The Final Design of the R3B-GLAD Cold Mass Assembly and Manufacturing Status

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***Abstract*—The R3B-GLAD (GSI Large Acceptance superconducting Dipole) magnet provides the magnetic field needed for the R3B (Reaction studies with Radioactive Relativistic Beams) experiment which will be implemented on the future FAIR Facility (Facility for Antiproton and Ion Research).**

There are six trapezoidal racetrack coils for the R3B-GLAD magnet. Two main coils and four lateral coils are connected in series in a butterfly-like shape. The total weight of the six coils is 5.2 t.

The cold mass assembly consists of coils, coil-casings, structural linking components and other non-structural components. The cold mass assembly weighs 22 t with envelope dimensions of 3.1 m (L) x 4.6 m (W) x 2.8 m (H). It is supported by the three cold to warm cryogenic supports.

The magnet configuration was finalized in June 2008. The final cold mass design was accomplished end of July 2008. The manufacturing of the cold mass assembly has been launched since January 2009. The cold mass will be ready for test in the test station at CEA Saclay by the end of 2010.

This paper gives an overview on the final design of the R3B-GLAD cold mass assembly and manufacturing status.

***Index Terms*—Superconducting magnet, engineering design, mechanical computation, FAIR R3B.**

I. Introduction

THE R3B-GLAD superconducting magnet provides the field needed for a large acceptance spectrometer, dedicated to the analysis of reactions with relativistic radioactive ions beams [1][2]. The technical study of the magnet has been carried out since 2006 [3]. The magnet configuration was finalized in June 2008. The final cold mass design was accomplished end of July 2008. The manufacturing of the cold mass assembly has been launched since January 2009.

II. Mechanical Design of the R3B-GLAD Magnet

An overview on the R3B-GLAD magnet design is shown in Fig. 1. With the cryogenic satellite on side, the overall dimensions of the magnet are: 4.0 m (length) x 7.8 m (width) x 4.5 m (height). The total weight of the magnet is 50 t. The vacuum vessel of the magnet consists of an outer vessel and an inner vessel inside where the particle beam passes.

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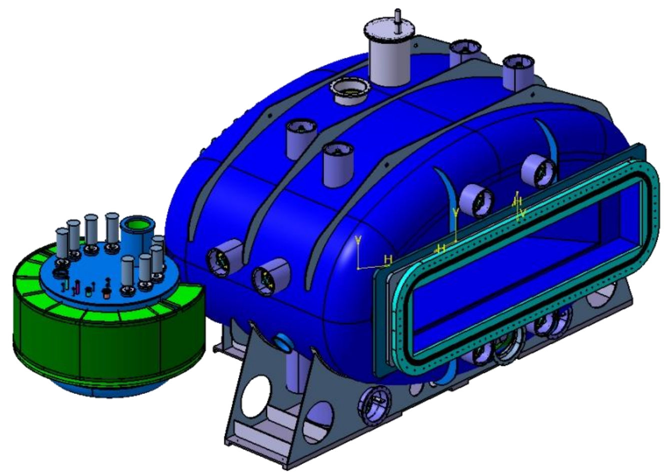

Fig. 1. Overview on the R3B-GLAD magnet in its cryostat with satellite.

The main components of the cryostat are vacuum vessel, thermal shield, cold to warm supports, cooling tubes on the coil casings and on the thermal shields, liquid helium tank, buses for electrical interconnections and for instrumentation (Fig. 2). The engineering design of the cryostat is in the final design phase.

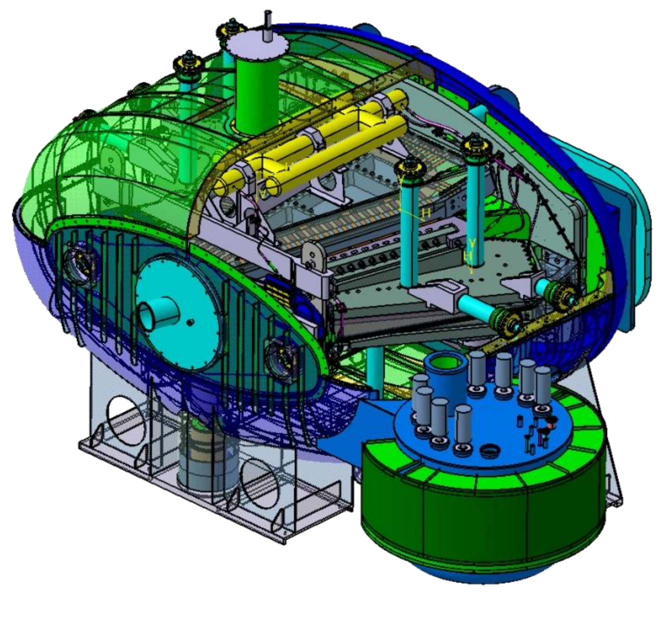

Fig. 2. Main components of the cryostat: the cold mass (grey) with the thermosiphon cooling reservoir (yellow) inside the cryostat (blue) with thermal screen (light green) and satellite (blue & green).

III. Cold Mass Assembly

There are six trapezoidal racetrack coils for the R3B-GLAD magnet. Two main coils and four lateral coils are connected in series in a butterfly-like shape. The six coils are tilted with respect to the beam direction. The total weight of the six coils is 5.2 t.

The cold mass assembly (Fig. 3) consists of coils, coil-casings, structural linking components and other non-structural components such as: cooling tubes, liquid helium tank (new layout in the final design), and buses for electrical interconnections and instrumentation. The cold mass assembly weighs 22 t with envelope dimensions of 3.1 m (length) x 4.6 m (width) x 2.8 m (height). It is supported by the three cold to warm cryogenic supports.

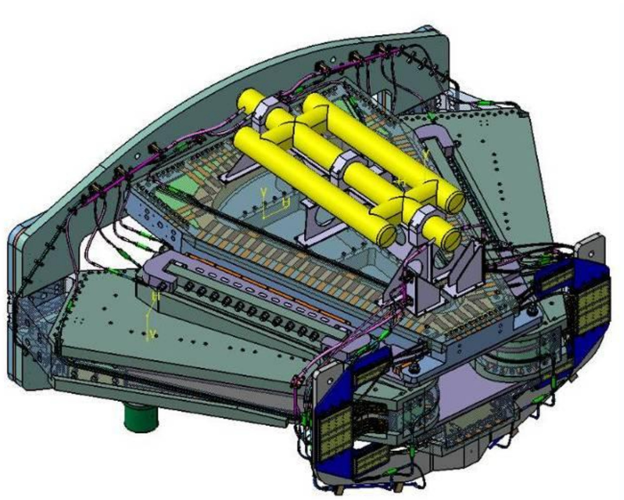

Fig. 3. The cold mass assembly including coils, coil-casings, structural linking components and other non-structural components.

IV. Mechanical Behavior of the Cold Mass Assembly

A. Magnetic forces with final magnet configuration

The resultant magnetic forces of each coil and the relative forces between the 6 coils are shown in Fig. 4.

In the horizontal plane of each coil, the magnetic forces are generated in the outward direction (expanding effect of the coil). In the normal direction of each coil, the magnetic forces are all towards the mid horizontal plane of the cold mass assembly.

The internal space of the cold mass structure is entirely reserved for the beam vacuum chamber. In order to resist to the closing effect (in the vertical direction) of the two main coils, arches are introduced at the wide end of the cold mass structure.

In the horizontal direction, the lateral coils on each side trend to be away from each other. The linking plates between lateral coil-casings are introduced to resist to these horizontal magnetic forces directly.

The implantation of wedges in-between each coil and coil-casing and the associated pushing system on each coil in order to ensure the coil positioning inside coil-casing have been studied in the final design phase.

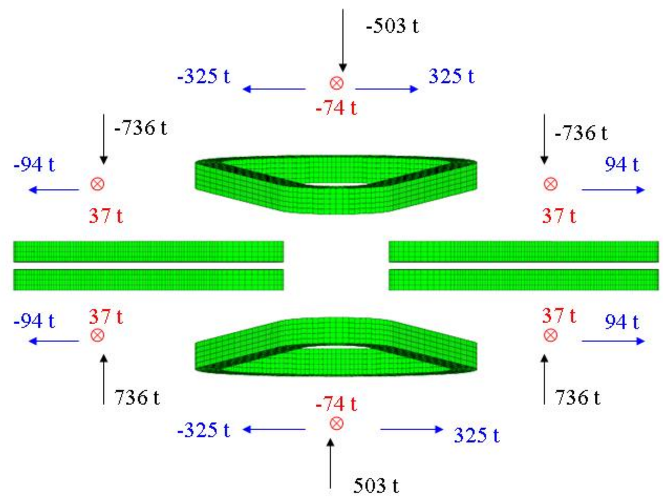

Fig. 4. The resultant magnetic forces of each coil and the relative forces between the 6 coils.

B. Thermal stresses in the coils after cool-down

The global FEA model [3] has been updated with final design configuration of the cold mass structure. Geometrical details of coils, coil-casings including wedges, all the structural linking components have been represented by solid elements in the FEA model (ANSYS software).

The conductor is a complex mixture between Copper, Nb-Ti, glass fibers and epoxy resin. The mechanical and thermal properties of the coils used for the final global calculation of the cold mass structure are based on the experimental results [4].

All the contact surfaces in-between: coil and coil-casing, coil and wedges, wedges and coil-casing, are represented by contact elements in the FEA model.

The coil is with copper stabilizer and the coil-casing is made of aluminum alloy, the difference on the thermal shrinkage between coil and coil-casing is considerable. In order to avoid over-stress in the coil after cool-down, initial gaps between coil and wedges have to be set during the warm assembly phase. The values of the necessary initial gaps have been defined through FEA calculations. The main results are shown in the Fig. 5.

When the cold mass is cooled down from 300 K to 80 K, the initial gap is closed. The final obtained pre-stress on the coil is the thermal stress generated during the cool down from 80 K to 4 K. The thermal Von Mises stress contours in the main coil and in the lateral coil after cool-down to 4K are shown in Fig. 6 and Fig. 7. In the main coil (Fig. 6), the thermal stresses are generally less than 50 MPa except some local stress concentrations around 102 MPa; in the lateral coil (Fig. 7), the thermal stresses are all less than 60 MPa.

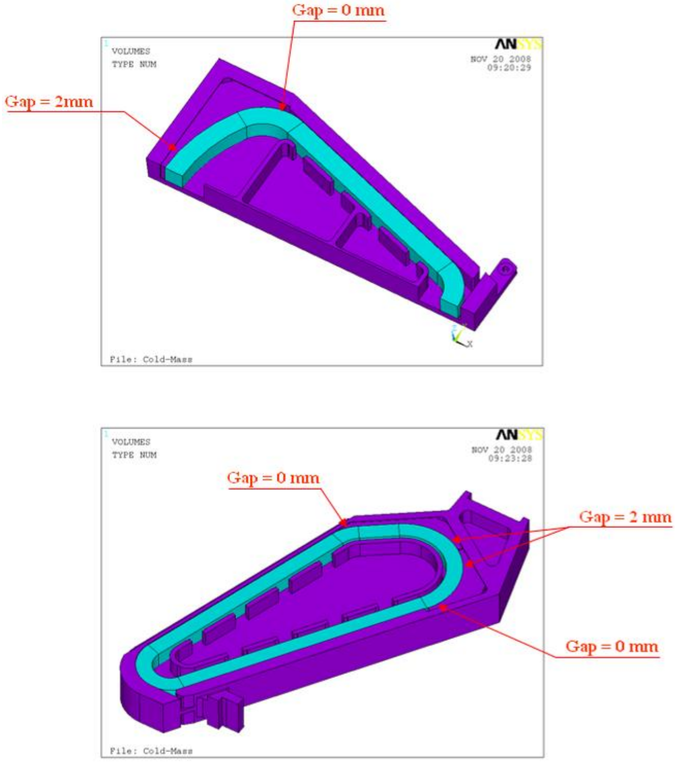

Fig. 5. The necessary initial gaps between coil and wedges during warm assembly phase (upper view: main coil, lower view: lateral coil).

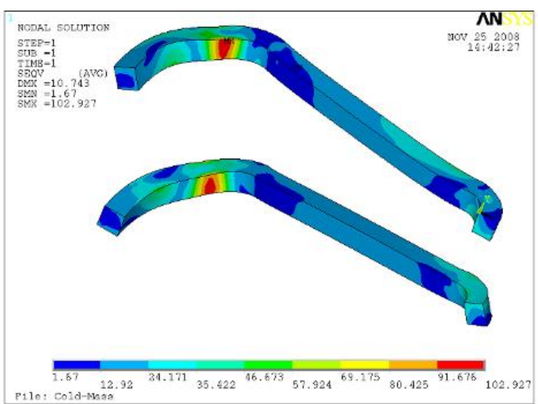

Fig. 6. In the main coil, the thermal stresses are generally less than 50 MPa except some local stress concentrations around 102 MPa.

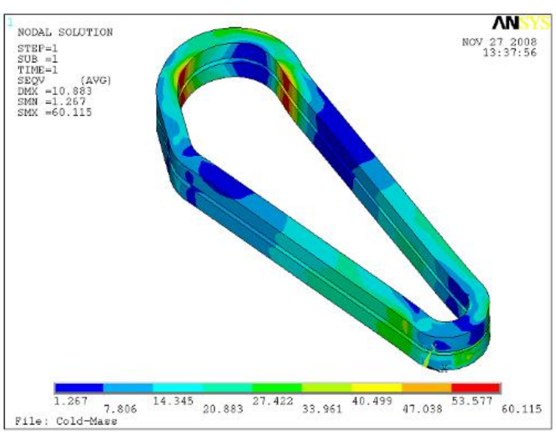

Fig. 7. In the lateral coil, the thermal stresses are all less than 60 MPa.

C. Deformation and stresses during energizing phase

The deformation of the overall cold mass structure is within 2.7 mm (Fig. 8). The maximum deformation of 2.7 mm occurs in the arch.

The deformation in the vertical direction in the median plane of the main coil, occurring at the wide end, is 0.7 mm. The deformation in the horizontal direction of the lateral coil is 0.4 mm.

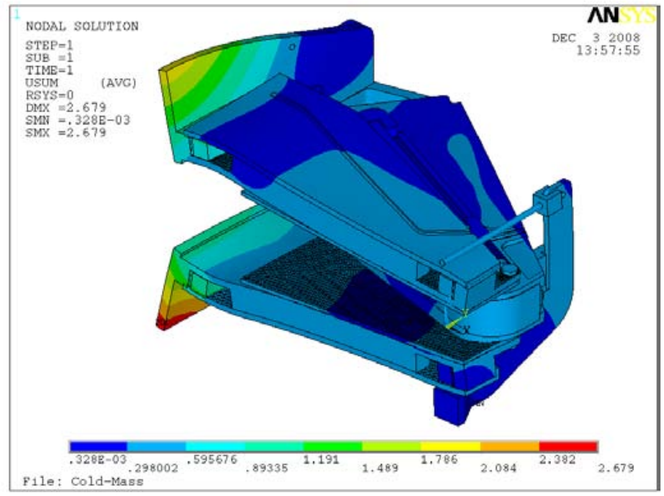

Fig. 8. Deformation contour [mm] of the cold mass structure during magnet energizing.

The stresses in the cold mass structure during magnet energizing are generally less than 60 MPa. Fig. 9 shows the Von Mises stress [MPa] distribution in the lateral coil.

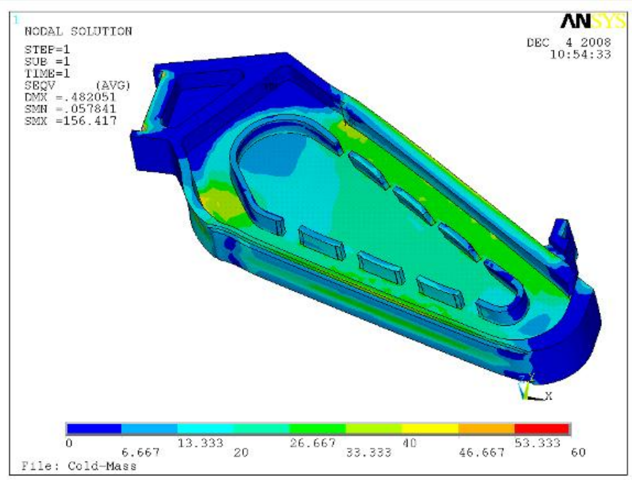

Fig. 9. The Von Mises stress [MPa] distribution in the lateral coil during magnet energizing.

V. Manufacturing of the Cold Mass

A. Coil- casing machining

The coil-casings are machined from aluminum alloy 5083 blocks, without any welds. All the blocks have been ultrasonic controlled and their mechanical characteristics have been checked.

In order to ensure the final precision needed for the integration of the coils in their casings, wedges are introduced in between the coil and casing. The casings and wedges are machined in two steps. The first step is a pre-machining (Fig. 10 and Fig. 11). The final machining of the casings and of the various wedges will occur only once the coils have been wound and impregnated, according to their final dimensions.

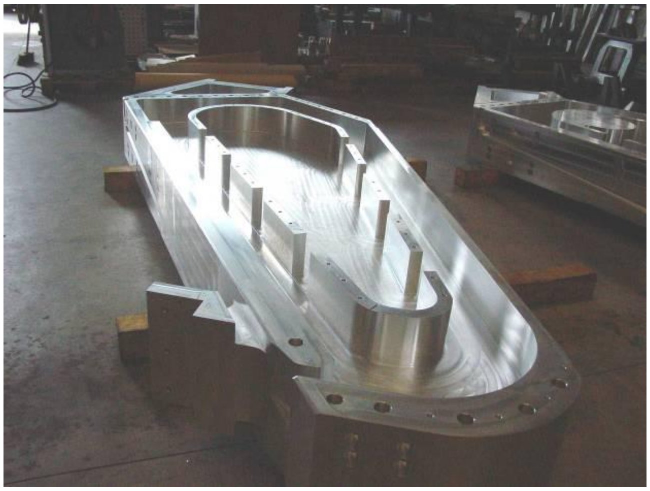

Fig. 10. Lateral coil casing after pre-machining (*courtesy of ASG Superconductors S.p.A., Genova, Italy*)

Fig. 11. Wedges after pre-machining (*courtesy of ASG Superconductors S.p.A., Genova, Italy*)

B. Coils manufacturing

The coils are made of four (for lateral coils) or five (for main coils) double-pancakes. Each double-pancake is wound on a mandrel. The double-pancakes are stacked on a special tool, for receiving fiberglass ground insulation before impregnation (Fig. 12).

The impregnation is made in a special mould, designed to the dimensions of the coils. To avoid pure resin volume, it is adjustable.

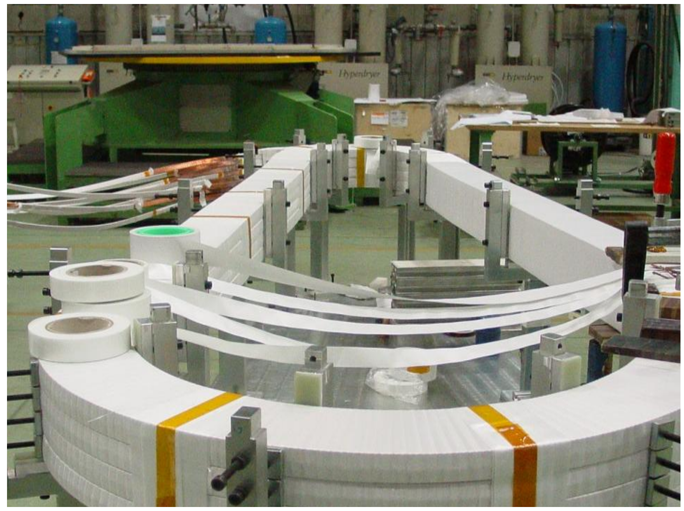

Fig. 12. The double-pancakes are stacked on a special tool, for receiving fiberglass ground insulation before impregnation (*courtesy of ASG Superconductors S.p.A., Genova, Italy*)

VI. Conclusion

The R3B-GLAD cold mass assembly has been designed to fulfill the magnetic and mechanical requirements. The manufacturing of the cold mass assembly has been carried out since January 2009. The cold mass will be ready for test in the test station at CEA Saclay by second half of 2010.

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