Understanding the landau octupole feed down in the LHC.

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Outline

Introduction

On several occasions this year we have observed variations in the tune, chromaticity and coupling, correlated with changes in the landau octupole (**MO**) powering.

Specifically I consider 3 occasions where we have made observations:

- Aperture study (*22nd April*)
- 60cm optics commissioning (*30th March*)
- MO instability MD (*20th June*)

In particular it is vital to understand the dependence of chromaticity on MO powering due to the influence on instabilities.

This talk will summarize our attempts to-date to try and understand these shifts.

22^{nd} April: Aperture study.

Began studying variation in Q,Q',c^- with MO powering following Aperture study (22/4/12).

- *LHC OP [Saturday 21-Apr-2012 Night]*
- *LHC OMC [Sunday 22-Apr-2012 Day]*

Coupling shift coincided with the depowering of the MO from 450→50[A]

$$\delta c^-_{B1} \sim -3 \times 10^{-3}$$

$$\delta c^-_{B2} \sim -2 \times 10^{-3}$$

Figure: Couplings logged from BBQ & MO current vs time.

- Small tune shifts were also observed.
- Corresponding δQ & δc^- seen on repowering MO at end of MD.

LHC MO feeddown
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Following 22/4/12 observations we re-examined old commissioning data.

· During (30/3/12) 60cm optics commissioning measurements were taken with MO powered.

- *LHC OP [Friday 30-Mar-2012 Morning]*
- *LHC OMC [Friday 30-Mar-2012 Day]*

= AC-dipole + BBQ data before/after MO depowered (250→0[A]).

· Observed tune shifts consistent with 22/4/12 measurements.

· Observed a coupling shift correlated to the MO powering.

- Δc^{-} ∼factor 5 smaller than 22/4/12.
- However coupling was better corrected at the start, and we don't know the phase on 22/4/12.

Measurements

30th March: 60cm commissioning.

In addition to BBQ data, from AC-dipole measurements observed a shift to the $|f_{1001}|$ on depowering the MO.

- The $\Delta|f_{1001}|$ is consistent with the δc^{-} observed by the BBQ.

This is the only occasion we have measurement of coupling RDT with octupole powering.

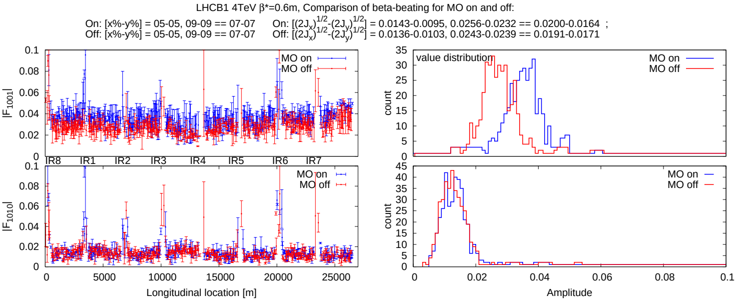

Figure: Comparison of $|f_{1001}|$ and $|f_{1010}|$ before/after MOs depowered.

Measurements
20th June: Instability MD.

Measurement of Q' vs I_{MO} during MD#2.

Performed during *Octupole Instability threshold MD* (20/6/12).

- *LHC OP [Tuesday 19-Jun-2012 Night]*
- *LHC OMC [Wednesday 20-Jun-2012 DAY]*

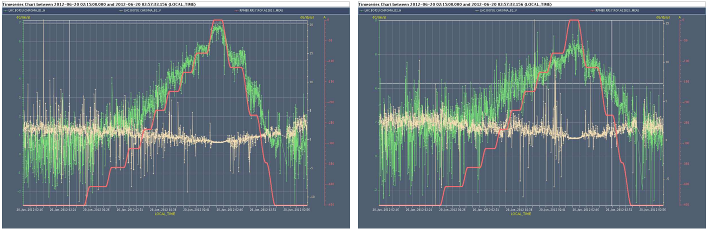

Figure: Beam 1 & 2 Q' and I_{MO} vs time.

- I_{MO}: 450⟶0[A]
- Observe large Q' dependence on MO powering ($\sim +6, -2$ units [B1]).
- Again see tune and coupling shifts correlated with MO powering.

Measurements Overview

Table: Summary of tune, chromaticity and coupling shifts.

	δ_{off-on}	30/3/12 250$\longrightarrow$0[A] (60cm)	22/4/12 450$\longleftrightarrow$50[A] (60cm)	20/6/12 450$\longrightarrow$0[A] (Flattop)	20/6/12 450$\longrightarrow$ 0[A] (60cm)
Beam 1	ΔQ_x ($\times 10^{-4}$)	2$\pm$1	5$\pm$2	5$\pm$4	7$\pm$4
	ΔQ_y ($\times 10^{-4}$)	3$\pm$0.7	5$\pm$2	8$\pm$1	4$\pm$1
	$\Delta Q'_x$	-	-	6.3$\pm$0.8	6.6$\pm$0.3
	$\Delta Q'_y$	-	-	-2.3$\pm$0.4	-2.1$\pm$0.6
	Δc^- ($\times 10^{-3}$)	-0.6$\pm$0.1	-3.2$\pm$0.2	-3.5$\pm$0.5	-0.9$\pm$0.1
Beam 2	ΔQ_x ($\times 10^{-4}$)	4$\pm$1	6$\pm$3	20$\pm$6	-
	ΔQ_y ($\times 10^{-4}$)	7$\pm$1	13$\pm$6	8$\pm$2	-
	$\Delta Q'_x$	-	-	4.7$\pm$0.7	-
	$\Delta Q'_y$	-	-	-2.2$\pm$0.6	-
	Δc^- ($\times 10^{-3}$)	-0.4$\pm$0.03	-3.5$\pm$0.8	-3.5$\pm$0.2	-

Matching to the δQ, $\delta Q'$, δc^-:

- We attempted to match systematic missalignments of the MOF and MOD to the measured δQ, $\delta Q'$, δc^-, focusing on the $\delta Q'$.

Table: Matching results B1.

Matching: Vary:	Q' only δ_x MOF & MOD	Q+Q' $\delta_{x,y}$ MOF & MOD	Q+Q'+Coupling $\delta_{x,y,\psi}$ MOF & MOD
$MOF : \delta_x [\mathrm{mm}]$	-0.36	-0.36	??
$MOF : \delta_y [\mathrm{mm}]$	0	-0.008	??
$MOF : \delta_\phi [\mu\mathrm{rad}]$	0	0	??
$MOD : \delta_x [\mathrm{mm}]$	-0.1	-0.1	??
$MOD : \delta_y [\mathrm{mm}]$	0	0.39	??
$MOD : \delta_\phi [\mu\mathrm{rad}]$	0	0	??

Similar results were obtained for beam 2.

- (??) matching to coupling consistently gave unrealistically large rotational missalignments.

We will use these values for comparison later when considering the measured missalignments.

Missalignments:
Outline.

We have attempted to determine whether the shifts to the Q,Q',c^- may be explained by the known missalignments and orbit.

In the following section I will discuss:

- Systematic mechanical missalignment of the MO
- Examine logged orbit during the MO instability MD (20/6/12).
- Consider the orbit at the MO around the ring
- Look at the effect of BPM missalignment on the estimate of systematic orbit
- Summarize the mean missalignments.
- Summarize resulting δQ, $\delta Q'$, δc^- in the model.

- Is there a systematic mechanical missalignment of the focusing or defocusing landau octupoles (*MOF(D)*)?

Averaging the missalignments detailed in the *'LHC-egeoc-b#.tfs'* tables, the mean mechanical missalignments are non-negligible.

Mean missalignments and corresponding δQ, $\delta Q'$, δc^- on reading these errors into MAD and depowering the MO are given below:

Table: Mean mechanical missalignments of the MOF(D), and resulting shifts to observables on inclusion in the model.

		$\bar{\delta_x}$[mm]	$\bar{\delta_y}$[mm]	$\bar{\delta_\psi}$[μrad]
B1	MOF	-0.0633	-0.146	-7.97
	MOD	-0.0588	-0.185	-0.476
B2	MOF	-0.0514	-0.231	-0.476
	MOD	-0.0663	-0.208	-7.98

	Beam 1	Beam 2
ΔQ_x	-0.0006	0.0036
ΔQ_y	0.0007	0.00007
$\Delta Q'_x$	0.96	2.12
$\Delta Q'_y$	-0.53	-1.31
Δc^-	0.00040	0.00047

Missalignments: Orbit at the MO.

- Is there any systematic orbit at the MOF or MOD?

Examined orbit data logged from YASP during the ‘MO instability MD’.
· average over BPMs with *status:‘OK’*, immediately proceeding MOF(D).

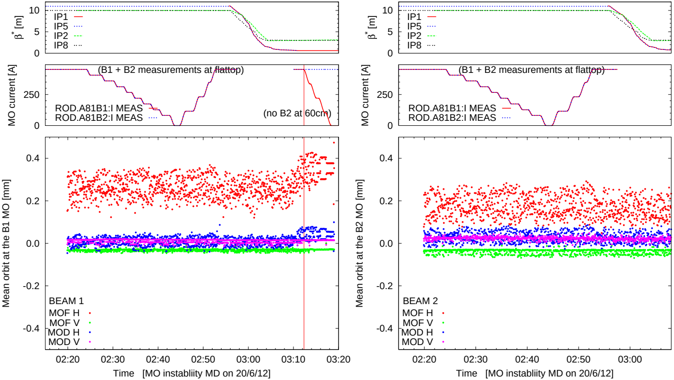

Figure: YASP orbit data, averaged over *status=‘OK’* BPMs next to an MOF(D).

Missalignments:
Orbit at the MO.

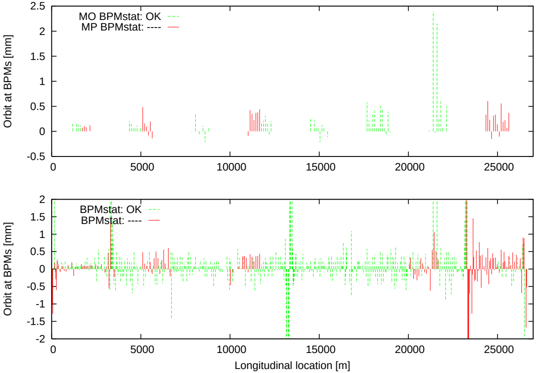

Figure: B1 H orbit at 02:19:54. BPMs with status:'OK' in green, others in red. Lower plot shows all BPMs, upper plot shows the BPMs immediately proceeding the B1 MOF.

Missalignments: Orbit at the MO.

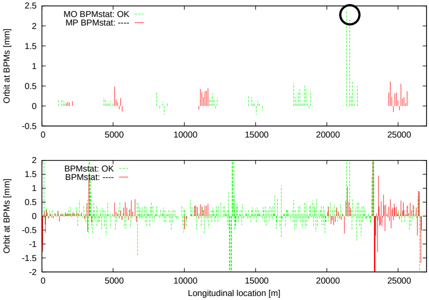

Figure: B1 H orbit at 02:19:54. BPMs with status:'OK' in green, others in red. Lower plot shows all BPMs, upper plot shows the BPMs immediately proceeding the B1 MOF.

$\sim$ 30% of the systematic horizontal orbit calculated for the B1 MOF results from the orbit at 2 BPMs:

- BPM.29R7.B1 $\rightarrow$ 2.40mm
- BPM.33R7.B1 $\rightarrow$ 2.15mm

- YASP data does not include BPM missalignment.

· BPM alignments are provided relative to the MQ.
· MQ alignments taken from *'LHC-egeoc-b#.tfs'* tables
· Include the BPM alignment in mean orbit calculation, eg B1 MOF H:

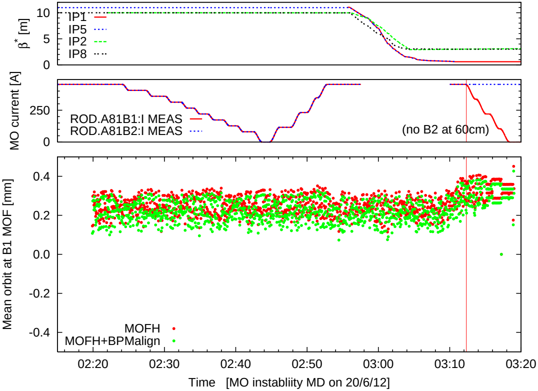

Figure: YASP data, averaged over *status='OK'* BPMs next to B1 MOF, including BPM alignment.

Missalignments:
Orbit at the MO + BPM missalignments.

- YASP data doesn't include BPM missalignment.

· BPM alignments are provided relative to the MQ.
· MQ alignments taken from *'LHC-egeoc-b#.tfs'* tables
· Include the BPM alignment in mean orbit calculation, eg B1 MOF V:

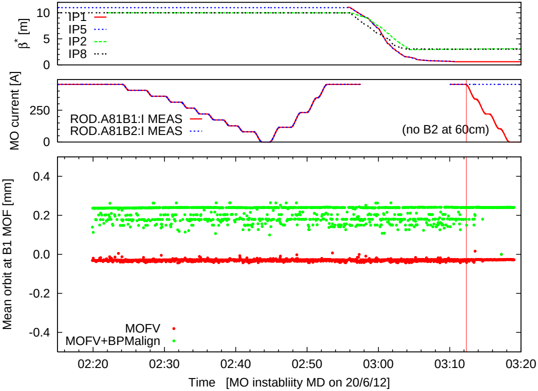

Figure: YASP data, averaged over *status='OK'* BPMs next to B1 MOF, including BPM alignment.

Missalignments: Orbit at the MO + BPM missalignments.

- YASP data doesn't include BPM missalignment.

· BPM alignments are provided relative to the MQ.
· MQ alignments taken from *'LHC-egeoc-b#.tfs'* tables
· Include the BPM alignment in mean orbit calculation, eg B1 MOF:

- Only a small change to mean horizontal orbit.
- Significant change to mean vertical missalignment.
- Similar results were obtained for MOF & MOD, both beams.

Missalignments summary.

Table: Summary of mean missalignments.

		MO	MQ	BPM wrt MQ	BPM	YASP orbit	YASP orbit + BPM align'	- MO + YASP orbit + BPM align'
B1 MOF	$\bar{\delta_x}$[mm]	-0.06	-0.07	0.04	-0.024	0.25±0.05	0.22±0.05	0.28
	$\bar{\delta_y}$[mm]	-0.15	-0.13	0.39	0.26	-0.030±0.005	0.21±0.03	0.36
	$\bar{\delta_\psi}$[μrad]	-7.97	-7.97	-	-	-	-	-
B1 MOD	$\bar{\delta_x}$[mm]	-0.06	-0.07	0.07	0.002	0.006±0.02	0.004±0.02	0.06
	$\bar{\delta_y}$[mm]	-0.19	-0.23	0.42	0.18	0.011±0.008	0.16±0.04	0.35
	$\bar{\delta_\psi}$[μrad]	-4.88	-4.88	-	-	-	-	-
B2 MOF	$\bar{\delta_x}$[mm]	-0.05	-0.07	0.07	-0.027	0.15±0.04	0.14±0.05	0.19
	$\bar{\delta_y}$[mm]	-0.24	-0.22	0.46	0.25	-0.036±0.008	0.18±0.06	0.42
	$\bar{\delta_\psi}$[μrad]	-4.88	-4.88	-	-	-	-	-
B2 MOD	$\bar{\delta_x}$[mm]	-0.07	-0.07	0.03	-0.034	0.025±0.02	0.007±0.02	0.08
	$\bar{\delta_y}$[mm]	-0.21	-0.14	0.43	0.29	0.021±0.007	0.24±0.06	0.45
	$\bar{\delta_\psi}$[μrad]	-7.98	-7.98	-	-	-	-	-

· *BPM* is calculated from the mean MQ alignment + the mean BPM alignment wrt the MQ.
· *+ BPM align'* indicates BPM alignment is added to the YASP data when averaging over status='OK' BPMs at the MO.
· ±*error* are std'dev of mean orbit (status='OK' BPMs at MO) when averaged between 02:29 & 03:00.
· The tilt error on the BPM alignments are negligible and have not been considered in the table.
· Total mean missalignment (MO+YASP+BPM align') is quoted without error as we did not have the error on the mechanical alignments.

Missalignments:
Modelled Q,Q',c^- shifts.

· Mechanical missalignments of MO read into MOD.

· Mean orbit as recorded at BPMs immediately proceeding an MOF(D) is included as a systematic missalignment of the MOF / MOD.

Table: Q,Q',c^- shifts in the model (450⟶0[A]).

		MO alignment	MO alignment + orbit from YASP	MO alignment + orbit from YASP + BPM alignments	Measured 20/6/12 FLATTOP
B1	$\Delta Q_x(\times 10^{-4})$	-6	-2	-8	5±4
	$\Delta Q_y(\times 10^{-4})$	7	7	11	8±1
	$\Delta Q'_x$	0.96	5.3	4.8	6.3±0.8
	$\Delta Q'_y$	-0.53	-1.3	-1.2	-2.3±0.4
	$\Delta c^-(\times 10^{-3})$	0.40	0.6	0.6	-3.5±0.5
B2	$\Delta Q_x(\times 10^{-4})$	35.9	44	42	20±6
	$\Delta Q_y(\times 10^{-4})$	0.7	-15	-12	8±2
	$\Delta Q'_x$	2.12	3.4	3.2	4.7±0.7
	$\Delta Q'_y$	-1.31	-0.5	-0.7	-2.2±0.6
	$\Delta c^-(\times 10^{-3})$	0.47	-0.003	-0.05	-3.5±0.2

Missalignments:
Applying orbit locally.

- Is there any significant difference between applying a systematic missalignment to the MOF(D) to model the orbit feeddown, and applying the missalignments locally?

I have considered again the orbit recorded at 02:19:54 during the MO instabiltiy MD.

Include mechanical missalignments, and apply locally to each BPM an additional missalignment calculated from YASP data & BPM missalignments.

Include all BPM in this model regardless of their status flag.

Missalignments:
Applying orbit locally.

- Is there any significant difference between applying a systematic missalignment to the MOF(D) to model the orbit feeddown, and applying the missalignments locally?

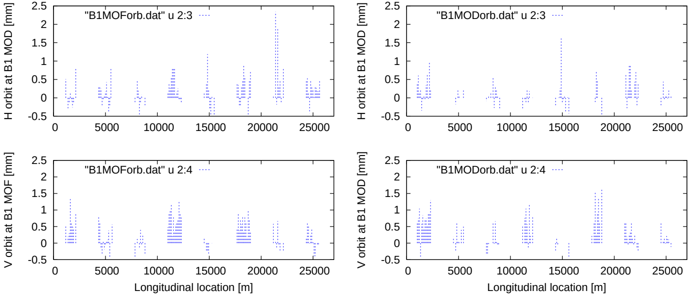

Figure: YASP data including BPM alignment logged at 02:19:54 on 20/6/12.

- Adding BPM alignment has not removed $\geq$2mm H orbit at 2 B1MOF

Missalignments: Applying orbit locally.

- Is there any significant difference between applying a systematic missalignment to the MOF(D) to model the orbit feeddown, and applying the missalignments locally?

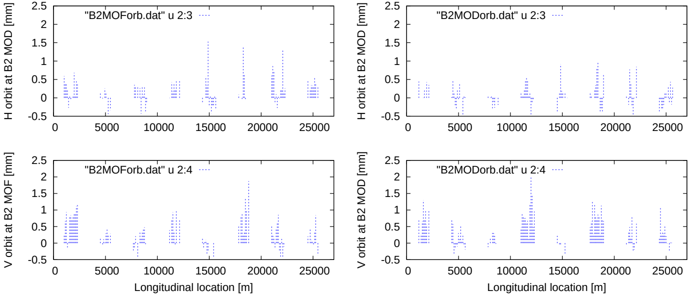

Figure: YASP data including BPM alignment logged at 02:19:54 on 20/6/12.

- Adding BPM alignment has not removed $\geq$2mm H orbit at 2 B1MOF

Missalignments:
Applying orbit locally.

- Is there any significant difference between applying a systematic missalignment to the MOF(D) to model the orbit feeddown, and applying the missalignments locally?

Table: Q,Q',c^- shifts in the model (450→0[A]).

BEAM 1	systematic	local
$\Delta Q_x(\times 10^{-4})$	-10	1
$\Delta Q_y(\times 10^{-4})$	13	3
$\Delta Q'_x$	4.4	4.6
$\Delta Q'_y$	-1	-1.2
$\Delta c^-(\times 10^{-3})$	0.5	-0.4
$\bar{\delta}_x MOF[\mathrm{mm}]$	0.20	
$\bar{\delta}_y MOF[\mathrm{mm}]$	0.24	
$\bar{\delta}_x MOD[\mathrm{mm}]$	-0.02	
$\bar{\delta}_y MOD[\mathrm{mm}]$	0.20	

BEAM 2	systematic	local
$\Delta Q_x(\times 10^{-4})$	40	41
$\Delta Q_y(\times 10^{-4})$	-9	-9
$\Delta Q'_x$	2.7	2.7
$\Delta Q'_y$	-0.4	-0.3
$\Delta c^-(\times 10^{-3})$	-0.05	-0.05
$\bar{\delta}_x MOF[\mathrm{mm}]$	0.12	
$\bar{\delta}_y MOF[\mathrm{mm}]$	0.21	
$\bar{\delta}_x MOD[\mathrm{mm}]$	-0.02	
$\bar{\delta}_y MOD[\mathrm{mm}]$	0.33	

Conclusions.

- Observed shifts to Q,Q',c^-
- Chromaticity is well understood taking into account mechanical missalignments and orbit.
- Dominant source of the $\delta Q'$ is orbit.
- This will be monitored online via the YASP application (J. Wenninger).
- Q and c^- are less well understood, but we are in the right ballpark (local distribution is important for the second order effects).