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LHC MD Test Program

MD2190: Q'' STABILIZATION DURING INJECTION

Abstract

The goal of the MD is to explore whether Q'' can provide beam stability at injection, which suffers mostly from electron-cloud effects. Ideally, this could relax the use of the Landau octupoles and may help in preserving the beam quality by reducing dynamic aperture limitations originating from the octupoles. The MD is split into two parts: Firstly, in MD block #4, optics corrections are put in place to minimize beta-beating and linear coupling introduced by the Q'' knobs. This correction is achieved by means of orbit bumps and skew quadrupole knobs. The machine safety is then validated with loss maps. If the outcome is successful, the effect of Q'' will be studied in terms of the mitigation of collective effects in the second part of the MD during block #5.

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LHC Engineers in charge, LHC operators

History of Changes

Rev. No.	***Date***	***Pages***	***Description of Changes***
0.1	15-Jun-2017	All	First draft
0.2	31-Aug-2017	4-6	Updates due to new knob and procedure (e.g. optics corr.)
0.3	01-Nov-2017	All	Updates on optics corrections, global beam parameters, splitting of MD into two parts between MD blocks #4 and #5

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1. INTRODUCTION

MD1831 showed that Q'' can mitigate impedance-driven head-tail instabilities at flat top with nominal optics as predicted in simulations [1,2]. Single bunches remained stable at significantly reduced, or even in absence of the Landau octupoles.

This MD aims at performing further tests of the effect of Q'' on beam stability. The idea is to explore the potential of a Q'' knob at injection energy with bunch trains for which electron-cloud is the main cause of beam quality degradation. The two main questions to be answered are: (1) Can Q'' provide a similar stabilizing effect like Landau octupoles for electron-cloud instabilities, and (2) how do the impacts of Landau octupoles and Q'' on dynamic aperture (DA) compare. In the best case scenario, Q'' would provide the same stabilizing effect while having a smaller impact on the DA.

A Q'' knob was developed for ATS optics (S. Fartoukh) with the idea of powering the main sextupole families in a specific scheme to minimize the effect on Q' (Q'''), as well as detuning with transverse amplitude, and to enhance Q'' at the same time [3]. A first version of the knob allowing only for positive Q'' was tested briefly for Beam 1 during a scrubbing fill (29.05.17). It was used with up to 12 bunches in the machine showing detrimental effects on the beam life time. More thorough measurements were performed by OMC with a pilot demonstrating that the knob introduces significant beta-beating and linear coupling which need to be corrected for [4].

In the meantime, the knob has been further improved (S. Fartoukh). The sextupole families are now powered in a different configuration using families in different arcs, making also negative values for Q'' accessible, which is advantageous for beam stability according to beam-dynamics simulations with electron-cloud. Due to the observations made in [4], the new knob must be validated in terms of optics and machine safety. For that reason, the MD is split into two parts between MD blocks #4 and #5. In the first part (4 h), optics measurements are taken and corrections for beta-beating are put in place by means of orbit bumps, the linear coupling is corrected with the skew quadrupole knobs. Due to the large number of bunches (several injections of batches of 144 b.) necessary to produce electron-cloud, machine safety is further validated with loss maps. An asynchronous beam dump test may be included in the validation procedure. Given that the preparations are successful, the second part of the MD (4 h) is foreseen for MD block #5 where the stability measurements with Q'' will be made.

Number of MD's	2
Time required per MD [h]	4 (optics corrections & loss maps, MD block #4) + 4 (stability measurements, MD block #5)
Beams required [1, 2, 1&2]	1
Beam energy [GeV]	450
Optics (injection, squeezed, special)	Injection (operational 2017)
Bunch intensity [#p, #ions]	1.1E11 #p
Number of bunches	2746 (in batches of 144 b.)
Transv. emittance [m rad]	Ideally BCMS to enhance electron-cloud effects
Bunch length [ns @ 4s]	1
Optics change [yes/no]	Yes
Orbit change [yes/no]	Yes (for optics corrections with bumps)
Collimation change [yes/no]	No
RF system change [yes/no]	No
Feedback changes [yes/no]	No
What else will be changed?	Landau octupoles, Q', Q'' (main sextupoles)
Are parallel studies possible?	Yes
Other info/requests	*OMC:* Optics measurements and corrections / *Collimation:* Loss maps / *ABT:* Asynchr. dump

Table 1: Machine parameters during the MD

2. DETAILED STEPS TO BE TAKEN BEFORE, DURING AND AFTER THE MD

2.1 PREPARATION OF THE MD

The Q'' knobs need to be implemented in LSA. This has been done for the first version already [4], but will need to be updated for the latest version. There are 2 knobs to be defined, *dKSF* and *dKSD*, and they act on 4 different sextupole families with the scheme

SF2.a12b1 + *dKSF*
SF2.a45b1 – *dKSF*

SD2.a81b1 + *dKSD*
SD1.a56b1 – *dKSD.*

When used separately, dKSD and dKSF should introduce mainly Q''_x and Q''_y respectively.

2.2 STEPS TO BE TAKEN DURING THE MD

Part I (optics corrections & loss maps)

In part I, the Q'' knob is validated for machine safety, and the necessary optics corrections are determined to reduce the beta-beating, as well as the linear coupling. The latter effects have been observed during an earlier test of a similar knob this year [4]. The beta-beating is a result of horizontal orbit offsets at the 4 sextupole families, SF2.a12b1, SF2.a45b1, SD2.a81b1, and SD1.a56b1, used to introduce Q''. The effect can be quite enhanced due to the large strength used in these magnets (about a factor 10 more than nominal, but with opposite signs for the two focusing and defocusing families respectively). The coupling is introduced by vertical orbit offsets at the abovementioned sextupoles. The linear coupling will be corrected by standard skew quadrupole knobs. The beta-beating will be corrected by 4 dedicated horizontal orbit bumps (one per strong sextupole family) in sectors 12, 45, 56, and 81. Each of the 4 orbit bumps is composed of several equally large π-bumps using about 10 correctors. The expected kick strengths are below 10 microrad, but will need to be adjusted online, once the input from optics measurements is known. The optics measurements and the implementation of the bumps as well as the correction of linear coupling are carried out by the OMC team (R. Tomas, L. Malina). The time for the measurements is about 30' (without corrections), and about 1 h (with corrections) for each setting of the Q'' knob.

Given these time constraints, the above measurements and corrections can only be carried out for 1, or at most 2, different settings of Q''. The Q'' set points must be the same as for part II of the MD. If only one set point of Q'' is possible, the go to value should be $Q''_{x,y}$ = -30 k (in absence of Landau octupoles), meaning that (from MAD-X)

$dKSF_{30k} = 0.620$, $dKSD_{30k} = -0.685$.

If time allows for 2 different settings, $Q''_{x,y}$ = -20 k and $Q''_{x,y}$ = -40 k (again in absence of Landau octupoles) would be the desired values with (from MAD-X)

$dKSF_{20k} = 0.496$, $dKSD_{20k} = -0.559$, and
$dKSF_{40k} = 0.724$, $dKSD_{40k} = -0.791$,

respectively.

By means of a Q vs. dp/p measurements for each of the Q'' settings chosen above, the non-linear chromaticity will be determined (range of $|dp/p| > 10^{-3}$ is desired to accurately measure up to Q''') and compared to expectations from MAD-X calculations.

With the knob verified and with the optics corrections in place, machine safety will need to be addressed by a collimation expert using loss maps to be taken according to the standard procedures for the given length of the bunch trains that the MD is aiming for in part II (several batches of 144 b. each). As part of the validation procedure, an asynchronous beam dump test may be performed as well.

Part II (stabilization with Q'')

Systematic studies of the beam stability as a function of the Landau octupole strength (aiming to go down to zero) will be performed using different lengths of bunch trains (injections of BCMS beam with 144 b. per batch) with the Q'' knobs set to 0 first, and then with the 1 (or max. 2) different settings of Q'', depending on how the preparations go in part I. For each Q'' set point, the following steps would be taken:

1. Optics corrections determined in part I are loaded for the given Q'' knob setting.
2. Given that part II is planned only for MD block #5, we would then test briefly the beam life time for 12 bunches first using nominal machine settings for the beam instability mitigation 'tools' (i.e. Landau octupoles, transverse feedback) and $Q'_{x,y} = 10$.
3. If step 1 is successful, i.e. no major degradation of beam lifetime, we would start injecting batches of 144 BCMS bunches, to guarantee the presence of electron-cloud (use monitoring tools to confirm), and closely watch beam stability, emittance blow-up and beam life time.
4. Reduce gradually the Landau octupoles while continuously monitoring beam stability, emittance blow-up, and beam lifetime.
5. If time allows, we would vary also Q' and reduce it to 5 units (or increase to 15) depending on the observations made.

2.3 RECOVERY AFTER THE MD

Revert changes for optics corrections.

3. CHANGES OF MACHINE PROTECTION SETTINGS DURING MD

3.1 CHANGES OF SAFE BEAM FLAGS

None

3.2 CHANGES OF COLLIMATOR POSITIONS AND LIMITS

None

4. CONCLUSIONS

This MD aims at following-up the studies of single bunch stabilisation with Q'' at flat top. This time the studies are performed at injection energy with longer bunch trains where electron-cloud has a major impact on the beam quality. They should give insight into whether Q'' is beneficial also against electron-cloud instabilities. Furthermore, the impact of Q'' on the dynamic aperture (beam life time) will be monitored and compared to that from Landau octupoles.

5. REFERENCES

[1] L. Carver et al., "MD1831: Single Bunch Instabilities with Q" and Non-Linear Corrections", CERN-ACC-NOTE-2017-0012 (2017)

[2] M. Schenk et al., "Practical stabilisation of transverse collective instabilities with second order chromaticity in the LHC", in Proceedings of IPAC'17, Copenhagen, Denmark, THPVA026, preprint.

[3] S. Fartoukh, "Second order chromaticity correction of LHC V6.0 at collision", LHC Project Report 308 (1999).

[4] E. Bravin et al., "LHC Machine Status", Daily LHC operation meeting, Week 23 (2017).