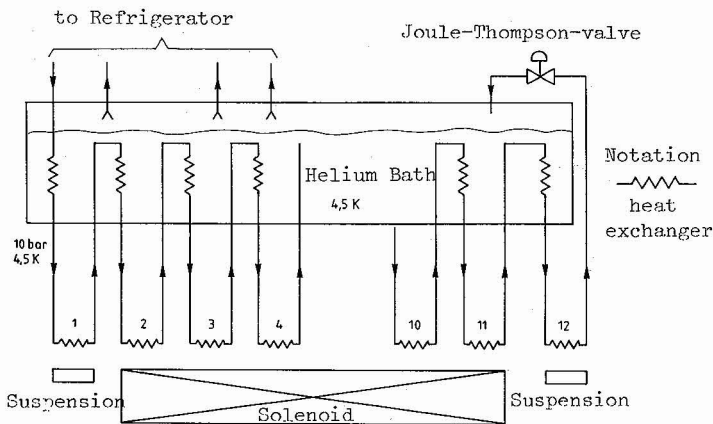


Figure 5:

Schematic diagram of cooling circuit

V - CRYOSTAT

Thermal radiation shields made out of aluminium at approximately 90K surrounded the coil surface. They are mounted in the cryostat. (see:Fig.4). Coil and thermal shields carry several layers of superinsulation, which is a common method for reducing thermal radiation losses. The cryostat must be leak tight and must suffice the force requirements with regard to mechanical stability. Forces arise from vacuum pressure and from 0.5bar peak radial pressure due to eddy currents during quench discharge. For the outer cryostat wall, which must be designed to avoid buckling, a honeycomb reinforced structure of low transparency is suggested, otherwise an aluminium shell of at least 12 mm thickness is required. In all cases the transparency requirement is fulfilled and the magnet material thickness does not exceed 0.57 radiation length.

## REFERENCES

- /1/ Engfer R., Domingo J., Walter H.C., et al., SINDRUM-Proposal, SIN.
- /2/ Zellweger J., Internal Report KRYO-81.11, SIN (1981).
- /3/ Genevey P., le Bars J., 6th International Conference on Magnet Technology (MT-6), Bratislava, (1977).
- /4/ Green M.A. et al., Adv. Cryog.Eng.25, (1980).
- /5/ Morpurgo M., Cryogenics, February (1977) 89.
- /6/ Reeve P.A., Internal Report, KRYO-81.10, SIN (1981).
- /7/ Vecsey G., 5th International Conference on Magnet Technology (MT-5), Roma (1975).