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UPDATE ON LHeC RING-RING OPTICS

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Abstract

An update of the LHeC Ring-Ring optics is presented which accounts for chromatic corrections and more flexibility in the tune adjustment.

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INTRODUCTION

The Large Hadron Electron Collider (LHeC) aims at lepton-proton and lepton-nucleus collisions with centre of mass energies of 1-2 TeV at $e^{+/-}p$ luminosities in excess of $10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$. The general layout and first optics for the Ring-Ring e-ring meeting the design parameters (Table 1) and the constraints imposed by the integration of the new electron ring in the LHC tunnel were described in [1], [2].

Table 1: Design parameters of the LHeC ring-ring option

Beam energy	60 GeV
Particles per bunch	1.98×10^{10}
Number of bunches	2808
Synchrotron radiation power	< 50 MW
Damping partition $J_x/J_y/J_e$	$1.5/1/1.5$
Hor./vert. emittance ($\kappa = 0.5$)	$5.0/2.5$ nm

The current design foresees two different interaction region layouts: a high luminosity option (HL) and a high acceptance option (HA). The optics of both options are shown in Fig. 1.

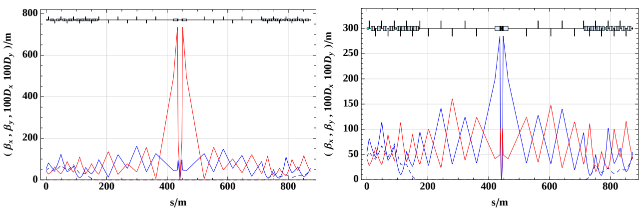

Figure 1: LHeC IR optics:
(Left) HA option with $\beta_x^\star/\beta_y^\star = 0.4/0.2\ \mathrm{m},\ l^\star = 6.2\ \mathrm{m}$.
(Right) HL option with $\beta_x^\star/\beta_y^\star = 0.18/0.1\ \mathrm{m},\ l^\star = 1.2\ \mathrm{m}$.

CHOICE OF WORKING POINT AND TUNE ADJUSTMENT

Because of the bypasses and the single interaction region, the LHeC lattice has no reflection or rotation symmetry. From experience with LEP the working point best avoids the first two synchrotron sidebands of the integer resonance and is placed below the diagonal [3]. Further the beam will suffer a maximum beam-beam tune shift of 0.087 in both planes in the case of the HA option and 0.085 in the horizontal and 0.090 in the vertical plane in the case of the HL option. Taking also the beam-beam tune shift and the detuning with amplitude from head-on interactions into account a possible working point could be $Q_x/Q_y = 123.155/83.123$ for both options. The working point diagrams for both cases are shown in Fig. 2. In general the working point can be easily adjusted by changing the phase advance of the FODO cells in IR3 and IR7 and rematching the dispersion suppressor or by just changing the strength of the main quadrupoles for smaller tune adjustments.

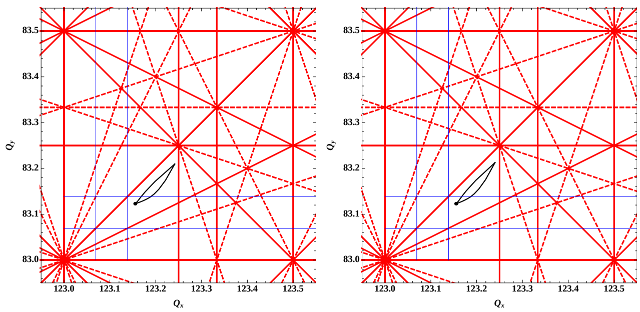

Figure 2: Resonance diagram up to 4th order. The synchrotron sidebands are shown in blue. The detuning with amplitude from head-on beam-beam is indicated in black. (Left) HA option (Right) HL option

GENERAL CONCEPTS OF CHROMATICITY CORRECTION

In an accelerator with low beta insertions it is often not sufficient to only correct the first order derivatives of the tune with respect to momentum as sizable higher order tune derivatives can appear. Further the off-momentum beta beating can significantly reduce the aperture along the ring and lead to an unwanted momentum dependence of the beta function at the IP.

It has been shown in earlier papers that by a correction of the off-momentum beta-beating also the higher order tune derivatives are considerably reduced without seriously increasing the geometric aberrations [4], [6]. In general two correction schemes are proposed: adjusting the phase advance between consecutive interaction points and the correction by using several sextupole families. As the LHeC hosts only one low beta insertion, only the correction with sextupole families is possible.

Number of Sextupole Families

As the beta-beating wave propagates with twice the phase advance, sextupoles of one family must be separated by a phase advance of π in order to add up constructively. To minimize in addition the effect of the most harmful $3\nu = p$ integer resonances the sextupoles are arranged in antiphase to this condition. This leads to the following rule for the number of sextupole families [5]:

$$2n\pi = 2(N+1)\mu_0 \quad (1)$$

$$3\mu_0(N+1) = (2m+1)\pi \quad (2)$$

where n, m are integers, N the number of sextupole families and μ_0 the phase advance per cell.

Correction of Low Beta Insertion

In large colliders like LEP, LHC and LHeC, each arc is usually powered individually. This allows the large beta beating wave created by a low beta insertion to be corrected with the two adjacent arcs [6]. The concept is most clear in the case of a phase advance of π per arc cell, where according to Eqn. (1), (2) two sextupole families per plane are required. By reducing the strength of one family and increasing the strength of the second family a beta-beating wave can be excited coherently without changing the first order chromaticity. This wave then compensates the wave excited by the low beta insertion. For the compensating wave to be in phase with the beta-beating wave excited by the low beta insertion, the phase advance between the first sextupole family and the insertion should be a multiple of π, so $\pi/2 \bmod \pi$ from the IP.

CHROMATICITY CORRECTION IN THE LHEC

The LHeC arc cell is a double FODO cell with a phase advance of $90°/60°$ per FODO cell. Applying Eqn. (1) and (2) each arc therefore hosts 2 horizontal and 3 vertical sextupole families. Furthermore each family should be completed in each arc in order to minimize geometric aberrations. As the LHeC arcs consist of double FODO cells the number of cells with sextupoles has to be divisible by 2 and 3. Further it has proven to be better to extend the placement of the sextupoles to the dispersion suppressor instead of having arc cells without sextupoles as then the strength of one sextupole is reduced and, with it, the geometric aberrations. These principles yield a sextupole scheme as illustrated in Fig. 3, where 23+1 stands for 23 arc cells + 1 dispersion suppressor cell. The two arc cells adjacent to the bypasses lie already inside the bypasses (the red 2) and therefore sextupoles are only placed in 19 arc cells +1 dispersion suppressor cell in arcs 1,8,4 and 5. In order to find a suitable correction scheme exploiting the flexibility of the 5 families, the insertions with the largest chromatic contribution, which are usually the low beta experimental insertion, have first to be identified. In the case of the LHeC all insertions contribute comparably equal, except in the vertical

Table 2: Contribution of the insertions to the natural chromaticity ($\frac{dQ_{x/y}}{dQ_{x/y,\mathrm{tot}}} \cdot 100$) for the HA with a natural chromaticity of $-dQ_{x/y,\mathrm{tot}} = 144.1/136.2$ and HL option with $-dQ_{x/y,\mathrm{tot}} = 151.8/122.8$.

	HA	HL
IR 1	6.9/5.5	6.5/6.1
IR 2	5.2/18.3	9.9/9.3
IR 3/7	3.2/2.7	3.1/3.1
IR 4/6/8	3.2/2.7	3.0/3.0
IR 5	7.0/5.7	6.7/6.4

plane of the HA option 2. This suggests as a first step a global correction for the HL option and a local correction for the HA option. In the following only the HA option will be described in further detail as the HL option is less challenging and can be corrected using the same principle as the HA option only with horizontal and vertical plane exchanged. The principle of a local chromatic correction

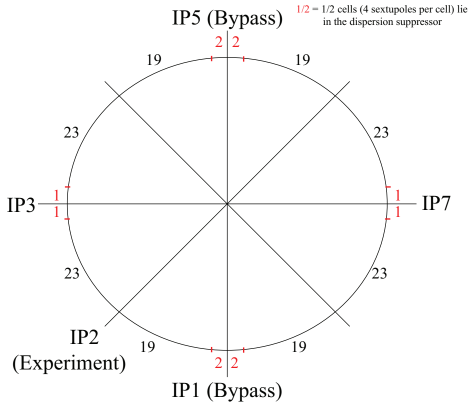

Figure 3: Sextupole Scheme for the LHeC.

of a low beta insertion was explained for a phase advance of $90°$. The only change for the LHeC is the $60°$ phase advance in the vertical plane. If we take the picture of the Montague functions [7], the orthogonal W-vectors in the case of the $90°$ lattice cells are arranged in a triangle for $60°$ (Fig. 4). In this case the betatron wave created at the IR will be compensated by one sextupole family, while the other two families act as counterparts. This scheme is in some sense more robust as small phase errors, which result in a B component at the first sextupole, can be compensated by the other two families. For the local compensation

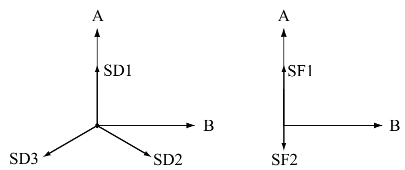

Figure 4: W-vectors for $90°$ and $60°$ lattice cells.

the two adjacent arcs were used and the interaction region rematched to a phase advance of approx. $\pi/2 \bmod \pi$, so that the Montague function vanishes in both planes at the IP and at the end of the two adjacent arcs. The remaining arcs were then used to correct the global chromaticity. For comparison, a lattice with 5 sextupole families was matched with PTC to $Q'_{x,y} = 2$, $Q'_{x,y} = 2, Q''_{x,y} = 0$ and last $Q'_{x,y} = 2, Q''_{x,y} = 0, Q'''_{y} = 0$. The momentum dependence for all four cases is shown in Fig. 5. It is linear over a considerably larger area for the local correction scheme. The gain is larger in the vertical plane as the low beta insertion introduces a considerably stronger beta-beating wave in the vertical plane than in the horizontal. Comparing the correction of only $Q'_{x,y} = 2$ (Fig. 5 (blue)) with $Q'_{x,y} = 2, Q''_{x,y} = 0$ (Fig. 5 (green)), the 2nd order term is corrected in trade of a 3rd order term. The 3rd order term can then again be matched to 0 causing a stronger 4th order term (Fig. 5 (purple)) .

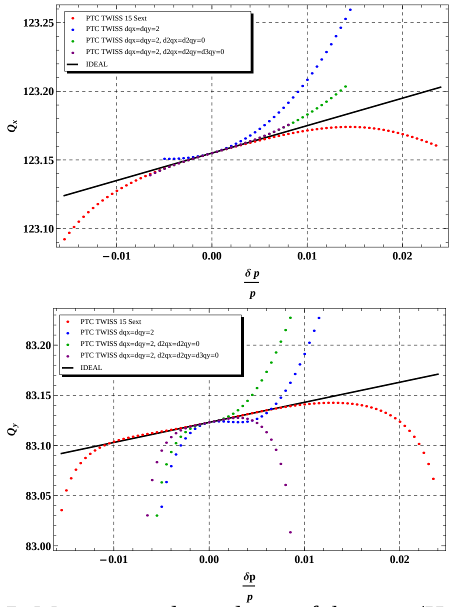

Figure 5: Momentum dependence of the tune (HA option).

The Montague function is shown in Fig. 6. The local correction of the low beta insertion clearly reduces the Montague function along the ring. Especially at the IP the momentum dependence of the β-function is unwanted and a clear improvement is also obtained due to the local correction (Fig. 7).

SUMMARY AND OUTLOOK

It has been shown that a local correction of the low beta-insertion considerably reduces the higher order derivatives of the tune with respect to the momentum and the momentum dependence of $\beta^{\star}$. Studies of the dynamic aperture and the detuning with amplitude are planned to compare the different correction schemes with respect to geometric aberrations.

ACKNOWLEDGMENTS

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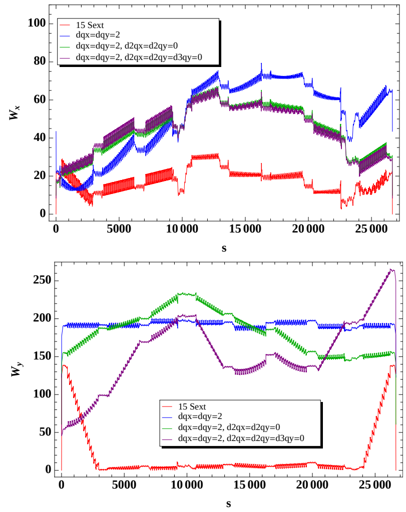

Figure 6: Montague function (HA option).

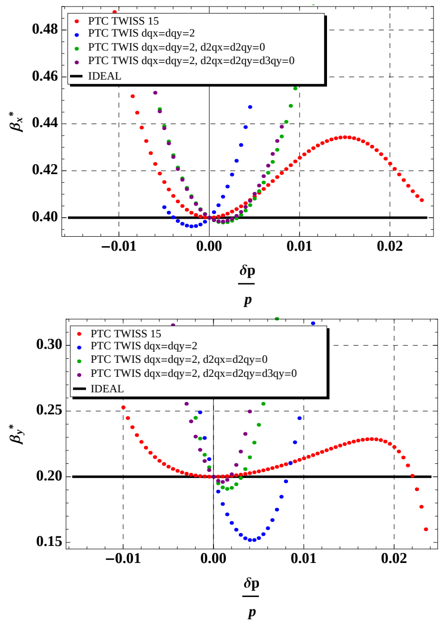

Figure 7: Momentum dependence of $\beta^{\star}$ (HA option).

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