INFN/AExxx, LAL-xxx, SLAC-R-xxx

Super$\boldsymbol{B}$ Detector
Technical Design Report

Abstract

This report describes the technical design detector for Super$B$.

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1 Magnet and Flux Return

The magnet for the Super$B$ experiment, is based on a thin superconducting solenoid placed inside a hexagonal flux return. This solenoid was initially designed and built in the 90's for the BABAR experiment. where it was successfully operated for approximately ten years, demonstrating a high degree of reliability. For this reason it has been considered as the preferred option for the Super$B$ detector. In this chapter the main characteristics of the magnet are briefly summarized. A section is devoted to the modifications required to allow its integration into the Super$B$ detector. Finally, a plan for transporting the magnet from SLAC to the Super$B$ site in Tor Vergata, re-assembly, installation and cryogenic tests is discussed.

1.1 Magnet main characteristics

The Super$B$ magnet, for which a schematic cross section is shown in Fig.1.1 includes:

1. The superconducting solenoid;
2. The laminated barrel flux return, composed of 18 steel plates of different thickness (from 20 mm to 100 mm);
3. The two doors of the flux return involving 19 steel plates of different thickness;
4. An iron end plug shield in the forward end door,
5. An iron end plug shield in the backward end door,

Differently from the BABAR magnet, the forward end plug shield has been modified and made as symmetric as possible with respect to the backward end plug. The reason is that in the BABAR magnet the forward end plug was designed with the specific goal of shielding the magnetic field on the Q2 final focus quadrupole, which is no more present in the SuperB lattice. In the present design the forward door remains unchanged with respect to the BABAR magnet. A future option for making the forward door completely symmetric with respect to the backward door is under consideration. Another difference with respect to the BABAR magnet is the presence of an additional 50 mm plate at the external ends of the backward door and of an additional 100 mm plate at the external side of the forwarsd door. More detailed information about the flux return can be found in chapter **??**. The core of the magnet is a thin superconducting solenoid with as-built characteristics shown in Table **??** and show in Fig. 1.2, a photo taken just after the preliminary test at Ansaldo premise, where the solenoid was built. The design of the solenoid was based on criteria developed and tested with many detector magnets employing aluminum-stabilized thin solenoids [2]. Examples falling in this category are the superconducting magnets for Delphi and Aleph experiments at LEP (CERN).

The coil is composed of two layers of Aluminum stabilized conductors. The layers were internally wound in a 35 mm thick 5083 aluminum support mandrel. Cooling pipes welded to the outside diameter of the support mandrel form part of the thermo-siphon system. Electrical insulation consists of dry wrap fiberglass cloth and epoxy vacuum impregnation. Fig. 1.3 shows a schematic cross section of the solenoid (the cold mass only). The conductor is composed of a superconducting Rutherford type cable embedded in a pure aluminum matrix through a co-extrusion process, which ensures good bonding between the aluminum and the superconductor. In order to have a field homogeneity of ±3% in the large volume speci-

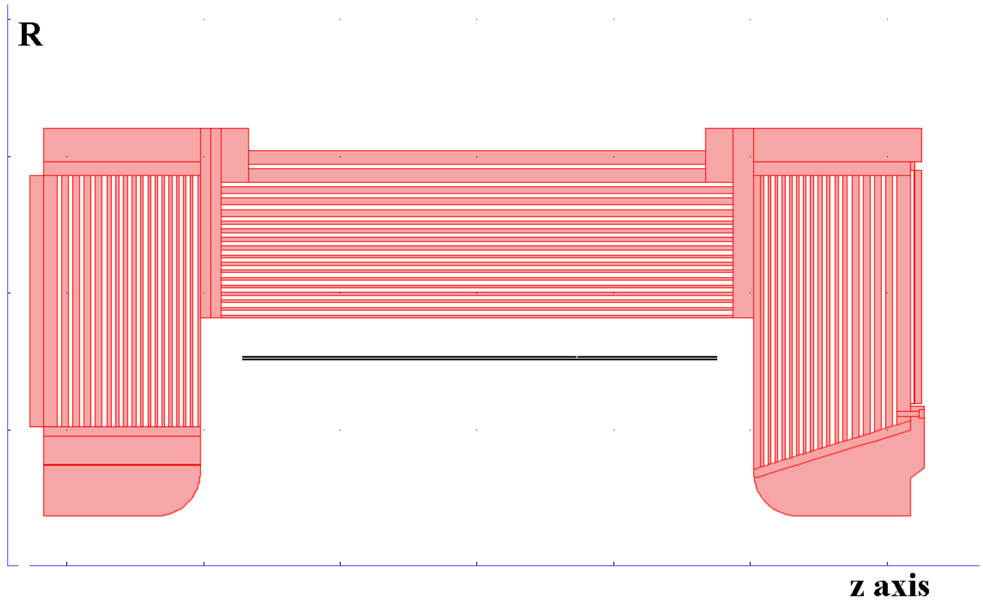

Figure 1.1: Simplified cross-sectional view of the magnet in the plane z-r (cylindrical symmetry with respect the axis shown at the bottom of the figure). This model is used for 2D magnetic computations. The thin black line represents the superconducting solenoid (just the coil, the cryostat is not shown). It is included in the flux return composed of a barel and two end caps (the doors) including two end plugs. The asymmetry is due to the reuse of the BaBar equipment.

Table 1.1: Main characteristics of the Super*B* solenoid, as built

Central Induction	1.5T
Conductor peak field	2.3T
Winding structure	2 layers graded current density
Uniformity in the tracking region	± 3%
Winding axial length	3512 mm at R.T
Winding mean radius	1530 mm at R.T
Operating current	4596 A
Inductance	2.57 H
Stored Energy	27 MJ
Total turns	1067
Total length of conductor	10 300 m

fied by the *BABAR* experiment (and confirmed for SuperB), the current density in the winding is graded: lower in the central region and higher at the ends. The gradation was obtained by using conductors of two different thicknesses: 8.4 mm for the central region and 5 mm for the ends. Both 20 mm wide conductors are composed of a 16-strand Rutherford cable stabilized by pure aluminum. Table xx?? shows the main characteristics of the conductor. In total six conductor lengths were employed in the construction. The electrical joints between the thin and the tick conductors are integrated into the winding, as it can be seen in Fig. 1.3.

1.2 Magnetic forces on the solenoid

The coil is placed inside a non-symmetric flux return yoke (this is a heritage of the BaBar con-

Figure 1.2: The superconducting solenoid after the cryogenic test at Ansaldo (Genova). One can see the annular cryostat enclosing the superconducting solenoid and the turret with proximity cryogenics and current leads.

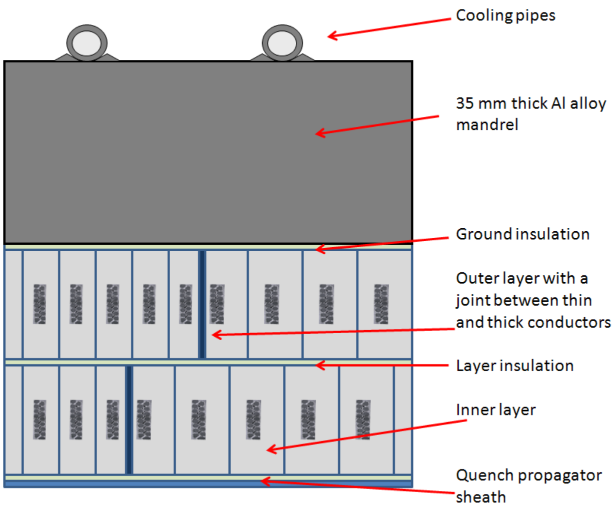

Figure 1.3: Cross section of the cold mass. One can see the two layers made of a two different conductors for grading the axial current density. The two layers were directly wound inside an external mandrel in aluminum alloy 5083. The LHe circulated in channels directly onto the external surface of the mandrel.

figuration). Though the forward plus has being modified and made more symmetric to the backward plug, axial offset forces are still present. For the *BABAR* magnet, in order to have an offset force in one direction only (no inversion during the ramp up), the coil was positioned with 30 mm axial displacement in the forward direction. The force was supported by three Inconel 718 tie rods placed at the backward side. These tie rods were designed to hold forces as high as 250 kN with a safety factor of 4. During the magnet operation in SLAC the axial force was continuously monitored and resulted to get a maximum of 80 kN at 3800 A. It is worth mentioning that there are three similar tie rods also in the opposite side (forward), which were never strained. The modification of the iron yoke introduced by SuperB requirements demands for re-considering the axial position of the coil inside the cryostat. A preliminary magnetic computation, for which the magnetic field map is shown in Fig. 1.4, indicates that the same conditions for the axial forces can be obtained in Super*B* with a displacement In the forward direction of 20 mm. It is confirmed that the gradient of the axial force is about 15 kN/mm.

1.3 Cryogenics

The coil is indirectly cooled at an operating temperature of 4.5 K using the thermo-siphon technique. The liquid helium is circulated in the channels welded to the support cylinder (see Fig. 1.3). The piping was designed for a steady-state cooling flow of 30 g/sec. In

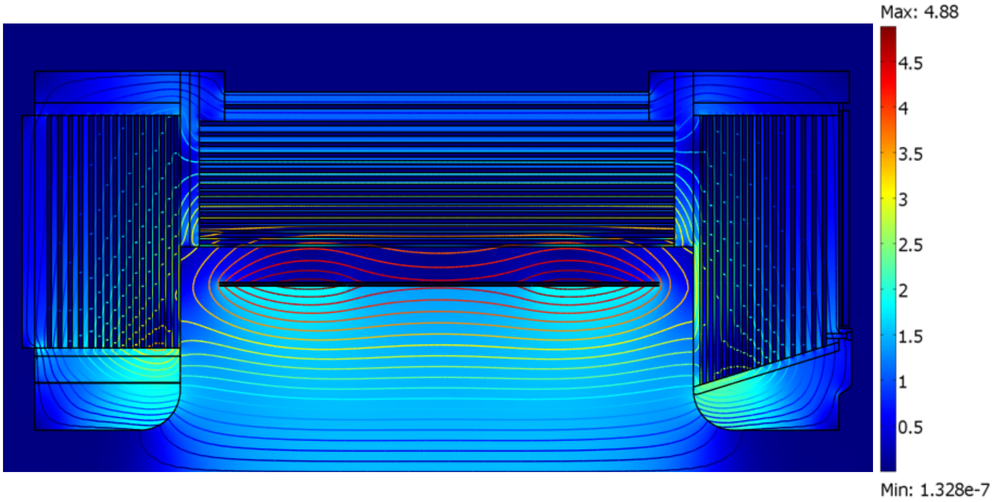

Figure 1.4: Magnetic field map (in T) in SuperB detector region. Indeed the field in proximity of the magnetic axis will be partially shielded by the anti-solenoids of the final focus. In this simulation the superconducting coil is axially displaced of 20 mm in the forward direction (right In the figure).

the BaBar magnet, cooldown and cryogenic supply to the coil and 40 K radiation shields was accomplished by a modified Linde TCF-200 liquefier/refrigerator. Liquid helium and cold gas from the liquefier/refrigerator and its 4000 liter storage dewar was supplied to the coil and shields via 60 m long, coaxial, return gas screened, flexible transfer line. A similar, though updated system, is being implemented for SuperB. However the proximity cryogenics integrated with the magnet (and hosted in the turret) will remain unchanged. The schematic of the cooling system is shown in Fig. 1.5. It is possible to cool down the coil by a mixture of warm and cold He gas or by supplying colder and colder gas through the refrigerator. The shields are cooled by part of gas coming back from coil. The cool-down at SLAC took about a week. The heat load measurement at 4.5 K was performed by closing the input valve to the 4000 liter control dewar and by measuring the LHe consumption in that dewar. This test gives pessimistic information because the transfer line losses. When coil was powered at 1.58 T the mass flow rate per lead (at a voltage across each lead of 40 mV) was 90 NLP/m corresponding to a heat load of 5 W per lead. Mixing these data and considering that 3 W loss can be due to the transfer line we can assume that heat load is between 19 W and 24 W + 14 l/h. This very low value of the loss is partially due to the shield temperature. The shields were cooled by cool helium gas coming from the LHe reservoir in the Valve Box. The shield temperatures range between 37 and 49K with a mass flow rate of 0.35 g/s. Since the enthalpy variation of helium gas at atmospheric pressure between 4.5 and 45 K(average shield temperature) is about 250 J/g, the total load at the shield is 87 W. We can assume the same heat load values for the magnet in the SuperB configuration. Presently two options are open regarding the refrigerator: 1) reuse of the BaBar refrigerator, 2) procurement of a completely new refrigerator better sized for the solenoid and for the other superconducting magnets of SuperB accelerator (namely the final focus quadrupoles).

1.4 Current supply and protection system

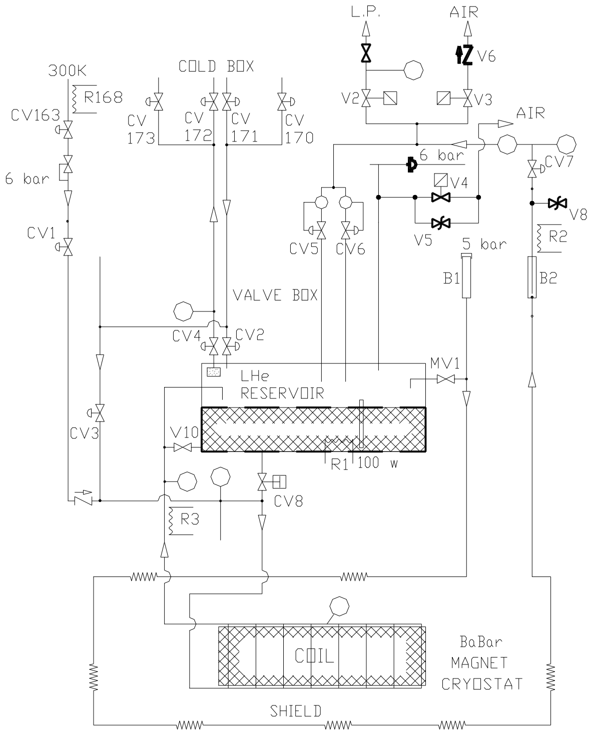

Figure 1.5: Schematic of cryogenic circuit with proximity cryogenics, which is completely integrated with the magnet. The reservoir, the valves and the current leads are hosted in the turret visible in Fig.1.2

The SuperB magnet will be electrically operated with the same circuit involved in BaBar magnet. The scheme is shown in Fig. 1.6 The magnet is fed with current with a 5 kA - 20 V two quadrants power supply. The solenoid is protected with a resistor electrically connected in parallel. The solenoid is protected with the usual method of a resistor in parallel. If a quench is detected (50 mV unbalance signal between the two voltages in two layers), the breakers opens closing the current in coil and dump resistor. The peak voltage at the coil ends can be as high as 340V. Considering that the center tap of the dump resistor shall be shorted to ground, the maximum voltage to ground is 170 V. The fast discharge from the nominal current causes a quench due the heating of the supporting cylinder (Quench Back). The coil temperature increases to 37 K uniformly. In these conditions about 5 hours are needed to cool-down the coil again, fill the reservoir and be ready for re-charging.

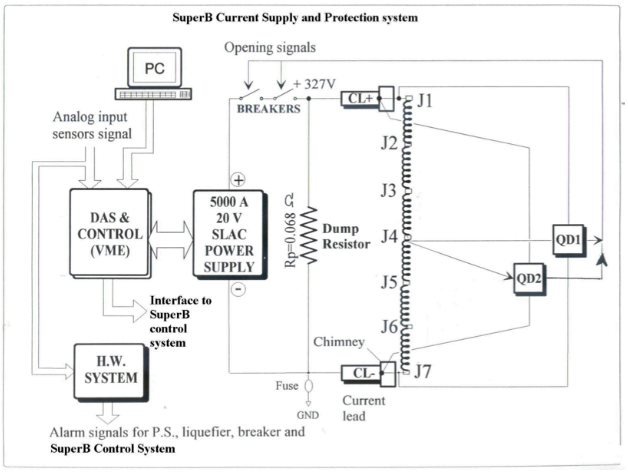

Figure 1.6: Electrical scheme for current supply and protection system

1.5 Plan for reusing the BaBar magnet equipment.

The superconducting solenoid and its ancillaries used in *BABAR* experiment at SLAC can be largely reused for Super*B* with a suitable refurbishing. The items involved are the following:

1. The superconducting coil composed of the cold mass (weight 7.8 t), the cryostat (3.0 t) and the valve box (0.8 t);
2. the dump resistor (1.2 t);
3. the power supply (5 kA, 20 V);
4. two racks with controls (0.3 t);
5. the vacuum pumps and related systems:
6. the transfer line and quench line;
7. the breaker for 5 kA;
8. Cables and miscellaneous hardware;

9. the cold box, the compressors, and the refrigerator controls.

Altohough some options are still pending, we report here the most credible scenario.

Superconducting solenoid. The coil has been dis-assembled (the turret has been removed) and it is presently mounted inside the transportation tool. There is a point to be fixed with relation to the cold mass blockage in the cryostat. Though the supporting system should be able to hold the transportation loads (3g vertical , 2g axial and 1.5 g lateral), when delivered to SLAC the cold mass was blocked wrt the cryostat. Prior to transport the solenoid back to Italy the flanges shall be removed and the transportation blocks re-applied. The same consideration applies to the valve box enclosed in the turret. A preferred option for the transportation is through a dedicated flight as done for the delivery to SLAC, because there are much less risks with respect possible damages. Once in Italy the solenoid should be reassembled in an area close to SuperB site (few chilometers) for allowing a cryogenic test before final assembly in the detector. Sensors on tie rods (strain gages and thermometers) are no more working. The re-assembly on site shall include a replacement of the sensors, a re-alignment of the cold mass, a re-connection of the current leads (with restoration of the electrical insulation).

Dump resistor, quench detectors and breakers . All these components are reusable after a check of their conditions. The breakers could need a maintenance.

Power supply and control system. The reuse of these electronic components puts many problems partially related to allowed standards (rules related to the use of electrical equipment) and partially due to their not negligible age. The plan is to procure these components as new.

Cryogenic devices . In principle the refrigerator could be reused, but its re-installation and commissioning in Italy would require the involvement of Linde and of the SLAC personnel, who operated the system (the control system was developed at SLAC). The cost of this operation is presently unclear and involves a lot of expert manpower. Further there are risks for using a machine now 15 years old, to be operative for further 15 years. The screw compressors shall be replaced in any case. The same consideration applies to whole cryogenic equipment but the flexible transfer lines. The option for a new refrigerator more sized for solenoid and final focus superconducting magnets has been studied.

As verified later the blocks were only used for the thermal shield