Meeting Minutes of the
196th FCC-ee Accelerator Design Meeting
and 67th FCCIS WP2.2 Meeting

Indico: `https://indico.cern.ch/event/1471642/`
When: 06.11.2024 11:00-12:30 GVA time

Agenda

Presenter	Title
I. Karpov	**Updates on the Reverse Phase Operation**
K. Oide	**Parameter Choices in Reverse Phase Operation and GHC Optics Updates**

1 General information

F. Zimmermann opens the meeting. The minutes of the previous meeting are approved with a minor comment.

F. Zimmermann proposes to have a review of tapering, particularly regarding its application to the FCC-ee, which is probably most relevant for ttbar operation mode.

He also highlights an upcoming workshop on other science opportunities at FCC-ee taking place on November 28-29.

G. Roy comments on recent initial studies with **X. Buffat** on parasitic encounters in the technical insertions, identifying multiple long-range encounters with significant impact on the beam. A proposed solution involves a vertical chicane combined with the horizontal crossing, which should avoid polarization impacts. This topic should be presented in a future accelerator design meeting.

K. Oide asks what is the necessary vertical separation. **G. Roy** answers that it should be sufficient to have two separate vacuum chambers but he will come back with precise numbers.

F. Zimmermann wonders how many wigglers would be needed for the booster, **G. Roy** adds that itis also important to consider where they would be placed.

2 Updates on the Reverse Phase Operation

I. Karpov presents updates on the Reverse Phase Operation (RPO) and approaches to mitigate transient beam loading effects. The nominal filling scheme involves 20 trains of 560 bunches. A proposed alternative features 40 trains of 280 bunches which results in about 10% synchrotron tune spread vs. 30% with the nominal filling scheme. This solution also halves the train gaps to about 600 ns, a duration the ABT team is currently evaluating as feasible.

F. Zimmermann raises concern about potential power reflection in RF cavities due to different bunch train gaps and increased beam current from injection to nominal levels. **I. Karpov** confirms this risk but he notes that klystron circulators protect the system.

A second option involving a 195 MV RF voltage (keeping the same gaps length) was tested but discarded due to poor beam lifetime (c.f. **K. Oide**'s results).

A solution considering 40 trains of 280 bunches spaced by 25 ns and 118 MV RF voltage proves to achieve a 5% synchrotron tune spread with a promising lifetime. Further stability aspects are still being investigated including beam-beam interactions and impedance.

To ensure 80% collider availability, a 10% RF redundancy is required, and is achieved by increasing the available RF voltage instead of adding more RF cavities.

Studies of the fundamental impedance for RPO result in stability under one direct feedback system using the main RF system as a kicker, which keeps the growth rate below the synchrotron radiation damping rate. However, if one RF cavity trips, the “-2 mode" requires a longitudinal feedback to remain stable. Without this, the beam is unstable due to uncompensated impedance, and it is uncertain whether longitudinal feedback alone could correct the instability caused by a single cavity failure. Besides the RF power is modulated up to +50% which is high even though the extra grid power would remain small as the focusing and defocusing cavities are in phase opposition.

Considering the 1-cell RF cavity configuration, the growth rate limit (with longitudinal feedback) seems to be reached for 6 tripped cavities in theory. However, the RF power variation allowed is about 10% (availability condition) which would suggest that a single RF cavity trip is allowed. In conclusions, zero RF cavity failure is allowed in RPO whereas one cavity trip can be sustained in the baseline RF configuration with 1-cell RF cavities.

F. Peauger comments that recovering a tripped RF cavity takes of the order of minutes and, as example in the LHC, there are four trips occurring every few weeks.

F. Zimmermann asks the reason behind stability issues arising from one RF cavity down. **I. Karpov** explains that the impedance becomes uncompensated, and a damper would need to work hard to compensate it (how much power would be needed should also be studied).

He then continues with the sensitivity of the RF voltage of focusing and defocusing RF cavities and phase error causing a small but visible variation of the synchrotron tune; up to 2% with a ±10% peak-to-peak voltage error and ±10 peak-to-peak phase error.

W. Höfle mentions that a longitudinal damper loop is not used in the LHC and should be developed. He also questions the impact of the RPO on pilot bunches which could potentially cause different synchrotron tunes, and impact energy calibration as well as the stability requirements for these 100-160 bunches spaced by 100 ns. He emphasizes that an even distribution would be necessary to mitigate RPO effects.

Beam-beam interaction and impedance interplay:

X. Buffat presents an additional slide on beam-beam interaction and impedance interplay. Strong-strong beam-beam simulations have been performed on 1/4 period of the FCC-ee, including longitudinal impedance showing a large stable tune space in the horizontal plane. Similar simulations have been performed by **Y. Zhang**, this time including transverse impedance, resulting in a much narrower stable tune space, without improvement applying $Q_x' = +5$.

He adds that first tests with Xsuite including transverse impedance indicate that the difference comes from vertical instabilities similar to the ones described in **Y. Zhang**'s IPAC2023 proceeding. It would confirm that the issue might not come from a higher RF voltage.

W. Höfle asks if the intra-bunch motion has been investigated for potential mitigation with a transverse damper. **X. Buffat** answers that he has not looked into the intra-bunch motion and there is currently no damper in the simulation. **M. Zobov** comments that a finite positive vertical chromaticity should mitigate this instability. In the baseline, vertical instabilities were observed and could be mitigated with a finite positive vertical chromaticity.

K. Oide comments that the width of the tune spread should be wider as it is a 4th order sideband.

M. Migliorati comments that the impedance model is incomplete, with more contributions to be added. The impedance was doubled to account for unknown sources. This conservative approach is a very pessimistic assumption. In **X. Buffat**'s simulations the impedance was not doubled, potentially impacting the results.

M. Zobov notes the importance of examining intermediate intensities, as these might reveal smaller stable tune regions compared to the nominal intensity.

3 GHC optics

K. Oide presents updates on the RPO performance and the associated beam lifetime for the 120 MV RF voltage solution. He highlights results from **X. Buffat**'s strong-strong simulations involving longitudinal impedance, where the X-Z instability seems manageable choosing a horizontal tune between sidebands. He notes a minor shift of the sidebands from $Q_x - nQ_s = 1/2$ that he attributes to $\xi_x Y_x/2$ where $Y_x = 4/3$ is the horizontal Yokoya factor for flat beams.

M. Migliorati suggests that the observed stable tune region shift might result from a synchrotron tune change introduced by the longitudinal impedance rather than the Yokoya factor.

K. Oide proposes that beamstrahlung effects could be reduced by increasing the number of bunches, assuming adequate spacing for the pilot bunches. Considering a 25 ns bunch spacing between pilot bunches, and additional 552 bunches could theoretically be added, resulting in a lower number of particles per bunch, improving beam lifetime, and reducing the vertical emittance blow-up from the beam-beam interactions.

He also mentions a slight modification of the optics (in the IR) to recover the previous aperture bottleneck values, as pointed out by **G. Broggi**.

K. Oide notes that adding collimators in more than one insertion could be considered with the LLSS optics design if a single-insertion solution is not feasible.

F. Zimmermann suggests using a 5 ns bunch spacing to increase the number of bunches with larger bunch spacing between trains, and he questions the impact on pilot bunches.

H. Bartosik, **W. Höfle** add that while 100 ns spacing between pilot bunches is suitable for bunch-by-bunch measurements, closer spacing would be more challenging and demand further studies involving, for instance, the length of the kicker.

G. Broggi comments he performed initial collimation performance studies featuring the LLSS optics design, involving primary collimators and local protection upstream each IP (no secondary collimators). He notes that this setup underperformed compared to a dedicated collimation optics design, which uses primary, secondary & tertiary collimators. **G. Broggi** plans to add secondary collimators in the LLSS optics design, though achieving optimal phase advance between primary and secondary collimators could be challenging. He adds that the vertical beta functions are small, leading to narrow vertical collimator gaps (close to the 2 mm limit set by impedance considerations. **F. Zimmermann** argues that a small gap has only a minor impact on impedance.

G. Roy highlights that the chromaticity correction was not performed consistently between the LLSS insertion and the dedicated collimation insertion, so far resulting in a poorer MA, and beam-beam performance for the dedicated collimation insertion.

41 Participants:
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