Construction of the ATLAS B0 Model Coil

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***Abstract* – The B0 coil is a technological model for the ATLAS Barrel Toroid coils. The major concepts and the construction procedures are the same as those specified for the BT coils. So the manufacturing feasibility has been extensively proved and the technological developments have been carried out for the industrial production of conductor, the welding technique of the coil casing, the prestress of the coil with bladders, the cold to warm supports, the construction and assembly of the cryostat. The paper illustrates all these phases.**

INTRODUCTION

The very early design of the Barrel Toroid (BT) was reported in 1993 [1] and further developed in 1995 [2]. The BT consists of eight flat race track coils assembled radially around the beam axis. The main parameters are listed in table I for BT and B0.

The motivation and the main aspects of the present technical design have been presented in 1997 [3][4]. No major changes of the basic design took place. Practical solutions have been developed within the B0 model coil project [5].

Many specific developments have been undertaken such as electron beam welding of the massive coil casings, proof test of the suspension rod behaviour, prestressing of the coil winding. The B0 coil has the same size as the BT coils in terms of width and cross section but a length of only 9 m so as to minimize the cost and the required means.

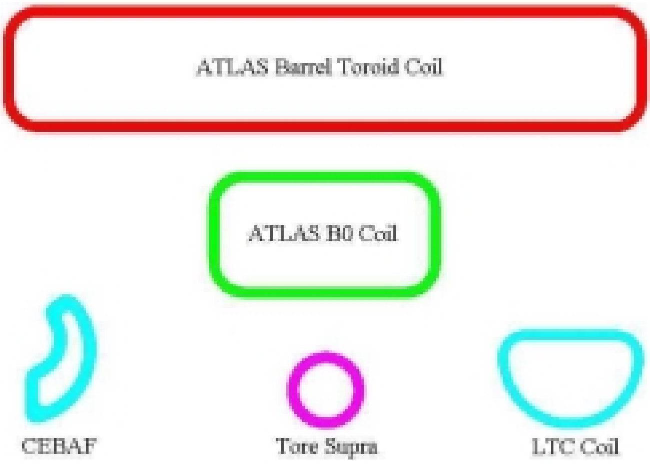

Fig.1. Comparison of size of existing coils and ATLAS coils

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TABLE I
UPDATED MAIN PARAMETERS OF THE BARREL TOROID

Overall characteristics :	BT	B0
Inner bore	9.4 m	
Outer diameter	19.5 m	
Axial length	26 m	9 m
Cold mass (incl. conductor)	8 x 47 tons = 376 tons	20 tons
Coil (incl. cryostats)	8 x 87 tons = 696 tons	37 tons
Total weight	832 tons	
Winding :		
Pancakes/coil	4	
Turns/pancake	30	
Operating current	20.5 kA	
Operating temperature	4.8 K	
Total ampere turrns	19.68 MAT	
Stored energy	1080 MJ	46 MJ
Peak field	3.8 T	4.2 T
Conductor :		
Size overall	57 x 12 mm^2	
Total length	56 km	1.7 km

I. COLD MASS CONSTRUCTION

A. Winding

The concept of coil manufacturing is based on winding the double pancake on a temporary mandrel and impregnating it inside a mould (under a 5 MPa prestress).

A specific and very efficient winding tool has been developed in industry. The double pancakes, are extracted from the winding mandrel after winding and receive a wrapped ground insulation before insertion in the impregnation vacuum vessel. A shear tissu is also wrapped. The as built dimensions of the double pancakes gave satisfaction especially the flatness. (see Fig.2)

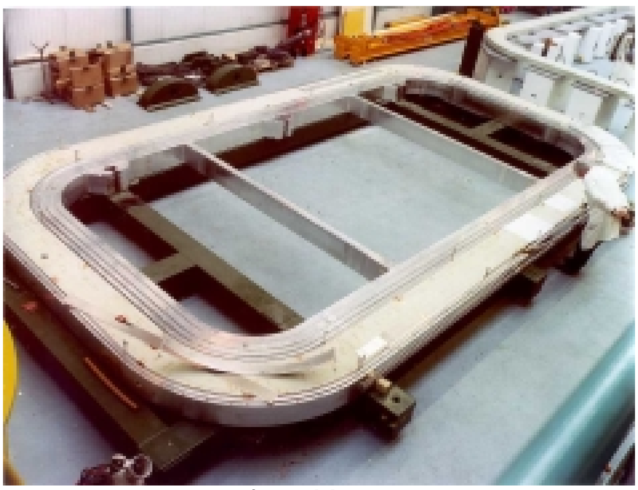

Fig. 2 View of B0 coil during integration #1

B. Coil Casing

For the construction of the B0 coil casing, elements made of 7-ton rolled billets are premachined and assembled by electron beam welding. The depth of this welding is limited to 120 mm. See the cross section fig.3

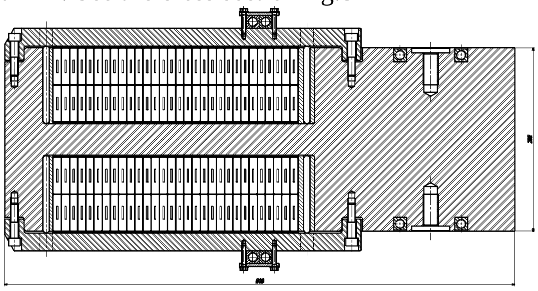

Fig.3. Cross section of the cold mass

C. Integration n°1

Integration n°1 consists in mounting and prestressing the windings in the coil casing. After impregnation, the insulated double pancakes are transferred into the coil casing where they are glued under radial precompression (12 MPa). The technique developed to impose the prestress is to use inflatable bladders on each side of the superconducting winding. The bladders are made of aluminum and are filled with glass microballs and impregnated with liquid epoxy resin. Once pressurised the bladders act as hydraulic jacks, putting the double pancake coils in compression and the coil casing in tension. After curing under pressure, the bladders work like shims under the compression due to the tensile strain stored in the coil casing. During the polymerisation the coil is heated uniformly from room temperature to 120° C by a direct current up to 800 A. The outer part of the coil casing protected by a special blanket is in natural convection with air at room temperature. A transient non linear 3D finite element analysis has been carried out in order to compute the temperature distribution and the thermomechanical stresses with the ramping time of 20 hours [6]. A lot of practical experience has been gained by the setting up of integration n°1: It has been concluded that the heating with the Joule effect in the winding should be very slow to limit the risk of differential constraints.

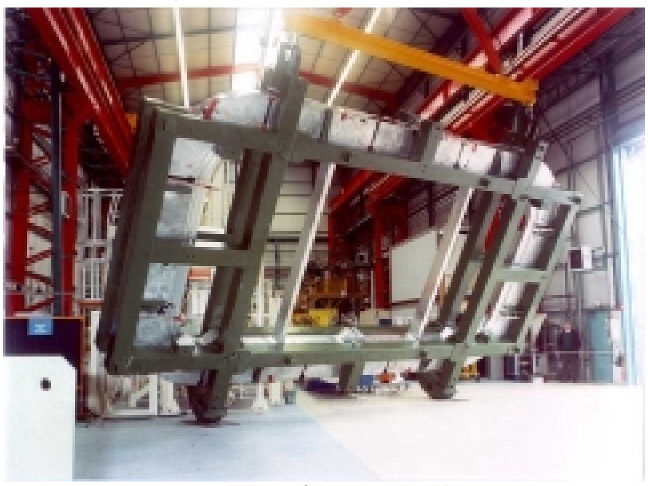

Fig 4 Handling of the B0 Coil cold mass

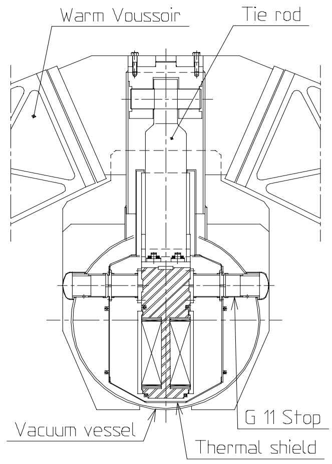

Fig 5 Cryostat and tie rod cross section

II. Cryostat

A. Tie Rods

The cold mass (Fig.5) is suspended by eight articulated titanium rods from vacuum vessel reinforcements which withstand net radial magnetic forces up to 180 kdaN. Three tie rods prototypes have been forged and machined for B0, in the TA5E ELI grade. A special cryostat (see fig. 6) has been built for testing them under load in cryogenic conditions and the three tie rods have been tested under a tension effort of more than 250 tons. The tie rod installation is representative including thermalisation at 77 K. The foot of the tie rod is inbedded in a local 1/1 model of the coil casing. This bulk part is the bottom of a vacuum vessel immerged in a helium reservoir. The tie rod is instrumented with a set of straingages. The tension effort is given, under load, by the average of the two straingages located on the tie rod web. The working point of the tie rod remains clearly in the linear section of the measured curve.

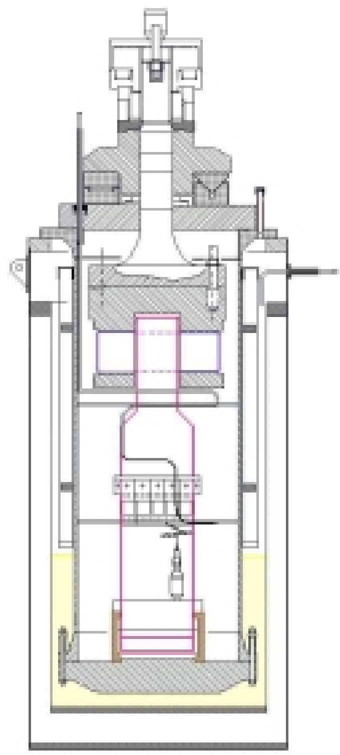

Fig.6 Schematic of the tie rod test

Fig.7 Set of cryogenic stops

B. Cryogenic stops

For the ATLAS B0, 24 cryogenic stops (Fig. 7) have been built. The cool down of the coil induces a sliding between the warm and the cold parts. This sliding is performed by a swivel. The cryogenic stops have been extensively studied both on calculation and experimental aspects. A global 3 D model has been prepared for analysis of all loading cases. The angle of the filamentary winding has been computed taking in account the thermal contraction of materials. During a rapid discharge, eddy currents are generated in the shield panel, and create a Laplace force on the shields. This force of 1 ton is picked up by the cold ferrule which support the shields. A special test facility has been used to test the cryogenic stops.

C. Integration n° 2

The integration n°2 consists in all the cryostating operations :

Assembly of the cold mass cooling pipes: It mainly consists in welding the unit pipes to create the complete coil casing lines with their bimetallic transition at each end, bending the pipe to follow the coil casing and testing the tightness inside a special flexible vacuum chamber. This last test includes a nitrogen thermal shock. Two steps are separated by the cold mass turn over. It allows to work on each side of the cold mass mainly to glue the cooling lines in the groves of the coil casing and on the cover plates.

Tie rod assembly : The mass of one tie rod is about 50 kg. Shims and special tools to prestress the washers have been used. The head of the tie rod has been equipped after the shield assembly. The mass of the head is roughly 300 kg, so a handling tool was used for assembly. The thermalization of the tie rod is made with a special piece fixed and glued on its web.

Thermal shield assembly : The C panels came with their welded tube. The tightness of each line was checked with a helium leak test. After installation with tools and supports, the C panel pipes are welded together. Then the complete lines to the outlet location of the vacuum vessel have been realised.

Superinsulation assembly : Each panel is covered by three layers of blanket, fixed to the shield by special items. Many holes are included for the different supports, such as the tie rods or the cryogenic stops, and the instrumentation wires.

Lower half vacuum vessel preparation : Before putting the cold mass into the vacuum vessel, the lower half shell has been equipped with the warm sleeves of the cryogenic stops. The height of each sleeve give the relative position between the cold mass and the vacuum vessel symmetry planes. The adjustment of the sleeves before welding on the vacuum vessel is done with accuracy of 0.2mm.

Cryogenic stop assembly : The cryogenic stops have been prepared. The sliding pieces are fixed on the cold sleeves and the swivels are mounted on the warm ones. The cold sleeves are mounted on the cold mass with the proper instrumentation. The warm sleeves are mounted in two steps. First before to lay down the cold mass in the lower half shell. Second, after the tie rod adjustment and before the closing weld of the vacuum vessel.

Cold mass installation : The cold mass, equipped with the thermal shield and superinsulation, is laid down into the lower half shell. When the cold sleeves contact the warm sleeves, the swivels accommodate the geometry or misalignment of the plane. During this operation also the instrumentation including the wires and terminations of the conductor which must go through the cryogenic line connection are installed.
The central rib of the cold mass is centreed in relation to its vacuum vessel with an accuracy of less than 1 mm.

Upper half vacuum vessel placement : The upper half shell has been positioned on top of the lower one. During this operation, all the wires are passed through their respective flanges. Mechanical adjustment is performed. Ground insulation test on the coil is made before welding.

Tie rod adjustment : With special tools, the cone and the lug of the tie rod are moved to have the correct inclination. Then, after each tie rod adjustment, the cones are welded on the vacuum vessel.

Vacuum vessel closing: The upper warm sleeves are installed in contact on the cold ones through the vacuum vessel holes. The weld is completed all around the vacuum vessel. After the closing weld, the test turrets are mounted and an helium leak test is done with the connecting flanges on the instrumentation ports. Then the stiffener plates are welded.

Finishing operations : The finishing operations consist of the cryogenic ring preparation. The terminations and the pipes come out of the cryoring ports. The whole instrumentation is checked and a final ground insulation test is made on the coil.

Fig. 8 View of the cold mass assembly in the lower half vacuum vessel

Fig. 9 The B0 vacuum vessel under final completion

D. Quench Heaters

A special technology has been optimised for producing robust quench heaters. A 0.4 mm thick sheet of 304 stainless steel is laser cut to form a resistor and insulated with prepreg. A plate of Titanium alloy is embedded along this resistor to create an asymmetry in the heat diffusion. All these different elements are vacuum impregnated in a machined mould, resulting in a flat object of 120 mm X 800 mm X 10 mm. This quench heater is taking the location of the shimming plate in the middle of the internal layer. It is supplied with a 30 A direct current and it is able to support up to 2 kW during a short burst.

E. Instrumentation

The B0 coil has been widely instrumented The sensors are the following :
The voltage taps are directly screwed in the aluminium of the conductor with special care for keeping the right ground insulation. A first set of 17 voltage taps is dedicated to the quench detection of the magnet safety system. The locations are the current leads, the sensitive internal junctions, the inlets/outlets of the double pancakes. A second set of 48 voltage taps has been distributed around the heaters for propagation studies. 16 flux coils (of NS = 0.5 m^2) are also foreseen for measurement of the propagation velocity. 81 compensated strain gages allow to control the mechanical behaviour and to check experimentally the F.E calculations of forces and deformation particularly on tie rods , cryogenic stops and coil casing. The cooling down and the steady state temperature map will be controlled by 22 carbon sensors, 28 CLTS, 44 Pt resistors and 3 thermocouples. 4 points heaters are triggering the quench for quench propagation studes and 4 protection heaters, controlled by the Magnet Safety System, are triggering the quench.

III Schedule

In terms of schedule, the construction was decided in June 1997. The most critical items have been conductor and coil casing. All the assembly has been done in 9 months.
After transportation to CERN site an extensive test programm will be applied to B0 in 2001.

IV. Conclusion

The main industrial orders of the B0 coil have been placed with european companies : Europa Metalli (I) for conductor, Ansaldo (I) for winding, ZANON (I) for cryostat, NFM Technologies (F) for coil casing and Technoplus (F) for cold mass integration.
The main items of the BT coils are already validated :
- production, verification and use at full scale of very long pieces of conductor,
- setting up the winding of technique, of the vacuum impregnation and of the prestressing inside the coil casing
- setting up of the manufacture of the coil casing by E.B welding
- setting up of cryogenic supports, thermal shields and assembly
- Quality control plan and training of personnel for the industrial phase.

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Références

[1] H. DESPORTES MT 13, IEEE Trans. On Magnetics 1525, vol.30.
[2] A. DAËL et al MT14 IEEE Trans. On Magnetics 2047,vol 32 (1996).
[3] A. DAËL et al. MT15 proceedings Beijing October 1997. Science Press. Beijing CHINA
[4] ATLAS Barrel Toroid TDR – CERN/LHCC/97-19 (1997)
[5] A.DAEL et al. MT16 IEEE Trans. On Applied Superconductivity n°1 March 2000 P. 361
[6] C. PES Temperature distribution and thermal stresses analysis during the heating of the coil. Sept. 2000 CEA int. Rep.