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CONSIDERATIONS FOR A NEW DAMPING RING DESIGN OF THE FCC-ee PRE-INJECTOR COMPLEX

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Abstract

The current injector complex design of the FCC-e^+e^- project consists of e^+/e^- LINACs, which accelerate the beams up to 6 GeV, a damping ring at 1.54 GeV, a pre-booster ring (or higher energy LINAC as an option), accelerating the beam up to 16 GeV (or 20 GeV) and a booster synchrotron ring integrated in the collider tunnel accelerating the beams up to the collision energies. The purpose of the damping ring is to accept the 1.54 GeV beam coming from the LINAC, damp the positron/electron beams and provide the required beam characteristics for the injection into the subsequent accelerator. The aim of this paper is to present several considerations for a new layout of the damping ring. The beam parameters are established and compared for different lattices at 1.54 GeV. Besides, a higher energy damping ring design option at 2.86 GeV is explored.

INTRODUCTION

The Future Circular Collider (FCC) e^+e^- project is a high-luminosity, high-energy circular electron-positron collider design study to be installed in around 91 km circumference. It is planned to be used as a high precision machine for the investigation of the Z, W, Higgs and top particles at center of mass energies varying between 91.2 and 365 GeV. The baseline pre-injector complex design consists of an electron source, three LINACs (for electron, positron and common for both e^+/e^-) up to 6 GeV, a positron target, energy compressor, bunch compressor and a damping ring at 1.54 GeV [1–6]. The layout of the FCC-e^+e^- collider complex (top) and the details of the pre-injector complex (bottom) so as to show the location of the damping ring, are presented in Fig. 1.

A design for the damping ring was provided in the conceptual design report (CDR-DR) of FCC project [1]. A FODO lattice was chosen with a large number of elements. The dipole magnet field was 0.66 T. Damping wiggler magnets (26.56 m) were introduced to reach to the required emittance and damping time. Two straight sections were allocated for injection, extraction and RF-Cavity. Horizontal and vertical phase advance of FODO lattice were chosen 69.5°/66°, respectively.

The CDR-DR used 232 dipole magnets, which requires high number of components such as quadrupoles, sextupoles, octupoles, steering magnets, and beam diagnostics. This determines high realization costs, complicate installation and alignment procedures. Thus, in parallel to CDR-DR design, a new DR layout study has been started. In this paper, several considerations about using alternative cell structures, such as FODO, reversed bend magnet, DBA, TBA lattices and combined function magnets, as alternative design for DR are discussed. Moreover, higher energy damping ring option is considered, which could lead to a remarkable simplification in the general injector layout maintaining or even reducing the LINACs total accelerating lenght [7].

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DESIGN REQUIREMENTS

The DR design features defined by the injected beam properties, the injection requirements of the upstream machine, and the injection filling scheme of the injector complex are quite challenging. DR should reduce by orders of magnitude the beam emittance in particular for the positron beams in a short stored time, and should provide large beam acceptance in order to admit the beam from the positron LINAC. The energy of the ring is chosen as 1.54 GeV to avoid spin resonances. The injection scheme of the injector complex imposes about 40 ms stored time, which requires around 8 ms damping time for the ring. The DR beam structure foresees 9 batches, each of them including 2 bunches. Thus, the circumference needs to be at least 250 m long in order to allocate 18 bunches with a reasonable bunch spacing of the order of 50 ns. However, a shorter bunch spacing will be also discussed in the following considerations. The geometrical horizontal emittance should be around 2 nm·rad at the extraction. Table 1 summarizes the design requirements for the DR.

Table 1: FCC-e^+e^- DR Required Design Parameters

Required Parameters	**Value**
Energy [GeV]	1.54
Circumference [m]	≈250
Stored Time [ms]	40
Damping Time (Hor.) [ms]	≈8
Geo. Emittance @Extraction (Hor.) [nm·rad]	2
Number of Bunches	18

ALTERNATIVE DR DESIGN OPTIONS

The reasons driving the new design necessity is as follows: increase the dipole field, optimize the phase advance per cell for minimum beam equilibrium emittance (around 135° for FODO) and thus reduce the number of elements, increase the number of straight sections in order to have independent sections for RF-Cavity, insertion devices, and injection-extraction elements. This new approach is expected to pro-

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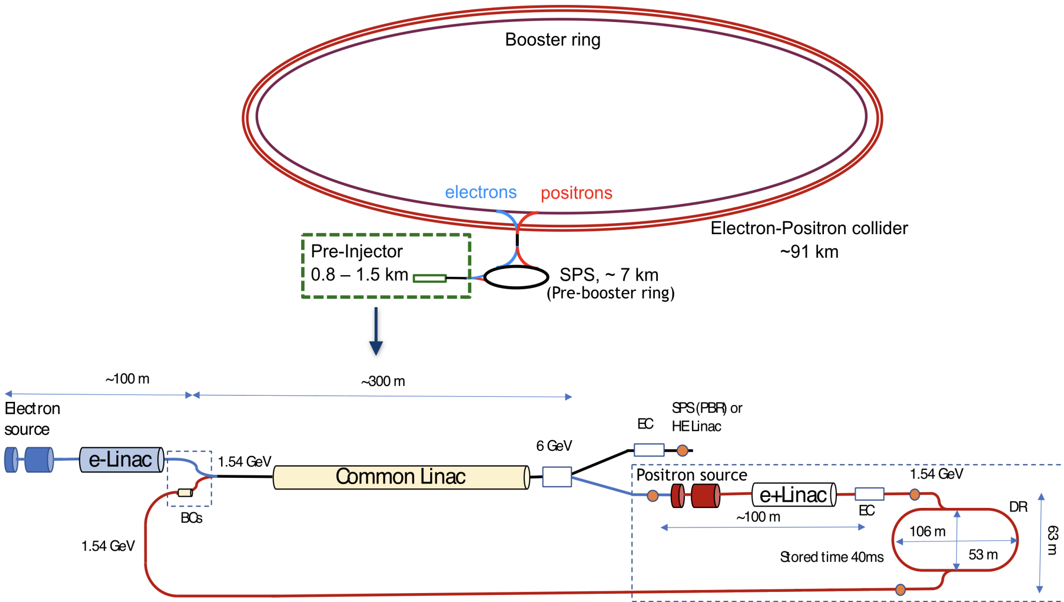

Figure 1: A schematic baseline layout of the FCC-e^+e^- collider (top) and the pre-injector complex (bottom) [3, 7].

vide shorter damping time to meet new recent injection requirements while ensuring the required emittance. Reducing the dipole magnet quantity secure a considerable reduction of the number of other magnets (i.e. sextupole, corrector) and beam diagnostics as well. Three straight sections are planned for this layout upgrade. In this context, several alternative considerations are evaluated so as to possibly replace the current CDR-DR design.

Alternative DR Option-1 (A-DR1)

The main structures of the A-DR1 has been provided based on analytic calculations and simulations: A FODO type cell is chosen, the layout consists of 3 arcs and 3 straight sections. Each arc consists of 11 FODO cells and the chromaticity is controlled by two families of sextupoles. Damping wiggler magnets and Robinson wiggler magnets are installed in the straight sections to provide smaller emittance and shorter damping time. Table 2 shows main beam parameters of A-DR1 option. Another possible approach consists in shortening damping wiggler magnet and eliminating Robinson wiggler magnet; however, in this case, superconducting damping wiggler (4.4 T/12 m) would be required.

Alternative DR Option-2 (A-DR2)

The initial basic parameters for A-DR2 option have been established with longer damping wiggler magnet compared to the A-DR1 in order to satisfy the required emittance and damping time. Similar layout is adopted: A FODO type cell is chosen with 3 arcs and 3 straight sections. Damping wiggler magnets are distributed in three straight sections in order to keep the periodicity while Robinson wiggler magnets are not used. 2.1 nm·rad horizontal geometric emittance and 8.1 s horizontal damping time are achieved with 9 FODO cells in each arc and wigglers in the straight sections with 2 T field for a total length of 36.45 m long. Table 2 shows the main beam parameters of A-DR2 option.

Combined Function Magnet

Cells based on combined function magnets have also been investigated as an alternative to the previously discussed options which all include separated function magnets. In this context, a lattice with combined dipole-defocusing quadrupole (DQ) has been analyzed in detail. In this cell a longer combined function dipole, dipole-quadrupole, is inserted between two focusing quadrupoles [8]. The horizontal (black) and vertical beta (red) functions and horizontal dispersion (green) of this cell are presented in Fig. 2. Combining secondary sextupole with DQ called as DQS is another possible option. The full ring design has not been provided yet, but first results showed that DQ magnet helps to reach smaller emittance and shorter damping time at the same time by modifying the horizontal damping partition

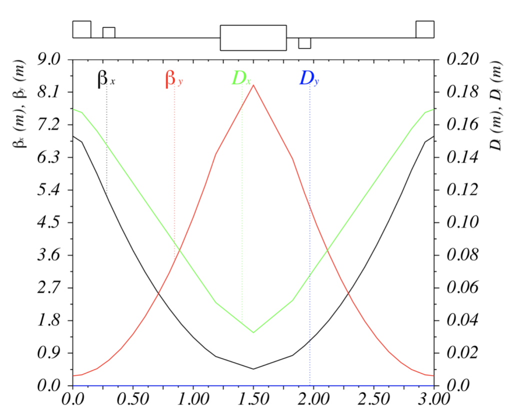

Figure 2: Optics functions of one main cell with DQ magnet.

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Table 2: Comparison of the CDR and Alternative Options of the DR Beam Parameters

Parameters	CDR-DR	A-DR1	A-DR2	A-DR3
Beam Energy [GeV]	1.54	1.54	1.54	2.86
Dipole Magnet Quantity	232	84	78	144
Dipole Magnet Length [m]	0.21	0.3	0.4	0.65
Bending Angle [degree]	1.55	4.28	4.61	2.5
Dipole Magnet Field [T]	0.66	1.27	1.03	0.64
Filling Factor	0.2	0.1	0.15	0.24
Damping Wiggler Field [T]	1.8	1.8	2	2
Damping Wiggler Length (Total) [m]	26.5	18.22	36.45	36.45
Robinson Wiggler Field [T]	-	1.8	-	-
Robinson Wiggler Length (Total) [m]	-	3.8	-	-
Circumference [m]	242	280.23	248.16	384.87
Horizontal Geometric Emittance [nm·rad]	2	2.12	2.1	1.2
Energy Loss per Turn [MeV]	0.255	0.23	0.31	1.13
Horizontal Damping Time [ms]	10.5	5.7	8.1	6.4

number (J_x). On the other hand, this option causes an increment in terms of energy spread and energy loss per turn, which however still seem to be in an acceptable range. A more exhaustive and comprehensive study of this option is under development.

In addition to the aforementioned FODO lattice options, DBA, TBA and reverse bend FODO lattices have also been investigated. For DBA and TBA, the required damping time cannot be achieved without long insertion devices while it provides smaller emittance. Besides, the number of elements need to be increased. For the reverse bend FODO lattice, long insertion devices should be used in order to reach to the emittance [9–12].

HIGHER ENERGY DR OPTION (A-DR3)

Recent simulations concerning the FCC-ee injector positron source prospect a rather high positron yield if compared with existing positron sources. This higher yield has started a debate about the possibility to use a higher-energy DR in the injector design. This solution might provide higher acceptance for the DR and simplify the pre-injector complex and possibly even shorten the total LINAC length [7]. In this regard, a preliminary DR layout study has been done considering a design energy of 2.86 GeV, which is compliant with the requirements coming from spin resonance.

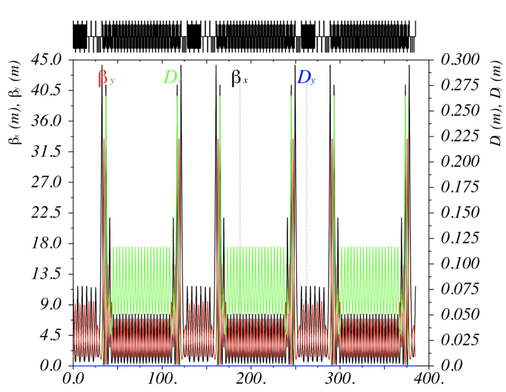

Figure 3: Optics functions of the A-DR3 option.

Higher-energy DR is made up by 3 arcs and 3 straight sections. Each arc consists of 18 FODO cells, while the straight sections consist of 5 FODO cells each. Required emittance is ensured by choosing the optimum phase advance per cell and by settling 36 m/2 T damping wiggler magnets in the non-dispersive section. Optics functions of the A-DR3 are shown in Fig. 3. The present layout has a circumference of about 380 m. Preliminary studies indicates it can provides the proper horizontal emittance and damping time as required by the pre-injector complex design. The main beam parameters of the 2.86 GeV option (A-DR3) are summarized in Table 2. Further optimization study to reduce the number of elements and shorten the circumference will follow in the next study.

CONCLUSION

This study presents possible new design approaches to the FCC-ee damping ring design, all of them are compliant with the pre-injector prescriptions. Several options are investigated such as: FODO with damping wiggler or combination of damping and Robinson wiggler, combined function magnet in order to provide compelling parameters such as emittance and damping time, DBA, TBA, and reverse bend lattice are also discussed. Beam parameters for different options are established, and compared. Such parameters can be achieved by using much less elements than in the CDR version, maintaining the same ring circumference and nominal energy, 1.54 GeV. Additionally, further detailed studies are in progress, adopting compact cells including DQ magnets, which can easily provide small emittance and short damping time with shorter or no insertion devices at all. Furthermore, it is also shown that the prerequisites of the pre-injector complex can be achieved with a DR having a nominal energy of 2.86 GeV, and larger circumference.

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