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The single arm forward muon spectrometer requires in addition a new dipole magnet with a very large aperture. This magnet has been developed and constructed and has now been installed in its final position.

Since this location adjacent to the large L3 solenoid leads to important interference between both devices the dipole has previously been assembled and tested in a pre-assembly location before the final assembly and commissioning in 2005. The techniques and results of geometrical, thermal, electrical, magnetic and mechanical measurements in the final location are presented. These values are also compared to those measurements obtained during the pre-commissioning campaign when the magnet was tested in a stand-alone position.

To provide the necessary data for the particle track analysis, the magnetic field of both magnets has been mapped in the entire detector space and also in the surrounding region where field sensitive electronics will be installed. Some relevant results are summarized.

Results from the ALICE Dipole Magnet Commissioning

D. Swoboda(¹), C. de Almeida(¹), A. Meynet(¹), H. Taureg(¹), A. Tournaire(¹)

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I. INTRODUCTION

ALICE is the dedicated heavy ion experiment at the future LHC accelerator at CERN. The spectrometer system of the experiment includes a big solenoid magnet previously used in the L3 experiment of LEP and a very large dipole magnet next to the solenoid. The paper describes the second magnet which has been newly developed by CERN in collaboration with a team from JINR. The 820 ton iron yoke has been manufactured in Russia, the two 30 ton each excitation coils by French industry and the stainless steel coil support structures in Spain.

II. ASSEMBLY

The magnet has been assembled for the first time in the ALICE underground cavern during 2004 in a preassembly position which provided convenient access for handling, machining and assembly work (Fig. 1). The aim of this preassembly was to test the complete assembly procedure including special handling jigs and to detect and correct any defects before assembly in the very restricted space of the permanent location of the magnet [1], [2]

Fig. 1. ALICE dipole magnet pre-assembly

It proved in fact to be essential for the long term operation of the magnet, as the tests revealed some significant manufacturing deficiencies that were corrected before final assembly. Indeed a rather complicated repair process for the coils became necessary. This involved partial separation of the sub-coils; replacement of the conducting rubber which filled the interface between sub-coils by electrically insulating material; and correction of the cross-section of the coils at the location of the stainless steel coil sleeves, in order to obtain a better geometry. A special jig had to be designed and constructed quickly to allow the sub-coils to be prized apart and put back into place after repair.

Beginning in January 2005, the magnet was completely dis-assembled for transfer, component by component, over the former L3 solenoid to a permanent location at the far end of the cavern [3]. By 5 July, the final assembly of the 900 ton dipole on top of the 3 m high reinforced concrete foundation was complete, and the magnet was ready to undergo its full commissioning for future operation in the ALICE experiment.

III. TESTS AND COMMISSIONING

In order to obtain comparable results the procedure for the final commissioning of the magnet repeated the sequence already followed during pre-commissioning in 2004. The observed values for the characteristic parameters are compared to the specification in table 1.

The parameters which had to be verified in addition to the main characteristics of the magnet concerned mechanical tolerances and movements as well as temperature elevation at the coil terminals and inside the magnet aperture.

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TABLE I
MAIN CHARACTERISTICS OF ALICE DIPOLE MAGNET

Parameter	Spec. Value	Meas. Value	Unit
Max Flux density	0.67	0.68	T
Bending Strength	3.00		Tm
Avg. Gap width	3.30		m
Ampere turns	1.97		MA
Operating Current	5.86	6.00	kA
Coil Voltage	590	597	V
Power	3.46	3.58	MW
Inductance	1.00	1.00	H
Stored energy	17	18	MJ
Diff. Pressure	10.9	12	Bar
Flow rate	115	130	m^3/h
Diff. Temperature	30	24	°C

IV. ELECTRICAL CHARACTERISTICS

During the pre-assembly HV insulation tests of the coils at 2.5 kV dc showed a leakage current to earth of about 0.5 mA. This defect could be traced to the electrical conductivity of the EPDM sheets which were inserted between sub-coils. Some of this rubber had moved during transport and assembly and had come into contact with bare parts of the coil terminals. This problem could be overcome through the repair of both coils.

The power supply characterization included the assessment of low frequency harmonics contents, EMC aspects (conducted noise compliance), characterization of the magnet load; i.e. frequency response of the magnet and estimation of the R and L parameters, were obtained from measurements.

The low frequency harmonic spectrum of the magnet voltage is presented in figure 2. The main frequencies are at 50 Hz (114 mV rms), 300 Hz (20 mV rms) and 600 Hz (40 mV rms) which is typical for the installed power converter with 12 pulse thyristor rectifiers.

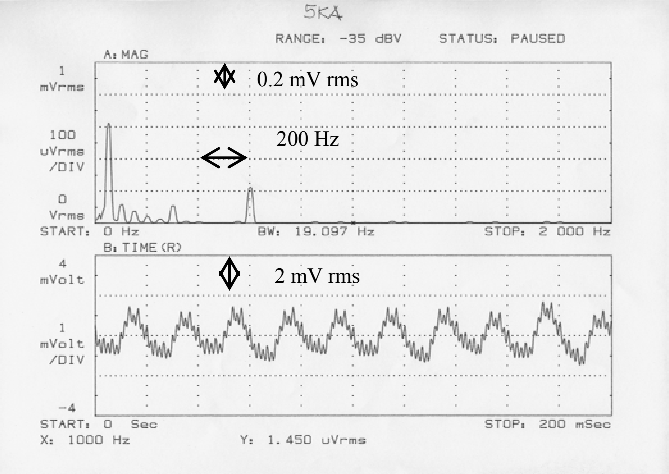

Fig. 2. Dipole power converter frequency spectrum

The measured high frequency EMC noise is in compliance with IEC standard 478-3 level C.

Power circuit and earthing system for the magnet is shown in figure 3. The imbalance measured for DC+ and DC- with respect to earth at the power supply is 7mV, corresponding to +/-1.5% which is within the tolerance range of the 10 kΩ earth resistors (5%).

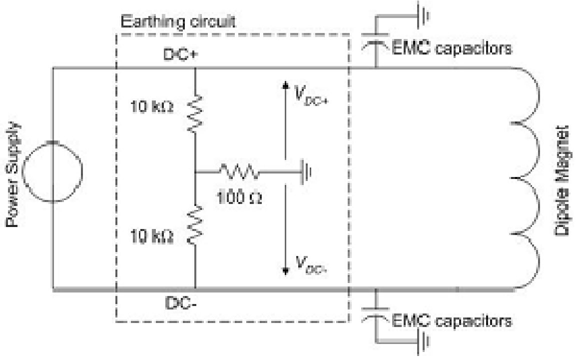

Fig. 3. Power circuit and earthing system

The Bode diagram of the magnet is presented in figure 4 and figure 5. The measured curve has been approximated by a 1st order Laplace transformation:

$$\frac{Imag(s)}{Vmag(s)} = \frac{1/R}{1+s\tau} \quad with\ \tau = \frac{L}{R}$$

Giving a time constant τ = 10 s with R= 0.1 Ω and L=1 H.

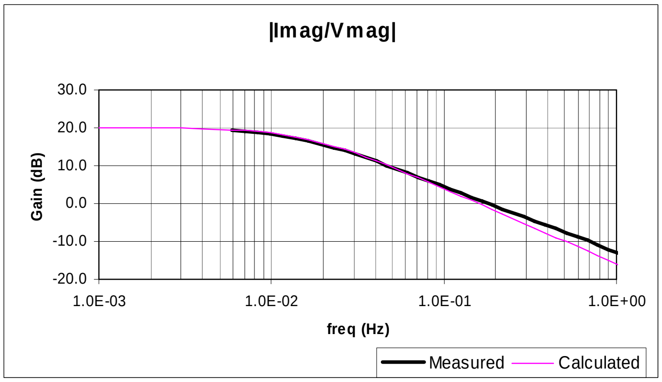

Fig. 4. ALICE dipole magnet transfer function

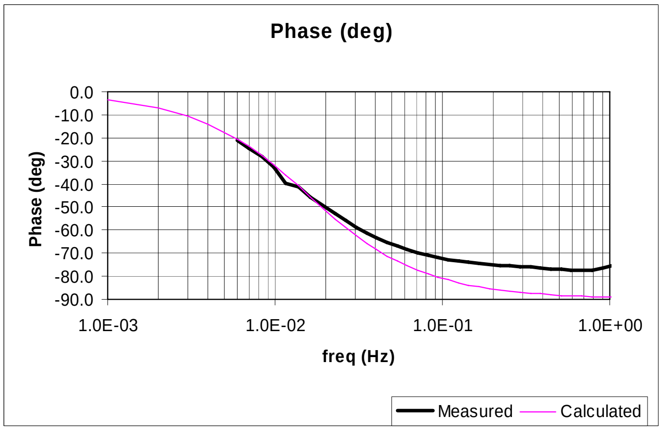

Fig. 5. ALICE dipole magnet frequency response

V. MAGNETIC CHARACTERISTICS

The magnetic field was monitored during the commissioning with a 3D hall probe which had been installed at approximately the location of the peak field inside the magnet gap. Stray field measurements were conducted during commissioning with a hand held gauss meter in areas were instrumentation will be installed.

VI. MAIN FIELD PARAMETERS

The measured values for excitation current and Bmod are shown in fig. 6 for both polarities. It can be seen that the onset of saturation is at approximately 4 kA but saturation remains small over the operation range. In addition no remnant effect is detectable and the B-curves for both polarities are identical.

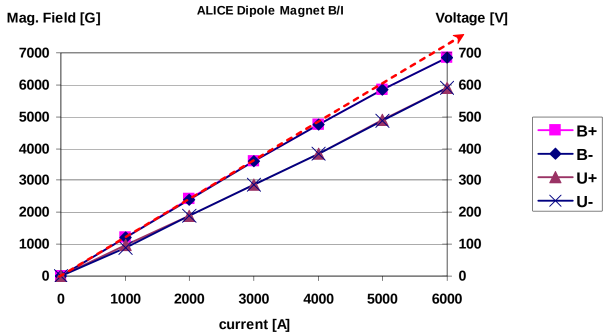

Fig. 6. B/H characteristics

VII. STRAY FIELD CHARACTERISTICS

The stray field in the surroundings of the magnet attenuates rather rapidly. The values at the level of the gangways at the experiment cavern sides are considerably less than 50 Gauss which is the threshold for the most sensible instrumentation. In the area of the magnet foundation at a height of 1.6 m above cavern ground the measured values are shown in figure 7 for the dipole only (lower numbers in italic) and with the perturbation from the adjacent solenoid (top numbers). The asymmetry of the stray field caused by the orthogonal directions of the fields of both magnets is well pronounced (top numbers).

VIII. MECHANICAL TOLERANCES

Mechanical tolerances and alignment were checked continuously with state of the art equipment by the CERN survey group. In order to reduce the required alignment operations of the yoke modules and the coil supports, 40 mm diameter dowels were already fitted after the completed pre-assembly of the magnet. Although the machining precision of the mating faces of the yoke modules lies within the specified tolerances of ±0.25 mm, shimming with thin steel plates between the base modules and the vertical pole modules was necessary in order to obtain the tolerance of 0/+1 mm at the top between opposite vertical modules to allow the fitting of the horizontal top modules.

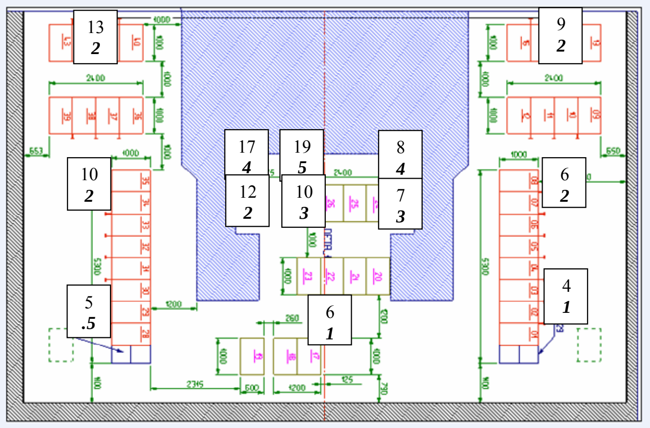

Fig. 7. Stray field levels close to dipole magnet [mT]

IX. MECHANICAL MOVEMENTS DURING OPERATION

Two kinds of mechanical movements were monitored. The support system of the coils has been designed to allow free movement of the coils in axial direction towards the side of the electrical connections, the opposite coil ends being clamped to the yoke. The coil movement is facilitated by the stainless steel sleeves in which the coils can slide during thermal expansion and by magnetic forces.

The radial forces on the coils are however directly transmitted to the magnet yoke.

The second type of movement which requires monitoring results from the proximity of the L3 solenoid. The magnetic coupling between both magnets should create rather important attraction between both magnet yokes [4].

In order to monitor these two types of movement strain gauges were mounted at strategic locations on the dipole magnet.

The observed longitudinal expansion of the coils corresponds very well to the 6 mm which had been calculated. This movement is completely reversible when the magnet is switched off.

A movement of yoke parts could not be detected within the resolution of the strain gauges.

X. THERMAL BEHAVIOR

After adjustment of the flow rates in the coil cooling circuits close to nominal values (table 1), the observed temperature gradients corresponded to the calculated levels during steady state operation (figure 8).

Important for the detector instrumentation is however the heat transfer to the environment. Extensive 2D and 3D models have been set up to estimate the temperature elevation inside the magnet gap in order to define the required cooling power for the tracking station which will be installed at the center of the magnet aperture[5]. To verify the obtained results, measurements were performed during pre-installation with an Infrared camera.

The observed temperatures are however inferior to the prediction of the 3D thermal model of the magnet (table 2.)

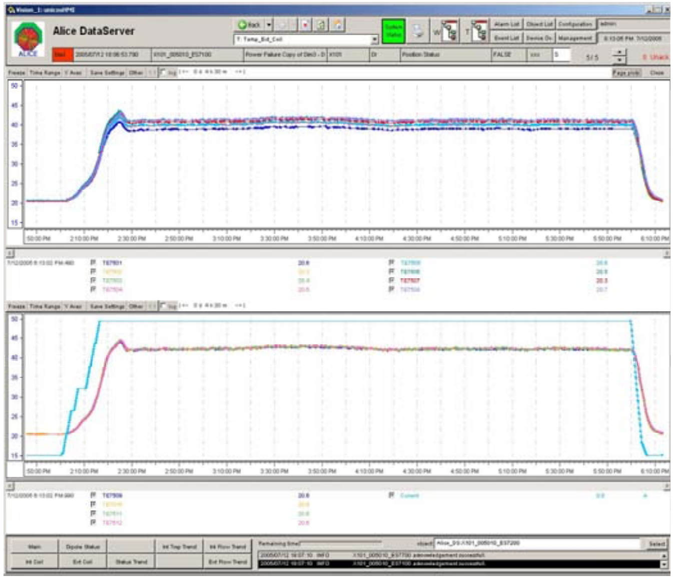

Fig. 8. Coil cooling circuit temperatures

The model has to be considered as rather conservative. But as can be observed the total dissipation to the environment is still below 3 per mille of magnet power consumption.

TABLE II

THERMAL DISSIPATION FLUX FROM 3D MODEL OF DIPOLE MAGNET

Source	Sink	Convective [W]	Radiative [W]	Total [kW]
Coil	Aperture	3360	2720	6.08
Coil supports	Aperture	2400	860	3.26
Yoke	Aperture	2344	-1304	1.04
Aperture	Environment	8104	2276	10.38

XI. CONCLUSION

The final assembly and commissioning of the ALICE dipole magnet has been successfully concluded. All monitored and measured parameters are complying with specification and calculated values [6].

The pre-assembly contributed significantly to the smooth progress of the final assembly and proved to be essential for the long-term operation of the magnet.

Heat dissipation and stray field values are inferior to estimations and permit relaxation on requirements for ventilation and magnetic shielding of electronics.

Features like easily accessible coil terminals, water connections and controls instrumentation will facilitate the maintenance of the magnet during the expected operation period of 10 to 15 years.

The removable yoke top allows the replacement of the coils and ultimate disposal of the device.

REFERENCES

[1] Towards the starting up of the ALICE Dipole - Proceedings 2003 18th International Conference on Magnet Technology Morioka, Japan June 2004.
[2] CERN bulletin 04/05.
[3] CERN bulletin 20-21/05
[4] Calculation of Thermal, Magnetic and Gravitational Stresses for the ALICE Dipole Magnet – CERN/ALICE int-2001-14, September 2001
[5] A Numerical Simulation of Alice Muon Dipole Thermal Behaviour, - CERN/Ts-Note-2004-047
[6] ALICE Technical Design Report Dimuon Forward Spectrometer – CERN/LHCC 99-22, 13 August 1999