Single-pass beam measurements for the verification of the LHC magnetic model

R. Calaga
Brookhaven National Laboratory

M. Giovannozzi, S. Redaelli, R. Tomas, W. Venturini-Delsolaro, F. Zimmermann
CERN

Y. Sun
SLAC

Presented at the First International Particle Accelerator Conference (IPAC'10)
Kyoto, Japan
May 23-28, 2010

Collider-Accelerator Department
Brookhaven National Laboratory
P.O. Box 5000
Upton, NY 11973-5000
www.bnl.gov

Notice: This manuscript has been authored by employees of Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy. The publisher by accepting the manuscript for publication acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes.

This preprint is intended for publication in a journal or proceedings. Since changes may be made before publication, it may not be cited or reproduced without the author’s permission.
DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party’s use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.
SINGLE-PASS BEAM MEASUREMENTS FOR THE VERIFICATION OF THE LHC MAGNETIC MODEL

R. Calaga, M. Giovannozzi, S. Redaelli, Y. Sun, R. Tomás, W. Venturini-Delsolaro, F. Zimmermann

Abstract

During the 2009 LHC injection tests, the polarities and effects of specific quadrupole and higher-order magnetic circuits were investigated. A set of magnet circuits had been selected for detailed investigation based on a number of criteria. The polarities of these circuits were verified in both the Beam 1 and 2 injection tests. Polarities of magnets which indicated a discrepancy in the model were checked with predictions from various optics models. These comparisons allowed confirming or updating the relative polarity conventions used in the optics model and the accelerator control system, as well as verifying the correct powering and assignment of magnet families. Results from measurements in several LHC sectors are presented.

INTRODUCTION

During the synchronization tests performed in November 2009 in the LHC, polarities of certain circuits in question from previous measurements [1, 2] in the Beam 1 & 2 were verified. Polarity conventions of magnets which indicated a discrepancy in the beam model were checked from single pass difference trajectories or from optics measurements in 2008 were compared to those in the MADX model. Missalignments inferred from the past measurements were also verified. Difference trajectories for two different settings of each circuit were recorded while launching a betatron oscillation (see Fig. 1). The effect of the initial orbit was removed with baseline trajectories without the corrector but for both polarities of the circuit under verification. Individually selected orbit correctors with optimum phase advance and inverted strengths of the magnet with their corresponding correctors (see Table 1) and found to be consistent with the model. The magnet circuits checked during these tests are listed in Table 1 along with the corresponding corrector magnet. Only trajectories of selected circuits are shown in graphic form to depict as a representative example. Optics measurements in 2008 showed a large beta-beat. The error sources were traced to potential particle issues or a cable swaps between beam 1 and 2 in the dispersion suppressor regions. Some of the potential candidates (Q4.L6.B2, Q4.R2.B1 and QT5.L7.B2) were tested using difference trajectories computed from nominal and inverted strengths of the magnet with their corresponding correctors (see Table 1) and found to be consistent with the model.

Table 1: The model strengths of the circuits and the corresponding correctors strengths used for betatron trajectories. Note that the nominal values of skew circuits and octupole circuits were zero.

<table>
<thead>
<tr>
<th>Circuit</th>
<th>$k_n$ [m$^{-1}$]</th>
<th>Corrector</th>
<th>Kick [µrad]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q4.R2.B1</td>
<td>0.00492</td>
<td>MCBHX3.R2B1</td>
<td>40</td>
</tr>
<tr>
<td>MQS.A23.B1</td>
<td>0.02</td>
<td>MCBCH6.R2B1</td>
<td>30</td>
</tr>
<tr>
<td>MQS.A78.B2</td>
<td>0.02</td>
<td>MBCVB3.L8B2</td>
<td>30</td>
</tr>
<tr>
<td>MQS.A56.B2</td>
<td>0.02</td>
<td>MBCYH5.R6B2</td>
<td>30</td>
</tr>
<tr>
<td>SD1.A23.B1</td>
<td>-0.1065</td>
<td>MCBCV5.R2B1</td>
<td>30</td>
</tr>
<tr>
<td>KOF.A23.B1</td>
<td>50.0</td>
<td>MCBCH6.R2B1</td>
<td>30</td>
</tr>
<tr>
<td>MSS.78.B2</td>
<td>3.0</td>
<td>MBCVB5.L8B2</td>
<td>20</td>
</tr>
</tbody>
</table>

*This work partially supported by the US Department of Energy through the US LHC Accelerator Research Program (LARP)
sistent with the model. Inclusion of $b_2$ component in the dipoles improved the agreement between the measured and model trajectories (see Fig. 2). Measurements in 2008 indicated trajectory discrepancies in QTL11.L8B2 polarity check which was reproduced by a 3mm misalignment in the model. However, measurements in 2009 were consistent with the MADX model. The discrepancy in 2008 measurements could perhaps be explained due to unintentional orbit changes during the measurements for this specific circuit, but the discrepancy is not reproducible. In addition, QT13.L8B2 measurements in 2008 were inconclusive due to noisy data. In 2009 they were confirmed to be consistent with the model. Additional trim quadrupole circuits in sector 78 (QTL11.L7B2, QT12.L7B2, QT13.L7.B2) were also tested in 2009 and found to be consistent with the model (Fig. 3).

For skew quadrupoles, difference trajectories for MQS23.B1 (beam 1), MQS78.B2 and MQS56.B2 (beam 2) circuits are shown in Fig. 4 using the associated correctors MCBCH6.R2B1, MCBXV3.L8B2 and MCBYH5.R6B2. All three circuits show a disagreement between the MADX model and the measured values similar to the 2008 measurements, pointing to a wrong polarity or a systematic convention difference between online LSA database and the MADX model.

For normal sextupole and octupole circuits tested in 2008, the polarity convention measured was found to be consistent with the model. However, inclusion of $b_2$ and $b_3$ components in the dipoles and initial trajectories help improve agreement between the measured and model trajectories as demonstrated for SD1.A23B1 and KOF.A23B1 (see Fig. 5) For the $b_3$ spool pieces, MCS circuits, only the polarity for MCS.67B2 (beam 2) was tested. The difference trajectories in Fig. 6 show good agreement for both
polarity and amplitudes between the model and measurements. A comparison with a model including the $b_2$ and $b_3$ components with the aid of PTC (black) gives a significantly improved agreement as opposed to the bare model (red). For the skew sextupole magnets, trajectories for the skew sextupole magnets, trajectories for


MSS.23B1 (beam 1), MSS.56B2 and MSS.78B2 (beam 2) circuits were tested for magnet polarity. The initial values of the skew sextupoles were zero. They were powered to finite values for the experiment (see Table 1). The difference trajectories are shown in Fig. 7 indicating opposite polarities or convention for all three circuits as compared to the MADX model.

Figure 7: Difference trajectories with a finite value of MSS.23.B1 and corresponding inverted strength using MCBCH6.R2B1 corrector compared with model prediction.

Table 2: Status of the circuits tested in 2008 and 2009 in Sector 23, Beam 1. B, H, T correspond to candidates with polarity issues found from β-beat, hardware or trajectory measurements in 2008 respectively.

Table 3: Status of the circuits tested in 2008 and 2009 in Sector 78, Beam 2. B, H, T correspond to candidates with polarity issues found from β-beat, hardware or trajectory measurements in 2008 respectively.

CONCLUSIONS

Polari for linear and higher order circuits in question from 2008 measurements were verified in the 2009 tests and listed in Table 2 and Table 3. The polarity verification of the magnet circuits tested indicate all normal circuits to be consistent with the model. Measurements for the skew quadrupole and sextupole circuits indicate either an opposite polarity of a systematic convention problem between the MADX model and LSA online database. Inclusion of $b_2$ and $b_3$ components of the dipoles in the model significantly improve the agreement to the measured values.

ACKNOWLEDGMENTS

We would like to acknowledge the support of M. Lamont for suggesting and supporting these measurements.

REFERENCES