ATLAS Superconducting Toroids and Solenoid

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***Abstract*—The ATLAS particle detector in the Large Hadron Collider at CERN features a hybrid system of four superconducting magnets: a Central Solenoid surrounded by 2 End-cap Toroids and a Barrel Toroid. The magnet system dimensions are 20 m in diameter and 26 m in length. With its 1.55 GJ stored energy in air, it actually is the largest superconducting magnet in the world. The construction of the magnets has started in 1998 and will end in 2006 with the completion of the installation underground. Currently, in October 2004, practically all magnet parts are manufactured and delivered to CERN for final integration. The first two out of 8 full size $25 \times 5\ \mathrm{m}^2$ size coils for the Barrel Toroid have been completed and tested while the other 6 are near to completion as well. The production of the so-called End-Cap Toroids is progressing well. The Central Solenoid is complete and ready for installation. The installation underground of the entire system including its services has commenced. In the paper the main features of the magnets, their common infrastructure and services are reviewed and the status of realization presented.**

***Index Terms*—Cryogenics, magnets, particle detector, solenoid, superconductors, toroids.**

I. Introduction

THE ATLAS Collaboration, about 150 institutes in 34 countries and 1700 scientific authors world-wide including CERN, is preparing the ATLAS Experiment at the new Large Hadron Collider at CERN. ATLAS is a general-purpose detector, which will analyze proton-proton collisions of 14 TeV level starting in year 2007. For analyzing the collision products a specific distribution of magnetic field in the detector space of 8000 m^3 is requested by the various detector communities. ATLAS optimized the configuration and decided to construct a hybrid system of 4 superconducting magnets: a Central Solenoid (CS) providing 2 T axial magnetic field for the central detector, and a Barrel Toroid (BT) and two End-Cap Toroids (ECT) that generate the tangential magnetic field of about 1 T for the muon detectors.

The position of the 4 magnets in the detector is illustrated in Fig. 1. The Central Solenoid, hidden in the Liquid Argon Calorimeter cryostat produces the axial component of the magnetic field parallel to the beam. At either end of the Central Solenoid an End Cap Toroid generates the tangential magnetic field in the forward direction of the experiment and essentially transverse to the beam axis. The End Cap Toroids are 5 m wide and have an outer diameter of 11 m. The core of the experiment comprising the Central Solenoid with inner detector, the various calorimeter and both End Cap Toroids is surrounded by the large Barrel Toroid with 9.5 m inner diameter and 22 m outer diameter. The main parameters of the magnet system are listed in Table I. Further system overviews in general are published elsewhere [1], [2].

TABLE I
Main Design Parameters of the Magnets

Property		Unit	Barrel Toroid	End cap Toroids	Central Solenoid
Size:	Inner diameter	m	9.4	1.65	2.46
	Outer diameter	m	20.1	10.7	2.63
	Axial Length	m	25.3	5	5.3
	Number of Coils	--	8	2 x 8	1
Mass:	Conductor	Tons	118	2 x 20.5	3.8
	Cold mass	Tons	370	2 x 160	5.4
	Total assembly	Tons	830	2 x 2.39	5.7
Coils:	Turns/coil	--	120	116	1173
	Nominal current	kA	20.5	20.7	7.6
	Magnet stored energy	GJ	1.08	2 x 0.25	0.04
	Peak Field	T	3.9	4.1	2.6
Conductor:	overall size	mm^2	57 x 12	41 x 12	30 x 4.25
	Ratio Al:Cu:NbTi	--	28:1.3:1	19:1.3:1	15.6:0.9:1
	No of strands	--	38	40	12
	Strand diameter	mm	1.3	1.3	1.22
Critical current @ 5T,4.2K		kA	58	60	20.4
	RRR Al	--	> 800	> 800	> 400
	I/Ic margin @ 4.5K	%	30	30	20
	Temperature margin	K	1.9	1.9	2.7
	No. units x length	#xm	32x1730	32x800	1x9100
	Total length	km	56	2 x 13	10
HeatLoad:	at 4.5 K	W	990	330	130
	At 60-80 K	kW	7.4	1.7	0.50
	Liquid He mass flow	g/s	410	280	6-20

The construction of the magnets commenced in 1998 and will last until autumn 2005.

The magnet system in installed in the 50 000 m^3 large ATLAS cavern located 100 m underground at LHC point 1 at CERN. In summer 2003 the civil engineering works were completed and the installation underground of the magnet system has commenced and will last until end of 2006 when the last End Cap Toroid will be taken into operation.

II. Central Solenoid

The 5.3 long and 2.4 m bore Solenoid, see Fig. 2, generates 2 T at 7600 A. The coil was engineered by KEK [3], [4] and

Manuscript received October 5, 2004. This work was supported by the ATLAS Collaboration, a collaboration of about 160 laboratories and funding agencies from 35 countries building up the Particle Physics Experiment ATLAS at the LHC located at CERN, Geneva, Switzerland.

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Digital Object Identifier 10.1109/TASC.2005.849560

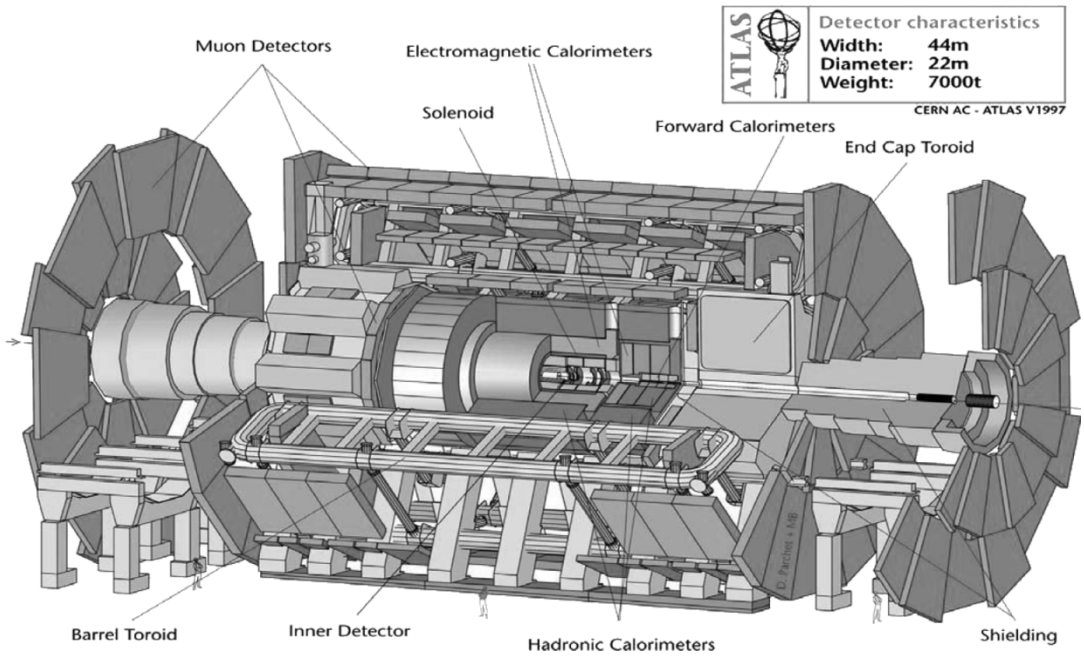

Fig. 1. Layout of the ATLAS detector also showing the 4 superconducting magnets, Central Solenoid, 2 End-Cap Toroids and the Barrel Toroid. The overall sizes are 26 m length by 20 m diameter. The entire set-up is installed at CERN 100 m underground in the ATLAS cavern.

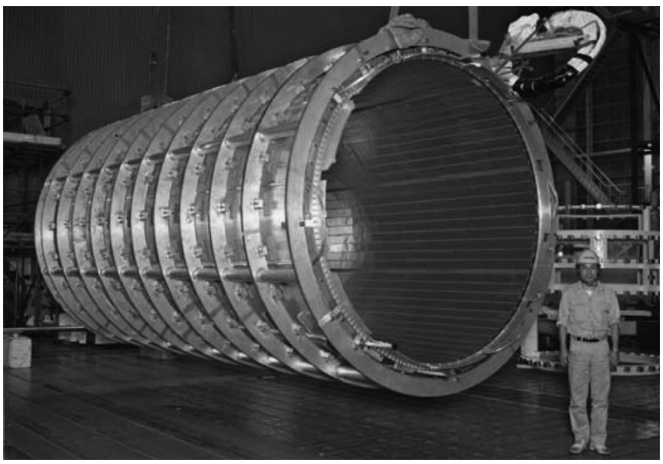

Fig. 2. Central Solenoid ready for shipment in the factory. One can see the size, the thin walled structure with temporarily supporting rings on the outside to maintain shape and the connection terminals to the services.

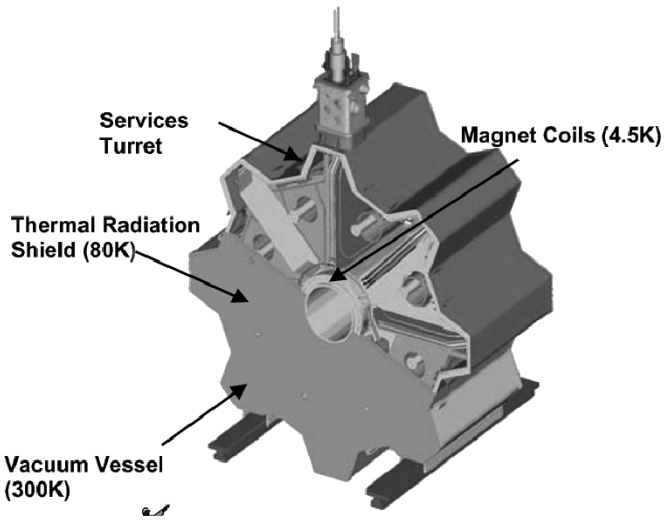

Fig. 3. End Cap Toroid design, showing the essential parts: 8 coils integrated in a single cold mass, surrounded by a radiation shield, built in a vacuum vessel and connected through a services turret.

manufactured mainly at Toshiba [5]. It is a layer coil made with a doped (for higher yield strength) Al stabilized NbTi/Cu rectangular conductor, made by Furukawa and Hitachi, wound on its thin edge inside a 12 mm thin Al 5083 support cylinder.

The coil was tested in the factory before shipment to CERN and achieved 8400 A. At CERN after integration with the LiAr calorimeter cryostat, the coil went through a final acceptance test in July 2004. The maximum test current of 8100 A was achieved after 2 training quenches, both beyond the nominal operating current. Based on this, the coil is accepted for installation, see [6]. Next is the move to the cavern in Oct 04.

III. End Cap Toroids

Two practically identical End Cap Toroids consist each of $85 \times 5\ \mathrm{m}^2$ coil modules interlinked by 8 so called keystone boxes, see Fig. 3. The cold mass is positioned on an 11 m diameter, 5 m wide vacuum vessel. The castellated shape of the vessel outer shell makes it possible to insert the End Cap Toroid with a 22.5 degree turn in the Barrel Toroid. Since the magnetic windings of the toroids overlap, the ECT is pulled inside the BT with a force going up to about 300 tons from either side, requiring a force transfer from ECT to the BT, which takes the reaction force. The design of the End Cap Toroid is essentially performed by RAL, supported during the production by NIKHEF and CERN [7]–[9].

The production of the 26 km of Al stabilized NbTi/Cu conductor with section $41 \times 12\ \mathrm{mm}^2$, produced by VAC (now EAS) and EM/Cortaillod (now Outokumpu/Nexans) is completed as well as the coil winding at Brush HMA. The $5 \times 5\ \mathrm{m}^2$

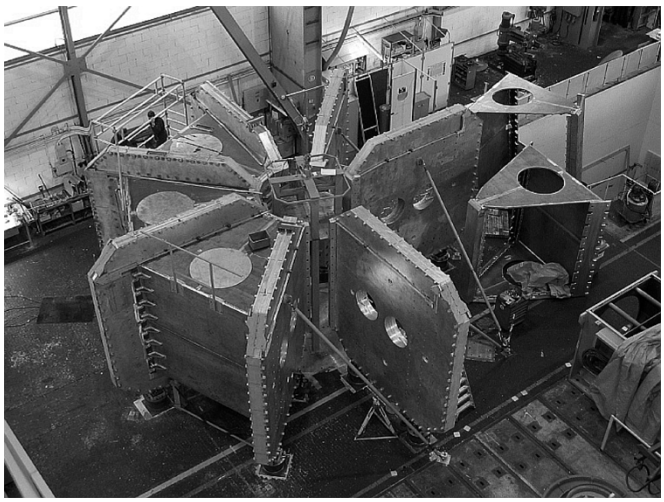

Fig. 4. End Cap Toroid cold mass in the factory, partly pre-assembled, showing the 8 coils and the 8 keystone boxes.

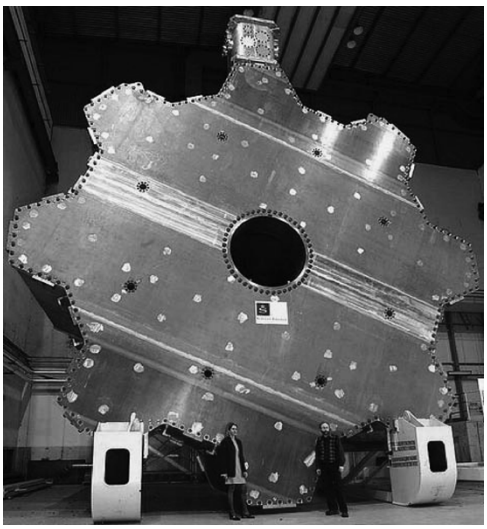

Fig. 5. End Cap Toroid vaccuim vessel, castellated outer shell, service turret on top and bore tube for the beam line and shielding.

size coil modules are a stack of Al5083 plates that sandwich 2 double pancake windings, which were vacuum impregnated in the module. The first cold mass was successfully pre-assembled at the factory, see Fig. 4, and delivered in parts to CERN where the final integration in the vacuum vessel will occur. The vacuum vessels made of Al5083, see Fig. 5, were manufactured at Schelde Exotech the Netherlands and delivered to CERN.

The first step of cryostating has been completed and the vacuum vessels are equipped with an Al thermal shield, produced by Hatehof, Israel and blankets of superinsulation made by Austrian Aerospace.

Next is the assembly of the cold masses at CERN followed by the final phase of cryostating, to position the cold masses in their vacuum vessel and establishing the mechanical connections and service lines. It is expected to complete the two End Cap Toroids by July and Dec 05 respectively, followed by their installation in the cavern in 2006.

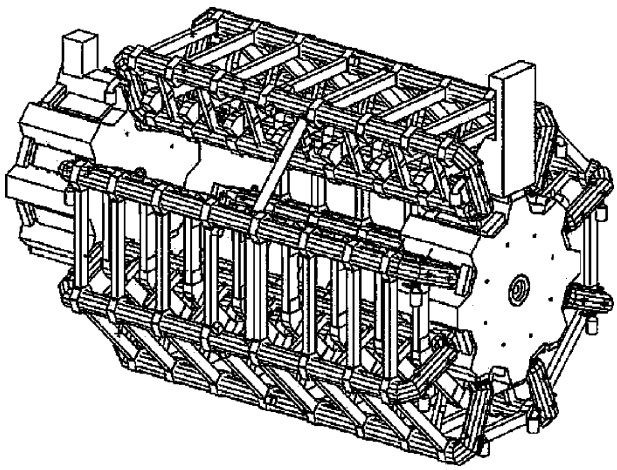

Fig. 6. Schematic view of the Barrel Toroid showing the 8 Barrel coils linked by struts, the cryoring for busbars and cryolines and the position of 2 End Cap Toroids, one inserted, one retracted.

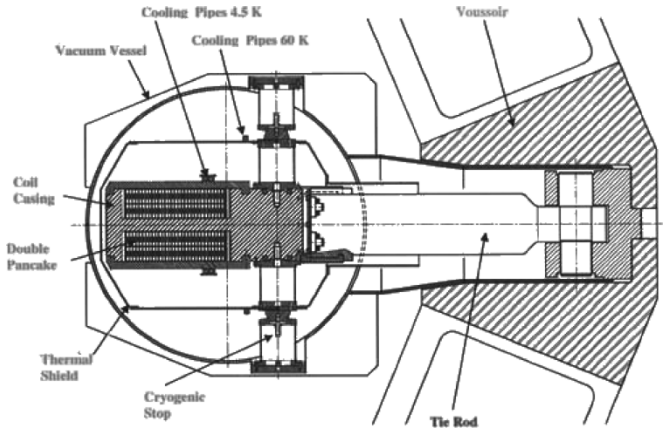

Fig. 7. Cross-sectional view of the BT coil showing the cold mass Al casing, which enclose 2 double pancakes with 120 turns of super-conductor. The cold mass has a thermal shield and is connected to the vacuum vessel with tie rods and cryogenic stops which hold the cold mass in position.

IV. Barrel Toroid

The Barrel Toroid, see Fig. 6, has 8 racetrack coils of $25 \times 5\ \mathrm{m}^2$ size. The 8 coils are kept in position in the toroidal structure by an inner and an outer set of 8 rings of struts positioned along the coils. The cryogenic connections and current bus bars are running through a cryoring linking the coils in the center plane of the toroid. The assembled toroid is resting on 18 feet connected to the floor of the cavern.

The design of the Barrel Toroid is performed by CEA-Saclay with contributions of INFN-LASA and CERN [10]–[12] (Fig. 7).

The production of the 56 km of Al stabilized NbTi/Cu conductor with section $57 \times 12\ \mathrm{mm}^2$, produced by VAC (now EAS) and EM/Cortaillod (now Outokumpu/Nexans) is completed as well as the coil winding at Ansaldo Superconductors. The Al coil casings and Vacuum vessels were manufactured by Alstom Switzerland and Felguera CM in Spain respectively. The cold mass integration was performed by Technicatome, France, in collaboration with the JINR-Dubna, while the thermal shield production is at Zanon, Italy. The final cryostat integration is

Fig. 8. Glance on the 1500 m^2 coil integration and test area at CERN.

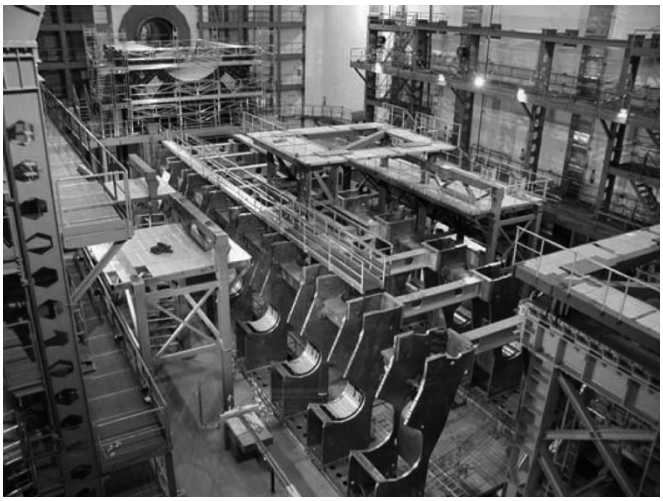

Fig. 9. ATLAS cavern 100 m underground, outer structures and feet installed, ready for receiving the Barrel Toroid coil in Oct 04.

performed by JINR at CERN under the guidance of CEA and CERN. Fig. 8 provides a glance of the ATLAS magnet integration and test hall at CERN. All coils pass this station before they are installed underground.

At this moment 6 coils are in various stages of integration, 1 coil is under test and most important, the first BT coil already passed its test and was accepted for installation. This test [13] has given the proof of the principle for the construction of 25 m long coils, the longest one ever built. The coil could be cooled down in 2 weeks, ramped up to 22 kA maximum test current without training and the coil mechanics showed no hysteresis, is predictable and reproducible. According the present schedule the last coil will be completed by May 2005.

The underground cavern is ready to receive the coils, see Fig. 9. The civil engineering works are completed and the general infrastructure like cranes, floors and platforms installed. The 18 feet that carry the toroid are installed and in Oct 2004 the first Barrel Toroid coil will start to rest on them. Then successively the other 7 BT coils, the Central Solenoid and End Cap Toroids will go into their final position.

V. Conclusion

The construction of the ATLAS Magnet System is progressing well: all main production contracts are completed; the Solenoid is finished, one Barrel Toroid coil already successfully tested without training, all other coils in various stages of integration and test at CERN. Installation underground has started as well and by autumn 2005 the final commissioning test in the cavern is expected.

Acknowledgment

The ATLAS Collaboration of about 150 institutes in 34 countries finances the Experiment and the Magnet System. In particular, the members of the magnet teams at CEA-Saclay (F), Rutherford Appleton Laboratory, RAL (UK), KEK (J), INFN-LASA (I), NIKHEF (Nl), and CERN are acknowledged.

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