EFFECT OF ALIGNMENT ERRORS AND ORBIT CORRECTORS ON THE INTERACTION REGION OF THE FCC-hh *

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Abstract

The Future Circular Collider (FCC) design study [1] aims to develop the design of possible circular colliders in the LHC era. In particular the FCC-hh will aim to produce proton-proton collisions at a center of mass energy of 100 TeV. The interaction region has been designed to meet the requirements in terms of energy and luminosity. However, as it is the case in any real accelerator, misalignments in the magnets are likely to occur; the effect of these misalignments, if not properly compensated for, can jeopardize the performance of the machine. This study contemplates alignment and field errors in the interaction region in order to estimate the tolerance necessary to provide a good correction measured in terms of deviation of the orbit and strength of the correctors.

INTRODUCTION

The design of the FCC-hh lattice comprises two high-luminosity insertions and two special purpose experiments, just as the LHC. Fig. 1 shows an illustration of the possible layout.

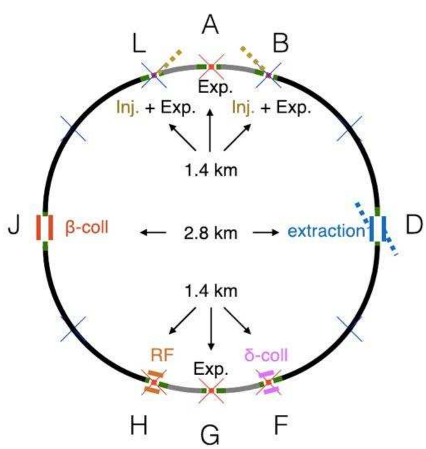

Figure 1: Layout of the FCC-hh ring [2].

The high luminosity insertions are located in the interaction regions A and G (IRA and IRG). The interaction region (IR) design is a challenging and important objective in the development of any accelerator [3]. Challenges arise as the beams are brought into focus with the smallest beam sizes with constraints given by both the accelerator and the detector. Several options have been proposed for the design of the high-luminosity IRs [4]. This work will present in the case where the distance between the interaction point and the first quadrupole (L^*) is 45 m, and for two different options of β^*: 1.1 m and 0.3 m.

As is the case for any real accelerator, misalignments are likely to occur. While other studies have been done focusing on the effects of errors in the arcs [5], our study will focus in misalignments in the magnets of the IR; in particular possible misalignments in the final focus quadrupoles and recombination and separation dipoles can have significant effects that can jeopardize the performance of the collider. Following the example of the work that has been done for the HL-LHC [6] this work aims to make use of a correction scheme in the IR to study the tolerance of the machine to these misalignments in terms of the resulting maximum deviation of the corrected orbit with respect to the original reference orbit and the strengths required by the linear correctors used to compensate for its effect.

CORRECTION SCHEME

The objective of the correction scheme is to restore the distorted orbit, product of misalignments in the magnets of the IR, back to its original values. This procedure is illustrated in Fig. 2 where the correction has been applied to IRA with horizontal crossing.

The corrector scheme used for this studies will include only correctors and monitors in the interaction region, which contemplates the following components:

- Correctors installed next to the final focus triplet quadrupoles, and next to the 4th quadrupole. These correctors are also used for the crossing angle. Both horizontal and vertical correctors are given at each location.
- Interleaved horizontal and vertical correctors next to the quadrupoles in the matching section (4th-7th, except the 4th quadrupole considered previously) and the dispersion suppressor (8th-13th quadrupoles).
- Beam Position Monitors (BPM) installed along the IR.

An illustration of the arrangements of the correctors with respect to the main quadrupoles and dipoles in the interaction region is given in Fig. 3.

Correction Technique

The correction technique starts with the assignment of random errors to either the quadrupoles in the IR (final focus triplet and matching section) and/or the separation and recombination dipoles; these errors are normally given with a gaussian around a certain deviation. The CORRECT method

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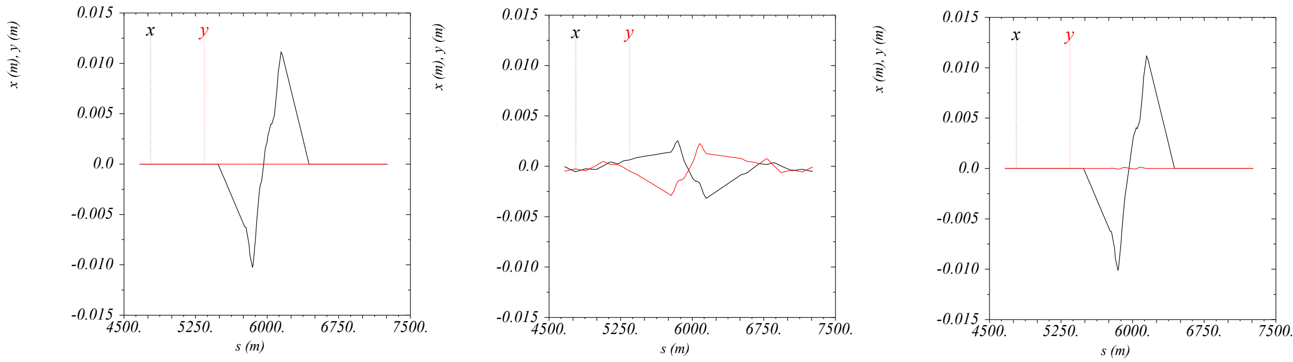

Figure 2: Representation of the correction procedure. The original orbit in IRA with horizontal crossing angle is presented at the left, when alignment errors are included the orbit gets distorted (middle) and then the correctors are used to restore the orbit as close as possible as the original one (right).

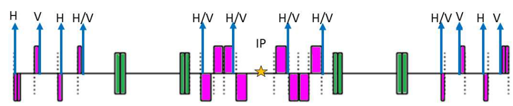

Figure 3: Arrangements of linear correctors along the interaction region (the dispersion suppresor is not included in the figure). Quadrupoles are represented in pink, separation and recombination dipoles in green, BPM's with a dotted line, and vertical and horizontal (H/V) correctors are represented with a blue arrow.

in MADX [7] is then applied, this procedure checks the values of the monitors when no misalignments are present and calculates the strength necessary for the linear correctors to restore the original orbit. Finally this procedure is repeated for 100 seeds and values are stored to be analysed.

RESULTS

The correction procedure is evaluated in terms of two parameters: the maximum deviation from the original orbit after the correction and the strength of the correctors needed. The first parameter gives information about how well the orbit is restored and the second one about whether the correction is achievable in terms of technology. To simplify the result among all seeds and to have consistency with the study in alignment errors in the arcs [5] the 90-percentile of each distribution is considered, meaning the value for which 90 percent of the distribution is contained.

Different errors have been considered for these studies: alignment errors on the final focus and matching section quadrupoles, and tilt (rotation around the reference orbit) errors for the separation/recombination dipoles.

Maximum Deviation

The resulting 90-percentile for the maximum deviation of the corrected orbit is illustrated in Fig. 4 for cases with misalignments on the quadrupoles only, tilt errors on the dipoles only and a combination of both. These results are shown for both optics with β^* of 1.1 m and 0.3 m. The reconstruction of the orbit is done with crossing angles on but considering the maximum deviation of the non-crossing orbit.

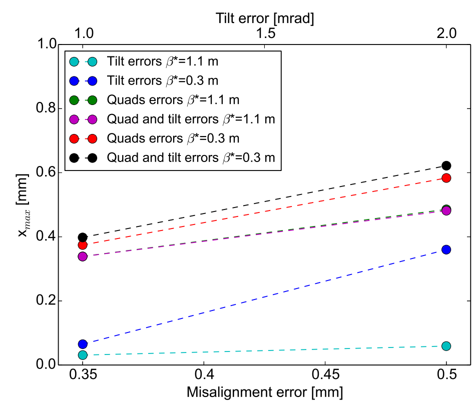

Figure 4: 90-percentile of the maximum deviation of the corrected non-crossing orbit with respect to the original orbit. Cases for quadrupole misalignments and/or tilt errors are presented and for two optics: β^*=1.1 m and 0.3 m.

Results show all studies have a 90-percentile maximum deviation below 0.7 mm. In particular tilt errors are corrected very well for the optics with β^*=1.1 m, where hardly any deviation is noticeable, while the most challenging case is presented with the largest quadrupole and tilt errors for the optics case of β^*=30 cm, being the only case resulting in a maximum deviation above 0.5 mm.

Strength of the Correctors

The corrector strengths needed for the orbit correctors in the non-crossing angle orbit are illustrated in Fig. 5. As can be observed from the figure the maximum strength needed is 1.5 Tm which is achievable in terms of technology. For the case of the crossing angle orbit some of the correctors needed for the orbit restoration are also needed to provide the crossing angle. The strength of these correctors are illustrated in Fig. 6; as expected, these correctors require a larger strength than the correctors used for the non-crossing orbit, particularly for the corrector next to the 4th quadrupole on the right hand side of the interaction region, where values up to 8 Tm are needed. These correctors however, already have a length of 3 m to be able to cope with the large kick required.

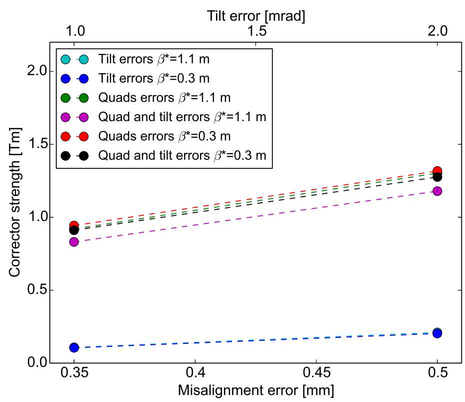

Figure 5: 90-percentile of the strength needed for the correctors on the non-crossing orbit to restore the original orbit. Cases for quadrupole misalignments and/or tilt errors are presented and for two optics: β^*=1.1 m and 0.3 m.

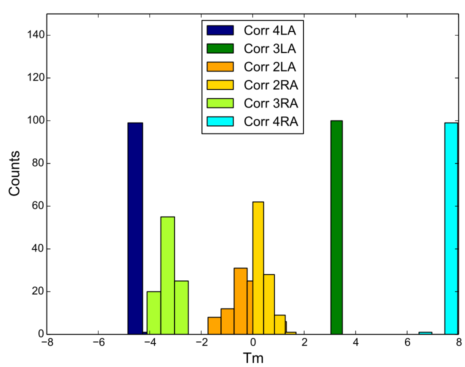

Figure 6: Distribution of the strength needed for the correctors which are used for both the correction and to provide the crossing angle. These values correspond to the case with largest misalignments and tilt errors and for the optics with β^*=0.3 m.

The next step for these studies is to combine errors in the arcs and the IR, such studies are currently being performed [5].

Maximum Deviation at Location of Crab Cavities

Another subject of interest in this study is the orbit deviation at the possible location of the crab cavities. Following the example of the HL-LHC [8] crab cavities should be located in a section where there is physical space and, in order to minimize the voltage, should be preferably placed where the β functions are large and the phase advance to the interaction point is close to $\pi/2$. With this in mind the possible location of the crab cavities could be in the space between the second separation dipole (D2) and the 4th quadrupole.

The same procedure as described in the previous section was repeated but considering only the maximum deviation at this particular location. The results are shown in Fig. 7. As shown in the figure, the maximum deviation for all cases is below 0.3 mm.

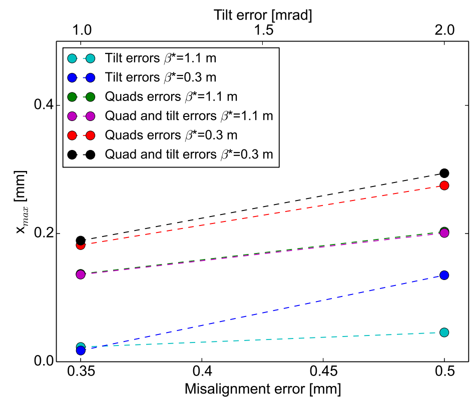

Figure 7: 90-percentile of the maximum deviation of the corrected non-crossing orbit with respect to the original orbit at the possible location of the crab cavities. Cases for quadrupole misalignments and/or tilt errors are presented and for two optics: β^*=1.1 m and 0.3 m.

CONCLUSIONS

This work was focused on studying the tolerance of the machine towards possible misalignments to make sure possible misalignments do not jeopardize the performance of the machine.

A correct scheme has been considered consisting on a series of beam position monitors and kickers in the interaction region. The efficiency of the correction has been studied in terms of the maximum deviation of the resulting orbit and the strength needed to do the correction. Several cases for misalignment errors in the triplet quadrupoles and separation dipoles, as well as different optics were studied. Results show a good quality correction with a resulting maximum deviation below 0.7 mm for all cases. The strengths of the kickers on the non-crossing orbit necessary to perform the correction needs to be 1.5 Tm or less for all cases, while the kickers on the crossing angle orbit require larger values, up to 8 Tm, but can be compensated by the length of such correctors. Further studies are being performed integrating both errors in the arcs and in the interaction region.

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