

REDUCTION OF MAGNETIC INTERFERENCE ON THE POSITION SENSORS OF THE LHC COLLIMATORS

A. Masi, M.Lamberti[#], R.Losito, M.Martino, CERN, Geneva, Switzerland

Abstract

The jaws of the LHC collimators have to be positioned with respect to the beam with an accuracy of 20 μm. On some collimators, installed in the LHC transfer lines from SPS, huge reading errors of several tens of micrometers have been observed on the Linear Variable Differential Transformer (LVDT) positioning sensors in synchronization with the variable magnetic field produced by the feed cables of the pulsed resistive dipoles of the transfer line. In this paper we introduce and describe in detail the problem, the model developed using FLUXTM for the simulation of the magnetic flux density generated by the current cables in the complex environment of an LHC transfer line, and the magnetic shielding we designed and implemented. Finally, we compare the results of simulations with experimental measurements taken during on-line pulsed magnets test campaigns.

INTRODUCTION

More than 700 radiation tolerant Linear Variable Differential Transformers (LVDT) sensors have been installed on the 108 LHC Collimators to measure the position of the collimator jaws to within the required 20 μm accuracy [1].

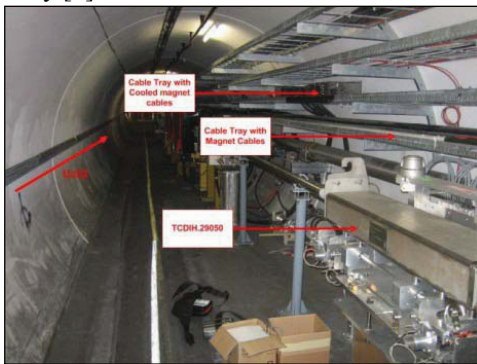


Figure 1: View of the TCDIH.29050 TI2 collimator and the high current cables trays.

A specific reading algorithm, based on the sine fit, has been developed to ensure a reading accuracy of a few micrometres, even with a cable length of up to 800 m [1]. Unfortunately on some collimators, installed in the transfer lines of the LHC, reading errors of more than 100 μm have been observed in synchronization with the low varying magnetic field produced by the high current cables feeding the warm magnets in the transfer line. Figure 1 shows the high current cable trays passing close to the collimators. The worst case is the LVDT D on the collimator TCDIH 29050 in the transfer line TI2. The

reading error peak reaches 90 μm and is in synchronization with the current in the magnets [2]. The reading error is due to the interfering magnetic field, principally the component aligned with the sensor axis [3]. The magnetic flux density, and not its time variation, is responsible for the reading error [3]. A complete characterization of the LVDTs has shown that, in order to have reading errors lower than 20 μm, the interfering longitudinal magnetic flux density should not exceed roughly 20 μT [4]. Up to 120 μT have been measured, the highest values being on collimator TCDIH.29050, close to warm magnets of the LHC transfer lines [2]. In Table 1 the maximum values of the measured magnetic flux density along the axis of all the LVDT sensors of the same collimator are summarized as well as the maximum reading error observed.

Table 1: Summary of the highest interfering magnetic field peak and related reading error on the TCDIH.29050. The LVDT ID reflects the naming convention used during operation.

LVDT ID	Max Bx [μT]	Max reading error [μm]	Max reading error with the proposed shielding [μm]
AB	80	70	19.12
C	60	35	24.48
CD	95	6	21.96
D	120	90	30.15

The collimator TCDIH.29050 is the most affected by the interfering magnetic field and has therefore been studied in detail. In the following section we analyse the problem via numerical simulations, and compare the result with measurements.

We made significant use of parametric simulations to design a magnetic shield that is able to reduce the interfering magnetic field below the acceptable threshold. The guidelines of the shielding design, as well as the verification of its effectiveness are reported in the last two sections.

MODELLING THE PROBLEM

Starting from the collimator geometry, the tunnel layout, the LVDT sensor design, as well as the distribution of the current cables in their trays we used FLUXTM [5] to carry out magneto-static simulations, in order to evaluate the interfering flux density along the axes of the sensors.

[#]CERN trainee in 2009

The simulation model

In Figure 2 the 3D model of the TI2 tunnel and the collimator is shown. Only the two shelves containing the high current cables have been modelled. The tunnel radius is 1.5 m, while the tunnel length has been set at 15 m, ten times the radius, to avoid edge effects near the collimator.

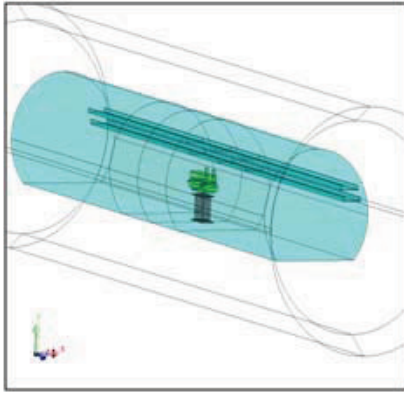


Figure 2: 3D model of the TI2 tunnel and the collimator.

The cable trails have been positioned 180 mm away from the tunnel wall, to take into account the supports of the two trails. All the objects in the tunnel, internal bodies and trails, have been modeled as non-magnetic materials. The simplified model of the collimator is depicted in Figure 3. It is based on three parts: the support (dark volume), made of aluminum, has been simulated as non-magnetic material; the vessel (horizontal volume) in stainless steel, non-magnetic material (same as for the support); finally, the LVDT sensors are simulated according to the model developed in [6].

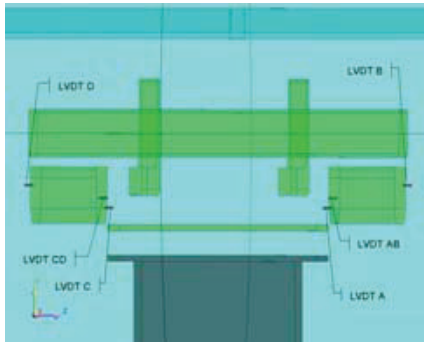


Figure 3: Magnetic model of the TCDIH.29050 collimator.

The interference sources, i.e. the system of cable pairs passing close to the collimator, have been modelled as non-meshed rectangular coils, one coil for each cable pair in order to have currents with the same intensity, but opposite flow. Thirteen coils are on the bottom trail, with typical current values around 500 A (i.e. 3×572 A, 3×497 A, 2×258 A, 1×372 A, 1×481 A, 1×487 A, 1×585 A) and two coils are on the top tray with a current value of 5000 A, to simulate the four water-cooled cables. A cylindrical box, centred exactly in the centre of the tunnel, has been considered as infinite box for the simulation (to reproduce radiation conditions on infinite domain).

Simulation results

Figure 4 shows the result of the Magneto Static 3D simulations. The magnetic flux density is roughly equivalent to that generated by a couple of wires carrying the same equivalent current.

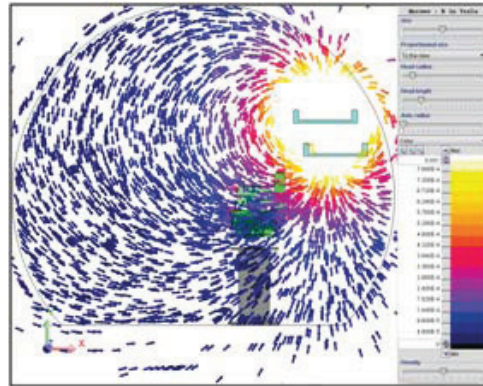


Figure 4: 3D magnetostatic simulation results.

Experimental validation

Table 2 gives the values of the simulated and measured magnetic flux density along the LVDT's longitudinal axes (i.e. x axis in the simulation reference system). The measured values have been obtained with Hall probes positioned a few millimetres away from the upper part of each sensor. The simulated values have been evaluated in the same positions. Differences can be explained with the difficulty to mesh with high precision the small LVDT volume in a large environment such as the tunnel. The model is however effective to compare different shielding scenarios, since the attenuation of the magnetic flux density in the LVDT volume will not depend critically on the mesh, provided it remains the same in the different cases.

Table 2: Comparison between simulated and measured magnetic flux density along the sensors' axes.

LVDT	Simulated Magnetic Flux Density [μ T]	Measured Magnetic Flux Density [μ T]	Simulated Magnetic Flux Density with the proposed shielding [μ T]
AB	121.11	80	2,63
C	97.18	60	7,52
CD	94.62	95	7,66
D	82.23	120	9,24

THE SHIELDING PROPOSAL

In the magnetic shielding design the following guidelines have been taken into account:

- Shielding effectiveness: in the region occupied by the sensors the magnetic flux density along the longitudinal axis has to be reduced by more than one order of magnitude.

- Geometrical constraints: the shield cannot go beyond the center of the tunnel not to interfere with the transport vehicles.
- Serviceability: the shield should be easy to mount and dismount in case an intervention on the collimator is needed due to the high level of radiation.
- Material: given the low frequencies of the interfering magnetic field, the material should be ferromagnetic, with a high saturation field, and high permeability. At the same time, it should be easy to machine and readily available. Annealed iron fulfils all the aforementioned requirements.

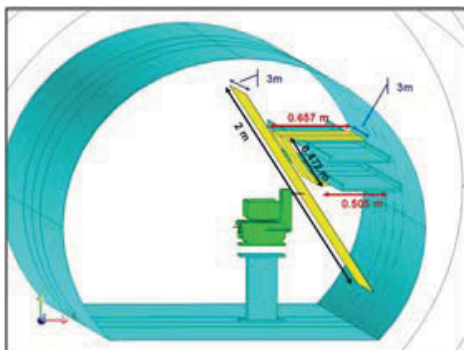


Figure 5: Optimized shielding design for collimator TCDIH.29050.

Different shielding geometries have been simulated starting from a simple planar shield inserted between the collimator and the tunnel wall. Even with a multiple layer shield, we were not able to achieve the required shielding effectiveness. A combined proposal based on a semi-closed shield around the cable trays and a planar shield has shown to be promising. The optimized design is shown in Figure 5. Parametric simulations have been performed to find the optimum set of design parameters. A summary is shown in Table 3.

Table 3: Optimal parameters for the TCDIH.29050 shielding design.

Planar shielding parameter	
Thickness	3 mm
Number of layers	1
Width	4 m
Length	2 m
Distance from cable` trays` shielding	96 mm
Cable trays shielding parameter	
Thickness	3 mm
Width	4 m
Front panel inclination angle	122°

In Table 2, the simulated magnetic flux density values along the sensors' longitudinal axes with and without the proposed shielding are compared.

EXPERIMENTAL RESULTS

The designed shield has been successfully installed on the collimator TCDIH.29050 in May 2009 (figure 6). Table 1 shows the reduction of the reading error on the most affected LVDT after the installation of the shield. Even if the reading error reduction is not the same on all the sensors, the shielding has reduced the maximum drift to within the acceptable sensor accuracy.



Figure 6: Magnetic shielding installed on the collimator TCDIH.29050 on May 2009.

CONCLUSIONS

The reading errors of more than 100 μm caused by magnetic interference on the LVDT sensors of the LHC transfer line collimators were brought below the acceptable threshold by installing shielding. The solution is the result of simulations and experimental verifications on the collimator TCDIH.29050. The latter is a case study, but the simulation model developed, as well as the solution proposed can be applied to collimators equipped with LVDTs and operating in a magnetic field.

ACKNOWLEDGMENTS

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REFERENCES

- [1] A. Masi, et al., "LVDT conditioning on the LHC collimators," *IEEE Trans. Nucl. Sci.*, vol. 55, no.1, pp. 67–75, Feb. 2008.
- [2] A. Danisi, "Simulation of DC Interfering Magnetic Field Effects on the LHC Collimators' LVDT Positioning Sensors," M.S. thesis, 2009. <https://edms.cern.ch/>, EDMS Id 1016998.
- [3] M. Martino, et al., "Design of a LVDT with high rejection to external interfering magnetic field," *IEEE Trans. Mag.*, vol. 46, no. 2, pp. 674-677, Feb. 2010.
- [4] G. Spiezia, et al., "An Automatic Test Bench for the Measurement of the Magnetic Interference on LVDTs," *IEEE Trans. Instrum. and Meas.*, vol.60, no.5, pp.1802-1810, May 2011.
- [5] Flux® User's Guide, CEDRAT, Meylan, FR, 2006.
- [6] A. Masi, et al., "Study of Magnetic Interference on an LVDT: FEM Modeling and Experimental Measurements," *Journal of Sensors*, vol. 2011, Article ID 529454, 9 pages, 2011.