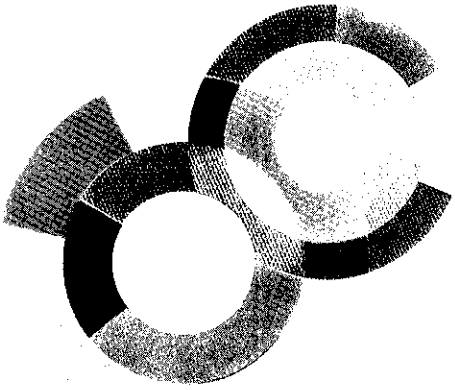
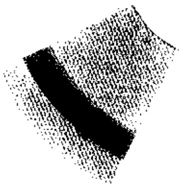
CEA/SACLAY
DSM

SERVICE TECHNIQUE DE CRYOGÉNIE ET DE MAGNÉTISME





DAPNIA/STCM 99-22 December 1999

MECHANICAL MEASUREMENTS ON THE RACE-TRACK PROTOTYPE FOR THE ATLAS B0 AND BARREL TOROID MAGNET

F. Broggi, J. Deregel, B. Gallet, B. Hervieu

DAPNIA

Presented at the 16th International Conference on Magnet Technology, Tallahassee (USA), September 26-October 02, 1999

Département d'Astrophysique, de Physique des Particules, de Physique Nucléaire et de l'Instrumentation Associée
CEA/Saclay F-91191 Gif-sur-Yvette Cédex

Couverture Sylvie Cabrit et Marc Sauvage

COMMISSARIAT A L'ENERGIE ATOMIQUE

DSM/DAPNIA/STCM

Rapport n° 22
le 15 décembre 1999

F. BROGGI, J. DEREGEL
B. GALLET, B. HERVIEU

MECHANICAL MEASUREMENTS ON THE RACE-TRACK PROTOTYPE FOR THE ATLAS B0 AND BARREL TOROID MAGNET

16th International Conference on Magnet
Technology, Tallahassee - Florida
26/09/1999 au 02/10/1999

Mechanical Measurements on the Race-Track Prototype for the ATLAS B0 and Barrel Toroid Magnet

F. Broggi(1), J. Deregel(2), B. Gallet(2), B. Hervieu(2)

Abstract--**The ATLAS Barrel Toroid (BT) consist of 8 superconducting coils 25 m long and 5 m large.**

In order to check the stability of the magnets and the technical solutions for the construction a scaled magnet, called B0, is under construction.

A race-track coil 2.7 m long and 0.7 m large has been built, to verify the characteristic of the superconducting conductor. As a matter of fact this race-track magnet is the first multi-turn superconducting magnet, with indirect cooling, built with fully bonded aluminum coil.

The mechanical deformations of the magnet during the energization and the induced quenches are monitored in 12 points. The overall transversal deformation of the magnet is measured by 6 strain gages placed on measuring clamps connecting the two arms of the magnets, 3 on the upper side, and 3 on the lower side of the magnet.

The other sensors are placed on one arm, on the casing of the magnet: 5 on the external part and 1 in the inner part in order to see the bending of the arm.

Removable reinforcing clamps are present between the arms. The mechanical measurements obtained with and without the reinforcing clamps are presented.

Index terms-- **ATLAS, deformation, strain gage**

I. INTRODUCTION

In the ATLAS detector, that will be installed on the Large Hadron Collider at CERN, the construction of three toroidal magnets is forseen [1], each of them is composed of 8 superconducting coils of very large size.

The side toroidal magnets are called End Cap Toroid (ECT), while the central magnet is the Barrel Toroid (BT). The BT has an external diameter of 20 m and a length of about 25 m. Each coil of the BT is composed by two double pancakes 25 m long and 4.5 m wide.

Because these coils are about 5 times larger than any other superconducting coil ever built, in order to validate the technical choices, it was decided to build a working model, called B0, similar to the BT concerning the materials, the width and the cross section (4.5 m x 0.25 m) but with reduced length (9 m).

In order to verify the stability of the superconducting cable, the mechanical characteristics, the working parameters of the BT and of the ECT and the technological solution of the multiturn fully impregnated indirectly cooled magnet, the ATLAS magnet collaboration CERN, CEA, RAL (INFN – LASA joined later), decided to build a small race-track coil [2-3].

II. THE RACE-TRACK

The race-track is composed by 2 double pancakes of 2 x 16 turns. In Tab.1 the characteristics of the race-track are listed.

Table 1 Main parameters of the race-track coil

Overall length	2.7 m
Straight section length	2 m
Width	0.7 m
N° of pancake	4
Turns/pancake	16
Operating current	20000 A
Magn. field (conduct./central)	4 T / 2 T
Operating temperature	4.4 K
Self Inductance	6.08 mH
Conductor cross section	70 x 7 mm^2
Rutherford cross section	2.2 x 20 mm^2
Aluminum RRR	500 (at 0 field)
Insulation thickness	0.125 mm

The race-track coil is mounted on a central plate of Al alloy. This plate forms the basis of the coil winding and retain the magnetic forces between the two straight sections.

The coils are enclosed in a sandwich type construction by outer plates and the magnetic forces are supported by outer blocks.

The race-track coil system is vacuum impregnated to give a fully bonded structure, indirectly cooled.

In fig.1 the race track just before the positioning into the cryostat is shown.

---

(1) INFN-LASA, Via F.lli Cervi 201, 20090 Segrate, (Mi), Italy.
(2) CEA SACLAY/DAPNIA/STCM, Gif-sur-Yvette, Fr.

The diagnostics of the magnet is provided by Pt100 and Carbon temperature sensors, by voltage taps, pick up coils and heaters for quench propagation studies.

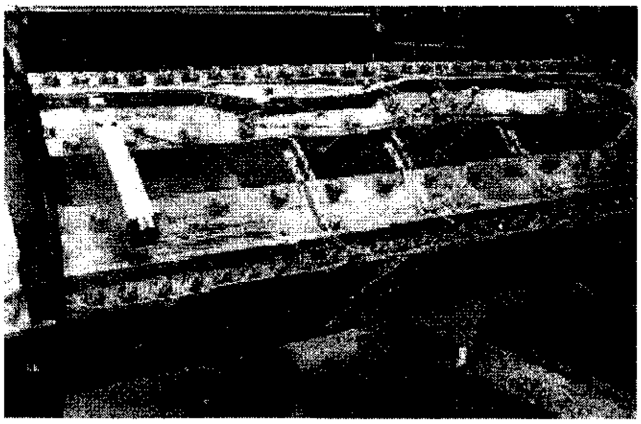


Fig. 1 The race-track magnet. (photo CEA).

III. MECHANICAL EQUIPMENT

The mechanical deformations were measured by a system of 12 strain gages MM SK-15-250AF-350 (¼ bridge connection).
12 more gages were used as compensation.
The strain gages for measuring the transversal deformation were mounted on thin clamps, connecting the two arms of the magnet, 3 on the upper part and 3 on the lower part of the magnet (see fig. 2).

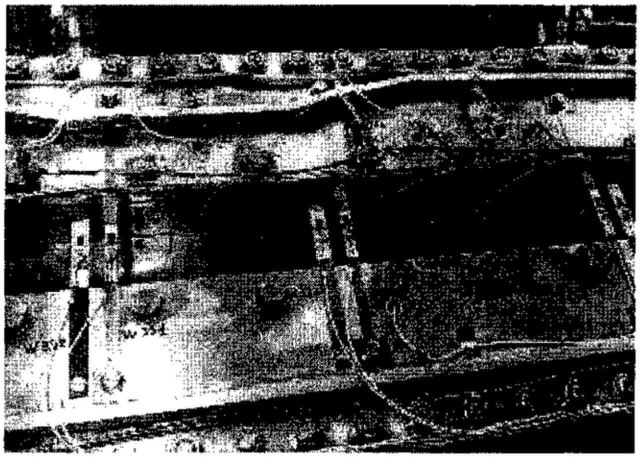


Fig. 2. The strain gages mounted on the transverse measuring clamps together with the compensation gages. The reinforcing system between the long arms of the magnet can be seen. (photo CEA).

The remaining sensors are glued on the body of the magnet, 5 at half length of the arm, on the external side (fig.3), and 1 on the internal side of the magnet, the last one at about ¼ of the length, one on the external side.
The name and position of the strain gages are listed in Tab.2.
The data from the strain gages were collected by an acquisition system HBM (Hottinger Baldwin Messtechnik), controlled by the software Catman, running under Windows 95 on a Personal Computer.

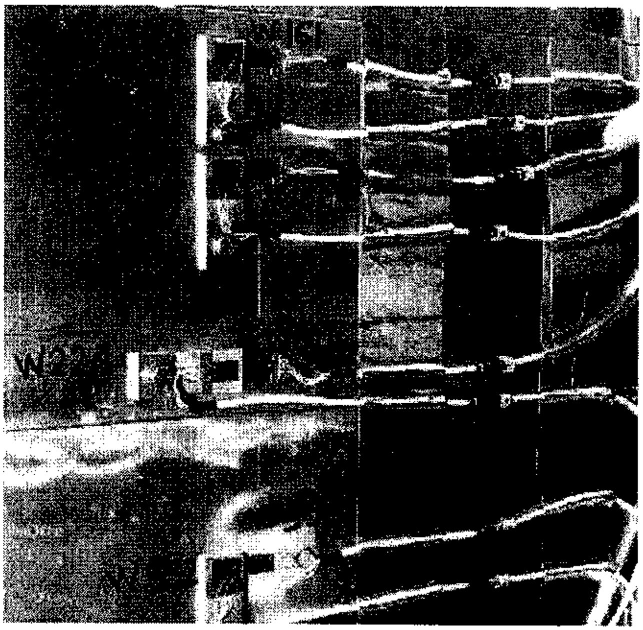


Fig.3 The strain gages on the body of the magnet (photo CEA)

Table 2. The location and naming of the strain gages

Sensor name	Location
W111	upper clamps
W121	
W131	
W311	lower clamps
W321	
W331	
W351	body of the magnet (ext.)
W211	
W151	
W161	
W221	
W361	body of the magnet (int.)

IV. TESTS PERFORMED

Two runs of measurement has been done, the first with the transverse reinforcing system between the two long arms of the magnet and the second run without it. In both the runs the full current has been reached both by step and continuous ramping of the current (with a ramp speed of about 8 A/s).

A. With Reinforcing system

The first run has been done by ramping up the current from 0 to 20 kA by step of 1000 A, the second one with the same step but shifted by 500 A. Unfortunately during this test the sensor W161 did not read because of a fault in the electrical connection occurred during the cool down. The data from the sensor W211 has been lost because of a software problem during the storing of the data.

In fig. 4 the transversal deformation versus the squared current is shown, while in fig. 5 the relative deformation of the body of the magnet is shown.

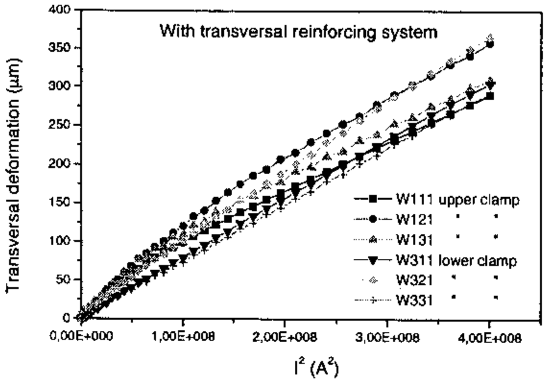


Fig.4. Transverse deformation vs. I^2 with the transverse reinforcing system

As can be seen there is a good but not perfect linear behaviour. This can be due to the tolerances in mounting the reinforcing system that can absorb and release the load.

As a matter of fact in the test without the reinforcing system the linear behaviour is almost perfect (see next section).

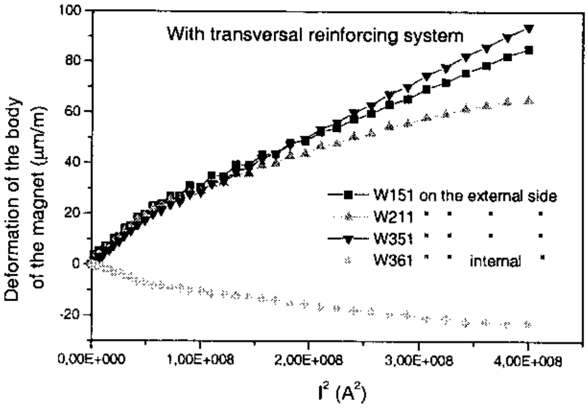


Fig.5. Deformation of the arm of the magnet vs. I^2 with the transverse reinforcing system

In fig. 5 the positive strain is due to the traction of the arm of the magnet, while the negative strain is the compression in the inner part of the arm.

The following runs, done by continuous ramping to the maximum current, has shown a repeatability for the deformation at the maximum current of about 1%.

The same values of deformation has been measured at the end of the stability tests[4].

B. *No Reinforcing System*

After the warm up the broken connection has been repaired and the reinforcing system between the arms of the magnet removed. Like in the previous tests at first the current has been ramped by step, then continuously.

In fig. 5 the overall deformation of the long arms of the magnet is shown, while in fig 6 the deformation of the body of the magnet is shown.

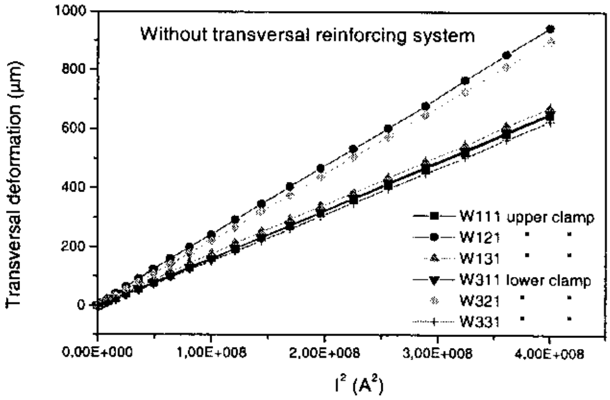


Fig.6. Transverse deformation vs. I^2 without the transverse reinforcing system

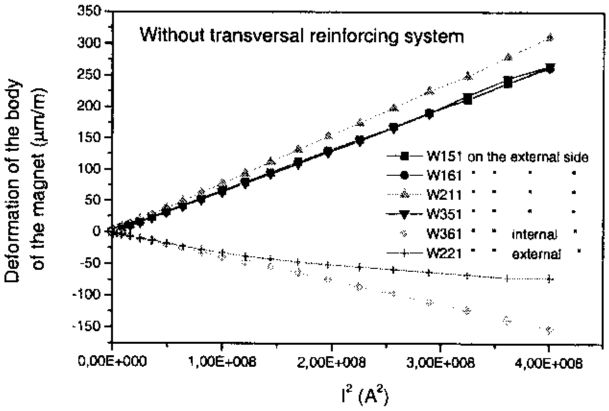


Fig.7. Deformation of the arm of the magnet vs. I^2 without the transverse reinforcing system

The meaning of the positive and negative strain is the same as in in fig. 5.

Note in this case the negative signal of the sensor W221, placed on the external part of the magnet at about ¼ of the length where a compression occurs.

V. COMPARISON WITH THE CALCULATIONS AND ANALYSYS

Computation of the deformation has been done both in 2D either in 3D [5]. The maximum transverse deformation for a clamp length of 489 mm is 1.42 mm and 0.4 mm for 2D and 3D calculation respectively. The difference is due to the fact that the 2D model determines the deformation of the clamp under the magnetic forces, without taking into account the detailed mechanical structure of the magnet together with its material characteristics. However the 3D model, because of the assumption of perfect impregnation and perfect mechanical assembly of the magnet underestimates the deformations. So the evaluated deformations are the extreme cases and the real deformations, i.e. the measured ones should stay in between, as it actually happens. In the following table the deformation of the clamps with length 449 mm (W111 and W311) and 489 mm (the others) at the maximum current are compared with the 3D calculation.

Table 3. Comparison of the measured deformation with the 3D calculations

Sensor name	calculated value (mm)	measured value (mm)
W111	0.47	0.65
W121	0.79	0.95
W131	0.51	0.67
W311	0.47	0.65
W321	0.79	0.90
W331	0.51	0.63

From the data obtained these considerations follow:

1. The repeatability of the measurement in both the configurations, as already told, is about 1%, while the measurement errors, evaluated over the various excitation of the magnet is about 4% at half the excitation (10 kA), and about 1% at the full current.

These errors are very small and for this reason the experimental plot of figs. 4 – 7 do not show the error bars.

2. Looking at the experimental data obtained with and without the reinforcing system, we can say that is evident its effect, both for the total transverse deformation and for the behaviour of the deformations versus the current.

As a matter of fact, by looking at fig. 4 and at fig. 6 the good linearity shown without the reinforcing system is not present in fig. 4 at low current excitation.
The reason of this behaviour can be due to the mechanical clearance in mounting the transversal reinforces.

3. In both the configuration the transversal deformation shows a good top-down and left-right symmetry.

The small variation in the deformation measured by the top central sensor (W121) respect to the corresponding sensor on the bottom part (W321) is probably due to a systematic error of the sensor.
As a matter of fact the tare values of the sensor was different respect to the others, the stability was poor too.
In fact the difference of the zero value of the gage W121 between the beginning and the end of a measurement run was about 5%, that is about the same difference of the deformation measured by the W121 and the W321 sensors.

4. No plastic deformation occurs.

5. The data show a very good top-down symmetry respect to the median plane (curves W151 and W351 of fig.7).

6. Finally it is important to observe the compression on the external side of the magnet as measured by W221.

VI. CONCLUSIONS

As from the analysis from the previous section we can say that the experience acquired so far on the race-track magnet can guarantee the correct choices of the sensors and for the data acquisition system for the mechanical measurements for the B0 and probably for the BT magnets.
Care must be taken in the controlling software for the problem arisen for storing the data, that leaded to a lack of part of them.
The deformations measured have shown good repeatability and low experimental errors, good linear behaviour with the square of the current, good symmetry respect to the median plane, both top-down and right–left.
So we can say that these mechanical measurement have good accuracy and are reliable, taking into account also the comparison with the calculated deformations.

VII. ACKNOWLEDGMENT

The authors are grateful to all the technical staff of the test station of the laboratory of CEA at Saclay for the installation of the system and the assistance during the measurements.
The authors wish to thank M.rs Sun for the coordination of the 2D and 3D calculations of ref.[5] and Ing. A. Daël for revising the manuscript and for the useful discussions.

REFERENCES

[1] ATLAS Barrel Toroid TDR – CERN/LHCC/97 – 19 (1997).
[2] ATLAS Toroid Magnet Syst. R&D Prop. to Construct a Racetrack Test Coil. CEA Saclay & RAL. CEA report STCM S94 116/JP/AR.
[3] A. Daël et al.," Synthesis of Technological Developments For The B0 Model Coil and the ATLAS Barrel Toroid Coils", this conference.
[4] F. P. Juster, "Stability and Quench Propagation Velocities Measurements on 'RACE-TRACK' Mock-Up of ATLAS Toroid Coil", this conference.
[5] D.Bossuat, Rapport de Stage de Fin d'Etudes, CEA, Saclay.