DETERMINATION OF OCTUPOLE AND SEXTUPOLE POLARITIES IN THE LHC*

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Abstract

We report the results of measurements to verify the polarity of higher-order corrector elements in the LHC. The polarities of the lattice focusing and defocusing octupoles, spool piece octupole correctors, arc skew sextupole correctors, and interaction region sextupoles have been verified. All were found to have the expected polarity with the exception of the arc skew sextupoles.

INTRODUCTION

In the course of operations, concerns have arisen about whether all higher-order magnet elements in the LHC have the correct polarities. Extensive tests to verify the polarities of arc trim skew sextupoles (MSS), Landau damping octupoles (MOF, MOD) and octupole spool correctors (MCO), as well as triplet sextupole and skew sextupole correctors (MCSX and MCSSX), have been made. All elements tested were found to have the expected polarity, with the exception of the arc sextupoles MSS. Measurements were made at injection energy.

MEASUREMENTS

Arc Octupoles

Octupole polarities were determined by measuring the change to second order chromaticity in response to octupole excitation. Each arc contains between 8 and 13 octupoles of each of the families MOF and MOD, and 77 spool piece corrector octupoles MCO. All octupoles of a family in each arc are powered in series. The polarities were verified by trimming a group of octupoles in one arc and measuring the resulting change in second order chromaticity (see Figs. 1, 2, and 3).

Trims for each magnet family were calculated to produce an approximately uniform shift to the second order chromaticity according to the lattice model. In most cases the predicted $\Delta Q''_x$ is within one or two standard deviations of the observed value. The MCO octupoles in arc 12 of Beam 1 and in arcs 12, 78, and 81 of Beam 2 were not tested because they were not operational at the time the measurements were made. The reduced number of MOF in arc 34 of Beam 2 and MOD in arc 34 of Beam 1 is due to the incident of 2008. For the MOF octupole measurement there was a small tune shift between the reference measurement and the trim measurements due to machine tuning, but this is not expected to have any effect on higher order chromaticities.

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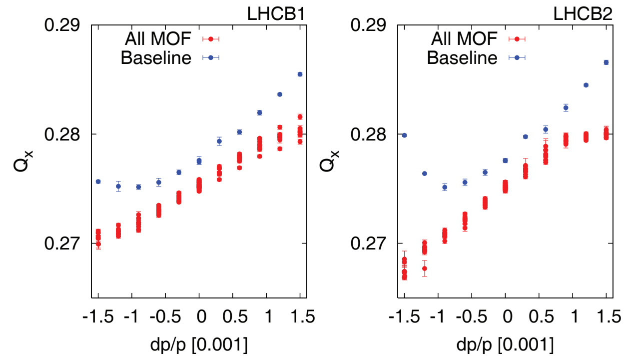

Figure 1: Chromaticity measurements with MOF trims.

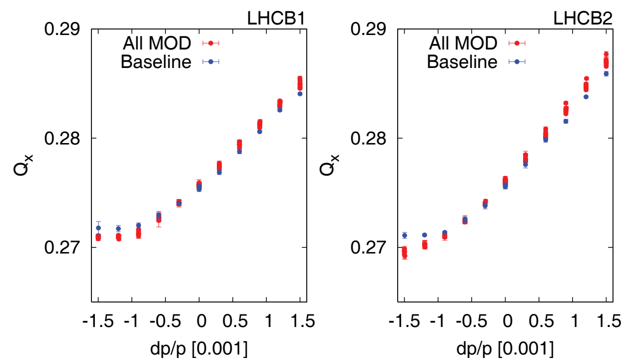

Figure 2: Chromaticity measurements with MOD trims.

One family of magnets, the MODs in arc 23 of Beam 1, had a measured $\Delta Q''_x$ greater than two standard deviations from the model value. To further check the polarity of these magnets, we made localized orbit bumps through each of the eight octupoles in this arc and measured the resulting tune shift. The tune shifted in the same direction with the orbit bump through each magnet, indicating that all magnets in the arc have the same polarity (see Fig. 4).

For many of the MCO spool corrector octupoles, particularly in Beam 1, the expected second order tune shift is nearly three standard deviations from the measured value. Further study is needed to understand this discrepancy, but one possibility is that this is due to hysteresis effects. The MCO octupoles are not pre-cycled, so the strengths may not be well-known, particularly at injection energy.

Arc Skew Sextupoles

Each arc contains four skew sextupoles MSS, powered in series. The polarities were checked by measuring the change to chromatic coupling when each skew sex-

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Table 1: Measured and Predicted $\Delta Q''_x$ and the Standard Error of the Fit for the Corresponding MOF Family Trim. The number of octupoles per family is also shown.

Family	Trim $[\mathrm{m}^{-4}]$	Num. of Magnets	$\Delta Q''_x$ Model	$\Delta Q''_x$ Meas.	Standard Error
A12 B1	-15.0	8	-2125	-2120	180
A23 B1	-12.5	13	-2875	-2700	190
A34 B1	-20.0	8	-2833	-2700	180
A45 B1	-12.5	13	-2879	-2510	180
A56 B1	-20.0	8	-2833	-2700	200
A67 B1	-12.5	13	-2879	-2670	190
A78 B1	-20.0	8	-2833	-2560	180
A81 B1	-12.5	13	-2879	-2600	200
A12 B2	-15.0	13	-3450	-3300	200
A23 B2	-24.0	8	-3400	-3500	200
A34 B2	-18.0	11	-3504	-3770	170
A45 B2	-24.0	8	-3368	-3400	200
A56 B2	-15.0	13	-3450	-3300	300
A67 B2	-33.0	8	-4675	-4000	200
A78 B2	-15.0	13	-3455	-3300	200
A81 B2	-24.0	8	-3400	-3700	200

Table 2: Measured and Predicted $\Delta Q''_x$ and the Standard Error of the Fit for the Corresponding MOD Family Trim. The number of octupoles per family is also shown.

Family	Trim $[\mathrm{m}^{-4}]$	Num. of Magnets	$\Delta Q''_x$ Model	$\Delta Q''_x$ Meas.	Standard Error
A12 B1	-54	13	3060	2860	190
A23 B1	-86	8	2981	3400	200
A34 B1	-65	11	3120	3120	180
A45 B1	-86	8	2981	2860	100
A56 B1	-54	13	3060	2900	200
A67 B1	-86	8	2981	2890	100
A78 B1	-54	13	3060	3010	140
A81 B1	-86	8	2981	2560	190
A12 B2	-43	8	1491	1570	90
A23 B2	-27	13	1530	1410	300
A34 B2	-43	8	1491	1590	70
A45 B2	-27	13	1530	1520	100
A56 B2	-43	8	1505	1570	100
A67 B2	-27	13	1530	1670	100
A78 B2	-43	8	1505	1720	90
A81 B2	-27	13	1530	1960	70

tupole family was trimmed. The chromatic coupling was determined through analysis of turn-by-turn oscillations driven using an AC dipole [1]. A comparison of the measured chromatic coupling with model predictions indicates that MSS magnets in all arcs have reversed polarity (see Figs. 5 and 6).

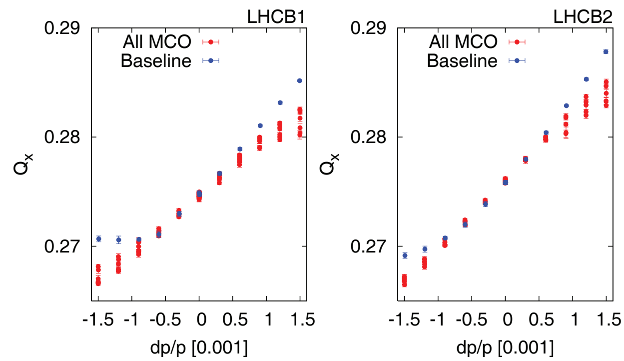

Figure 3: Chromaticity measurements with MCO trims.

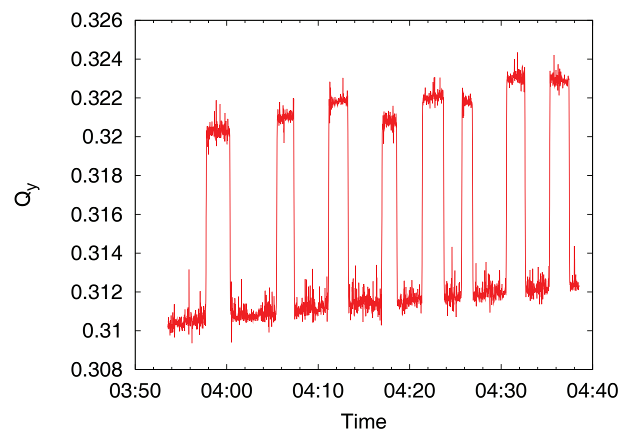

Figure 4: Measured tune as the orbit was displaced through each of the eight MOD magnets in A23 B1, showing that each has the same polarity.

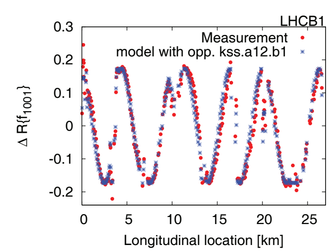

Figure 5: Measured change to chromatic coupling for Beam 1 resulting from KSS arc 12 trim (red) compared to model assuming opposite polarity (blue).

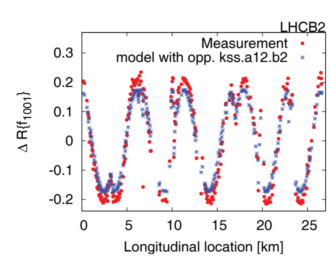

Figure 6: Measured change to chromatic coupling for Beam 2 resulting from KSS arc 12 trim (red) compared to model assuming opposite polarity (blue).

Table 3: Measured and Predicted $\Delta Q''_x$ and the Standard Error of the Fit for the Corresponding MCO Family Trim. In arcs with no measurement shown, magnets were not operational.

Family	Trim $[\mathrm{m}^{-4}]$	Num. of Magnets	$\Delta Q''_x$ Model	$\Delta Q''_x$ Meas.	Standard Error
A12 B1		77			
A23 B1	-30.0	77	-2170	-2900	220
A34 B1	-30.0	77	-3260	-3840	130
A45 B1	-30.0	77	-2160	-2590	130
A56 B1	-30.0	77	-3080	-3840	140
A67 B1	-30.0	77	-2130	-2920	180
A78 B1	-30.0	77	-3011	-3540	180
A81 B1	-30.0	77	-2200	-2940	140
A12 B2		77			
A23 B2	-30.0	77	-3200	-3200	120
A34 B2	-30.0	77	-2080	-2470	90
A45 B2	-30.0	77	-3050	-3300	160
A56 B2	-30.0	77	-2170	-2500	70
A67 B2	-30.0	77	-3020	-2960	130
A78 B2		77			
A81 B2		77			

Triplet Sextupole Correctors

Each triplet contains a normal sextupole corrector MCSX and a skew sextupole corrector MCSSX. The polarities of the skew sextupoles left and right of IR1, where the crossing angle is vertical, and the normal sextupoles left and right of IR5, where the crossing angle is horizontal, were verified by measuring the tune shift resulting from magnet trims. Comparison of the measured tune shifts with model predictions shows that the polarities of MCSSX in IR1 and MCSX in IR5 are correct.

CONCLUSIONS

The reults of these extensive polarity checks are summarized in Table 4 summarizes the results. While the polarities of all elements tested are clearly determined, the strengths of the spool piece octupoles were several standard deviations from expected values and merit further study. Note that not all MCO octupoles were tested, as detailed in Table 3.

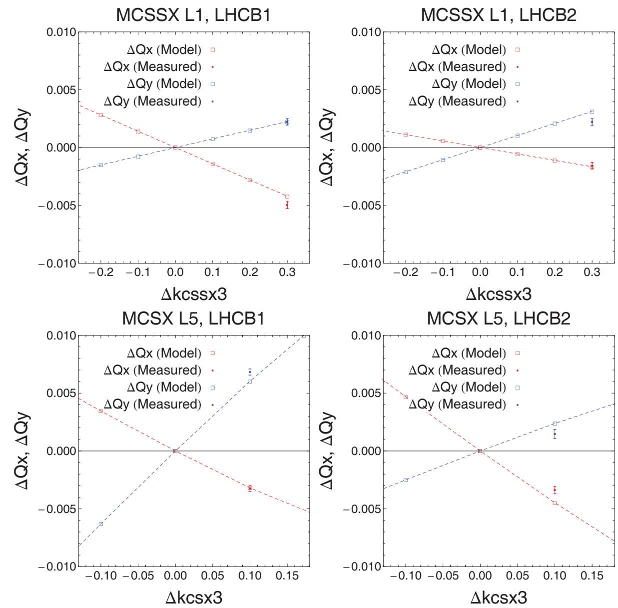

Figure 7: Tune shifts resulting from MCSSX trim in IP 1 and MCSX trim in IP 5.

Table 4: Summary of Polarities of all Measured Magnet Families. See Tables 1, 2, and 3 for details of which magnets in each family were measured.

Type	Polarity	Type	Polarity
MOF B1	Correct	MOF B2	Correct
MOD B1	Correct	MOD B2	Correct
MCO B1	Correct	MCO B2	Correct
MSS B1	Reversed	MSS B2	Reversed
MCSSX IP1	Correct	MCSX IP5	Correct

REFERENCES

[1] T. H. B. Persson et al., "Chromatic Coupling Correction in the Large Hadron Collider", to be published (2013).

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