Meeting Minutes of the
190th FCC-ee Accelerator Design Meeting
and 61st FCCIS WP2.2 Meeting

Indico: `https://indico.cern.ch/event/1444797/`
When: 10.07.2024 15:00-17:00 GVA time

Agenda

Presenter	Title
I. Karpov	**Reverse Phase Operation**
K. André	**Dynamic Aperture Studies with Xsuite**
G. Roy	**Update on the Lattice Repository**

1 General information

F. Zimmermann opens the meeting. The minutes of the previous meeting are approved with with two minor comments.

F. Zimmermann notes that the Xsuite beam-beam Particle In Cell (PIC) module is nearing deployment. There is an ongoing collaboration with an EIC team to implemente spin tracking in Xsuite. A 1-2 years postdoc position opened at INFN Frascati to work on the Damping Ring (DR) design and its dynamic aperture optimization.

F. Zimmermann shares outstanding issues:

- **Baseline Optics for Feasibility Study Report**: The definition of a baseline optics for the feasibility study is ongoing. This work includes finalizing the GHC lattice, potentially with an alternative arc optics, and incorporating collimation and injection insertions along with optics tuning. The goal is to complete this by September to enable beam-beam studies.
- **Solenoid compensation scheme**: There is the need to define a solenoid compensation scheme, and assess its effects on polarization. **K. Oide** is examining the non-local scheme to compare with the local solenoid compensation scheme, to be presented at the next MDI meeting.
- **Dynamic Aperture Discrepancy**: A discrepancy exists between codes (pyAT, Xsuite and SAD) to compute the dynamic aperture of the LCC (and GHC) lattices. This issue needs to be resolved to ensure accurate simulations.
- **Beam Lifetime Discrepancy**: Differences in beam lifetime predictions between SAD and Xsuite require further investigation to identify the underlying cause.
- **Beam-Based Alignment scheme for the arcs**: The beam-based alignment scheme for the arcs needs to be finalized and initial alignment tolerances for the arcs need to be defined.

F. Zimmermann asks what are the tolerance requirements with the detuned optics and what the arc alignment tolerances should be documented as -either 100 or 150 µm. **R. Tomás** answers that a tolerance of 150 µm girder to girder was decided as presented in ATDC#2. Though, this number needs to be demonstrated from the beam dynamics perpsective. If not validated, the tolerance might revert to 100 µm.

F. Zimmermann suggests following up on the SuperKEKB measurements and compare beta function measured by CERN team and KEK team. He also recommends checking the RDTs for Low Energy Ring (LER) with the relevant KEK optics, as SuperKEKB saves the optics at all times during operation, making it possible to obtain the optics provided date and time. Additionally, the measured tune shift versus amplitude should be compared with the model.

C. Carli asks about the criteria for selecting the baseline optics. He suggests that it should be a lattice with sufficient lifetime including errors and beam-beam interaction. **F. Zimmermann** agrees, emphasizing that it should be a lattice with sufficient DA/MA/lifetime even without errors. **G. Roy** adds that other factors such as the number of magnets, their types, power consumption and tolerances could be considered as secondary criteria.

C. Carli asks about the SuperKEKB specific luminosity being smaller despite a smaller beta star. **F. Zimmermann** confirms that it is due to a higher emittance, and some abberations from the solenoid are enhanced as the beam is further squeezed.

2 Reverse Phase Operation

I. Karpov presents the reverse phasing mode for the FCC-ee RF system, focusing on how to optimize the RF cavity operation across different energy modes (Z, W, H).

The baseline RF system configuration considers 28 cryomodules with single-cell RF cavities for the Z operation, which would need to be replaced by 2-cell cavities for W and H modes after a one-year shutdown. However avoiding this shutdown by using the same 2-cell RF cavities for Z, W and H operation modes would offer significant advantages, necessitating minimization of the steady-state beam loading.

The external quality factor must accommodate a wide range (approximately 75-600). Detuning is much more pronounced at the Z mode due to its inverse relationship with the RF voltage, leading to potential instability. Increasing the RF voltage at the Z operation mode could mitigate these issues.

The reverse phase operation (RPO) mode, already experimentally verified at KEKB and used as baseline for the EIC ESR, allows for an increase of the RF cavity voltage. This mode involves dividing the RF cavities into two groups -focusing and defocusing- such that the sum of their RF waves at the synchronous phase ϕ_s yields the required total voltage.

Preliminary results:

- 132 RF cavities (same number of 2-cell cavities as 1-cell cavities for Z operation):
  - 71 focusing cavities and 61 defocusing cavities.
  - RF Voltage increases to 0.088 GV for Z (+12% w.r.t. baseline), 1.049 GV for W (+5%), and 2.098 GV for H operation (same as baseline).
  - Synchrotron tunes are 0.0311 for Z (+7.5% w.r.t baseline), 0.0833 for W (+2.9%) and 0.0343 for H operation (+0.9%).
- 152 RF cavities (same number of 2-cell cavities as foreseen for the W operation):
  - 81 focusing cavities and 71 defocusing cavities.

- RF Voltage remain unchanged for Z and H operation modes, only W operation mode sees a 4.5% increase.
- Synchrotron tune remains the same for Z and H operation modes, and a slight increase for W operation mode by 2.6%.

X. Buffat comments that a 12% increase of the cavity voltage 7.5% increase of the synchrotron tune for Z seems reasonable from the beam-beam interaction standpoint.

J. Wenninger notes that a higher synchrotron tune could benefit the resonant depolarization process.

F. Zimmermann comments that with the reverse phase operation mode, the transition between Z, W and H operation modes could potentially be made seamless, eliminating the need for a shutdown between Z and H modes.

3 Dynamic Aperture Studies with Xsuite

K. André presents Dynamic Aperture (DA) studies performed with Xsuite.

He evaluates the impact on the Momentum Acceptance (MA) changing the nominal LCC lattice from four RF sections to one RF section, with the RF voltage reduced from 100% to 85% of the GHC RF voltage, shared evenly between the 400 and 800 MHz RF cavities. The MA gradually decreases from beyond ±3% to $[-2.0, +2.5]\%$. Additionally, the synchrotron tune reduces from $Q_s = 0.115$ to $Q_s = 0.084$, while the bunch length increases from 1.8 mm to 2.4 mm over the same RF voltage range. He adds that an uneven reduction of the RF voltage between 400 and 800 MHz RF cavities will be explored next.

A discrepancy between SAD and Xsuite results is noted for the H operation mode of the GHC lattice, where a difference between -2% and -1.5% remains unexplained. However, results for other modes align well.

He presents a comparison of the Dynamic Aperture (DA) and MA resulting of the LCC and GHC optics for the Z and $t\bar{t}$ modes. For the Z mode, the LCC lattice demonstrates larger DA and MA, further optimized with magnet strength adjustments provided by **S. White**. Conversely, for the $t\bar{t}$, the LCC lattice exhibits smaller DA and MA. Further studies will consider the $t\bar{t}$ optimal magnet strengths from **S. White**.

K. André shows MA comparison between SAD and Xsuite without crab waist nor decapoles, for which the results agree well. However, the MA results including 80% crab waist strength, still without decapoles, do not match very well, potentially due to different number of turns considered in the simulations. He plans to repeat the analysis with a consistent number of turns.

Finally, he presents MA results from relaxed optics for the GHC and LCC lattices. The GHC lattice has the maximum normalised horizontal amplitude extending beyond $40\sigma_x$ in the range $\delta \in \pm 0.25\%$. The detuned optics provides a more than two times larger transverse aperture compare to the nominal optics.

The MA for the nominal LCC lattice extends beyond $60\sigma_x$ in the range $\delta \in \pm 0.5\%$ and $20\sigma_x$ at $\delta = \pm 1\%$. The detuned optics provides a more than three times larger transverse aperture compare to the nominal optics. He highlights that the results agree well between SAD and Xsuite.

G. Roy comments that it would be interesting to convert from the sequence from SAD to Xsuite and back, to ensure that the conversion process does not alter the machine performance and that the DA/MA results are consistent.

M. Koratzinos expresses skepticism about the reported 10-12% smaller energy loss per turn in the LCC lattice compared to the GHC lattice, given that his GHC lattice with nested sextupoles shows a 7% gain. **K. André** answers that the LCC lattice features weaker and fewer sextupoles which might account for the difference.

4 Update on the Lattice Repository

G. Roy reports on the optics repository. He beings with the latest version of the GHC ad LCC lattices.

- **V24.3_GHC**:
  - Nominal optics, for all four operating modes, in SAD and MADX formats, high beta star optics, at Z operation mode, in SAD and MADX formats named “fccee_z_hibs.seq”.
  - Small geometry correction in the non-colliding insertions at Z and W operation modes, BRX1 and BRX2 are now equal and opposite compensated by BRI1. Only the MADX sequence was affected.
  - The two solenoid compensation schemes at Z operating point available in the toolkit folder.
  - The “RFdefinitions_<mode>.madx” for all <mode>, to install realistic model of the RF modules.
- **V24.3_LCC**:
  - Nominal optics, for Z and $t\bar{t}$, in MAD8 and MADX formats, high beta star optics, at Z operation mode, in MADX format named “fccee_z_hibs.seq”.
  - The two solenoid compensation schemes at Z operating point available in the toolkit folder.
  - “fccee_zRF.seq” and “fccee_tRF.seq” feature a more realistic model of the RF modules but still requires re-matching of the geometry (crossing beams at non-colliding insertions).

G. Roy provides details on the high beta star optics, the GHC optics is matched to $\beta_x^* = 0.33$ m and $\beta_y^* = 0.07$ m, and the LCC optics is matched to $\beta_x^* = 0.30$ m and $\beta_y^* = 0.07$ m. Attempts at ballistic optics by **K. André** not successful yet.

He details the more accurate RF model for the GHC and LCC lattices, for which at Z and W there is a beam crossing in the center of the straight section, whereas at H and $t\bar{t}$ there is an electromagnetic separator such that both beam go through all the RF cavities and are directed in separated beam pipes afterwards. The GHC lattice offers enough free space from the end of the arc to place the EM separator on either side of the straight section, not the case of the LCC lattice. Regarding the LCC lattice the dispersion suppressor ends just before the straight section and may be an issue as the dipoles will radiate SR onto the cavities. In summary, he highlights that a seamless change of operation mode between Z, W and H is not possible at the moment with a realistic RF model. It is followed by a discussion on the length available in the straight section to fit all RF cavities up to the H operation mode while having the beam crossing achieved with dipoles and/or EM separator.

Y. Dutheil comments that the EM separator to be considered is about 100 m. **G. Roy** replies that it is the length he assumed.

F. Zimmermann comments that there should be enough space to have all RF cavities in one straight section from Z to H including bypasses from dipoles and EM separator. The length of RF cavities should be 800 m at H for a straight section of about 2 km. **G. Roy** answers that he will check.

Y. Dutheil asks if having the RF cavities directly at the end of the arcs is conceivable. **G. Roy** replies that it is unlikely as the synchrotron radiation from the dipole will be an issue.

He concludes with the following to-do list:

- Match RF geometry for the V24.3_LCC at all energies with a potential modification of the end of arcs and dispersion suppressors.

- Provide both thick and thin lattices in json format in the lattice directory, need to build and test automatically, **J. Salvesen** provided a python script to perform SAD to Xsuite conversion. He emphasises that it should be compared to SAD $\rightarrow$ MADX $\rightarrow$ Xsuite.
- Provide the solenoid compensation scheme for all operating points that should be simple linear scaling of the magnetic fields.
- Develop solenoid model and compensation with Xsuite, MAD-NG and SAD to avoid th dependence of the orbit on the field map in MADX and properly implement special features such as nested correctors and rotations.
- Provide the Collimation insertion optics (Point F / IP4) and Injection/Extraction insertion optics (Point B / IP2).
- Provide the electron counterclockwise sequences explicitly (as opposed to the current reflected positron sequence) with special care for single beam magnets versus shared magnets and beamlines (*e.g.* RF).

Y. Dutheil asks if a survey of the machine is available. **G. Roy** replies that the reference point is the center of the cavern at point A that matches with the IP of the FCC-hh. There is work to be done to fit the GHC and LCC lattices in the tunnel as close as possible to the FCC-hh beam line.

F. Zimmermann asks if the Final Focus Quadrupoles (FFQs) should be rotated between energies. **G. Roy** answers that skew quadrupoles should be sufficient to align the magnet axis to the rotated reference frame of the beam. However the alignment of the magnet with the beam orbit distorted by the solenoid could be done mechanically or with orbit correctors perhaps. **M. Koratzinos** comments that although not impossible he would recommend not having the FFQs moved to align with the beam.

P. Janot emphasises that one RF section (vs. 2 RF sections) is mandatory to achieve the required center-of-mass precision for the ZH operation mode, and the Z and W operation modes should have the same configuration.

29 Participants:
K. André, A. Apyan, H. Bartosik, X. Buffat, C. Carli, Y. Dutheil, A. Frasca, C. Garcia, V. Gawas, C. Goffing, W. Hölfe, A. Inanc, S. Jagabathuni, P. Janot, I. Karpov, R. Kieffer, M. Koratzinos, Y. Papaphilippou, F. Poirier, G. Roy, L. Sabato, K. Skoufaris, R. Tomás, A. Vanel, L. von Freeden, R. Wanzenberg, J. Wenninger, S. Yue, and F. Zimmermann