Determination of Octupole and Sextupole Polarities in the LHC

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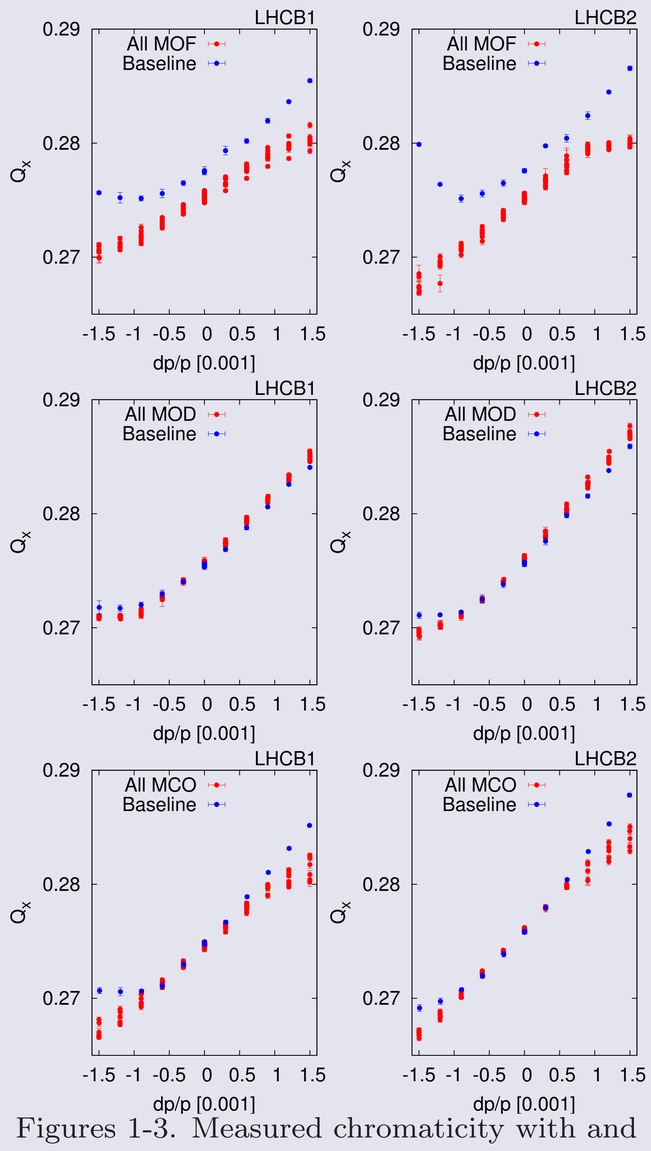
ABSTRACT

In the course of operations, concerns have arisen about whether all higher-order magnet elements in the LHC have the correct polarities. We report the results of extensive measurements to verify the polarity of sextupolar and octupolar corrector elements in the LHC. The polarities of the Landau damping octupoles MOF and MOD, octupole spool correctors MCO, arc trim skew sextupole correctors MSS, and triplet sextupole correctors MCSX and MCSSX have been checked, and all elements tested were found to have the expected polarity except for the arc skew sextupoles.

Octupoles MOF, MOD, MCO

- Each arc contains between 8 and 13 Landau damping octupoles MOF and MOD, and all octupoles of a family in an arc are powered in series.
- Polarities were determined by measuring the change to second order chromaticity d octupole trims.
- In most cases the ovserved value for $\Delta Q''_x$ is within one or two standard deviations of the model predicttion.
- For MODs in arc 23 of Beam 1, measured $\Delta Q''_x$ was greater than two standard deviations from the model value. Polarity of individual magnets in this section was checked by making localized orbit bumps through each of the eight octupoles in this arc and measured the resulting tune shift, which confirmed that all magnets in the arc have the same polarity (see Fig. 4).
- For many MCO groups, the expected second order tune shift is nearly three standard deviations from the measured value. These magnets are not pre-cycled, so these discrepancies may be due to hysteresis effects; further study is needed to fully understand these results.



Figures 1-3. Measured chromaticity with and without octupole family trims.

Family	Trim 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 1. Measured and predicted $\Delta Q''_x$ and the standard error of the fit for MOF family trims.

Family	Trim 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

Table 2. Measured and predicted $\Delta Q''_x$ and the standard error of the fit for MOD family trims.

Family	Trim 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			

Table 3. Measured and predicted $\Delta Q''_x$ and the standard error of the fit for MCO family trims. In arcs with no measurement shown, magnets were not operational.

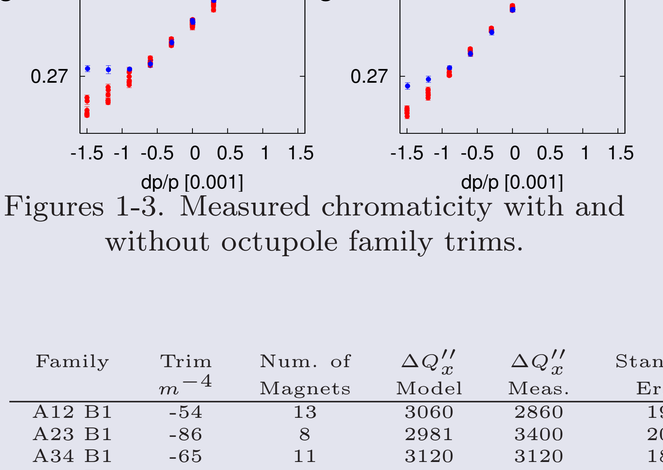
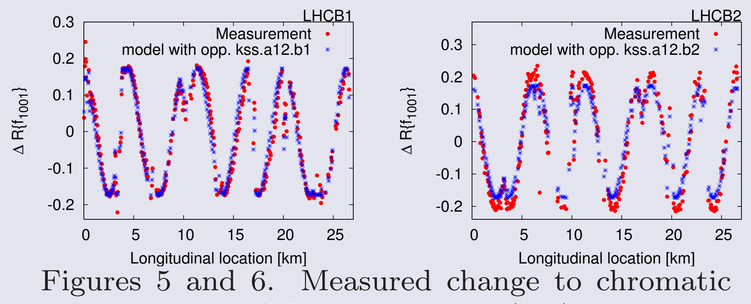


Figure 4. Measured tune as the orbit was displaced through each of the eight MOD magnets in A23 B1, showing that each has the same polarity.

Arc skew sextupoles

- Each arc contains four skew sextupoles MSS, powered in series.
- The polarities were checked by measuring the change to chromatic coupling due to skew sextupole trims.
- The chromatic coupling was determined through analysis of turn-by-turn oscillations driven using an AC dipole.
- A comparison of the measured chromatic coupling with model predictions indicates that MSS magnets in all arcs have reversed polarity.



Figures 5 and 6. Measured change to chromatic coupling from KSS trim in arc 12 (red), and corresponding model values assuming opposite magnet polarity (blue).

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 shifts due to sextupole trims.
- Comparison of the measured tune shifts with model predictions shows that the polarities of MCSSX in IR1 and MCSX in IR5 are correct.

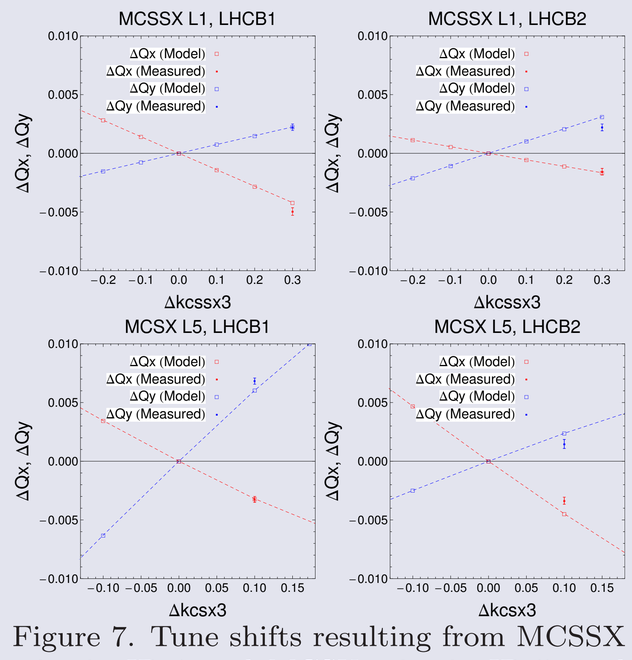


Figure 7. Tune shifts resulting from MCSSX trim in IP 1 and MCSX trim in IP 5, and corresponding model values.

Summary of Results

Family	Polarity	Family	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

Table 4. Summary of polarities of all measured magnet families. See Table 3 for arcs in which MCO magnets were tested.

Acknowledgments

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