

A LOW ENERGY POLARIZER RING FOR FCC-ee

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Abstract

Precise beam energy calibration is a basic requirement for the Future electron-positron Circular Collider (FCC-ee) operation at the Z and WW energies. The present baseline foresees to polarize low intensity bunches in the collider using asymmetric wigglers during about one hour prior to ramping up the intensity of bunches brought into collision for physics. Generation of polarized bunches at low energy in a dedicated ring is proposed as an alternative to improve the efficiency of FCC-ee exploitation. First designs of such a dedicated polarizer ring and performance estimates will be presented.

INTRODUCTION

FCC-ee is an electron-positron collider studied as possible next CERN flagship project [1]. This machine, with a circumference of about 90.7 km, aims at providing large luminosities at four different energies ranging from 45.6 GeV to 182.5 GeV. In order to fully exploit the expected integrated luminosity, experiments require a precise energy calibration at the lower two energies of 45.6 GeV corresponding to the threshold for Z production and 80 GeV corresponding to WW production [2]. This energy calibration requires polarized bunches with an intensity of about 10 % of the one of nominal colliding bunches.

The present baseline foresees that low intensity bunches, which are not colliding at the Interaction Points (IPs) are injected prior to intensity ramp up of colliding bunches. Asymmetric wigglers are foreseen to reduce the time required to generate sufficient polarization to about an hour, but are not compatible with high intensity bunches. Thus, about an hour would be lost for luminosity production at the beginning of each fill.

Generation of polarized bunches at low energy followed by acceleration and injection into the collider is proposed as an alternative to enhance the efficiency of FCC-ee exploitation. To this end, tools to study polarized beams have been implemented in the code Xsuite [3] and used to develop a polarizer ring as part of the FCC-ee injector complex [4]. In this paper, a summary of first designs of a polarizer ring is presented together with basic properties such as equilibrium polarization and build-up time constants. Studies on the acceleration of polarized bunches are required in parallel.

POLARIZER RING DESIGNS

A Design based on 60° FODO Arc Cells

First polarizer ring designs were based on 60° arc cells allowing to implement a simple dispersion suppression with the missing dipole scheme. A large number of short cells allows to reduce equilibrium emittances. The arc has been

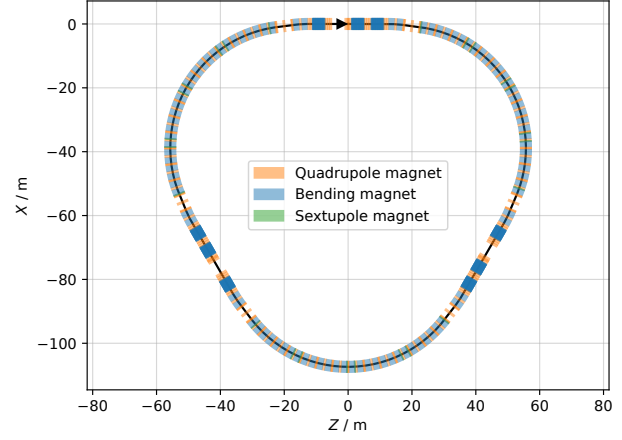


Figure 1: Layout of the first polarizer ring design based on 60° arc cells.

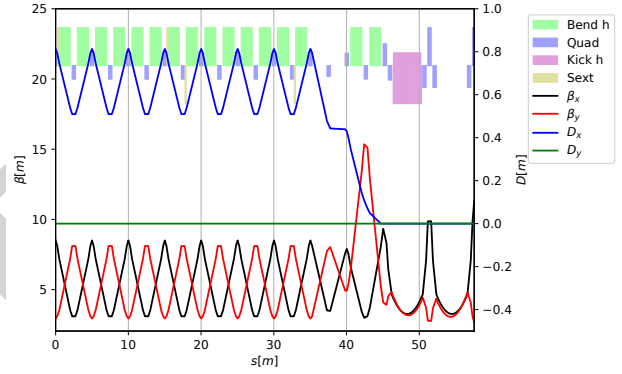


Figure 2: Twiss parameters for one sixths of the first polarizer ring design based on 60° arc cells.

matched to straight sections with triplet focusing. The resulting layout of the ring and Twiss parameters for one sixth of the ring are shown in Figs. 1 and 2. Main parameters of all three designs studied are given in Table 1. The ring has three fold symmetry to adjust to FCC-ee damping ring designs and, possibly installation of the two rings in the same tunnel. Each straight section is divided into four drifts separated by triplets. Three out of the four drifts are filled with asymmetric wigglers to speed up polarization build-up and to reduce equilibrium emittances. Each wiggler is composed of 19 periods, each one consisting of a 1.5 T and 5 cm long high field pole and a 0.5 T and 15 cm long low field pole. The wiggler is modeled optimistically with hard edge transitions and starts and ends with a high field half pole. Without imperfections, this configuration results in an equilibrium polarization of 78.42 %, which is lower than the theoretical maximum due to the Sokolov-Ternov effect of 92.4 % due to the presence of asymmetric wigglers, with a polarization build-up time constant of 3640 s. Synchrotron

radiation damping characteristics are an equilibrium horizontal emittance of 19.5 nm with a damping time constant of 12.71 ms.

For the preliminary studies presented here, in each of the remaining straight sections a cavity with an integrated gradient of 9 MV and a frequency corresponding to an integer harmonic number closest to 400 MHz was placed.

Chromaticity has been corrected using sextupoles spaced by three arc FODO cells such that the phase advance between magnets is 180° . Each sextant comprises two sextupole pairs for independent adjustments of the horizontal and vertical chromaticity. The chromaticity correction introduced significant momentum-dependent betatron beating. This may be one of the reasons for the relatively high second order chromaticity in both planes.

Dynamic Aperture (DA) and Momentum Acceptance (MA) for the machine with corrected chromaticity are plotted in Figs. 3 and 4. The initial particle positions have been normalized to the expected physical rms emittances of positron beams accelerated to 2.86 GeV of $\varepsilon_{\text{rms},x} = 2.32 \mu\text{m}$ and $\varepsilon_{\text{rms},y} = 2.14 \mu\text{m}$ in the horizontal and vertical plane, respectively. For this design, the DA is large compared to the dimensions of the injected positron beams. As the injected positron beam is expected to have a large energy spread, it still has to be verified whether the MA of about $\pm 2\%$ is sufficient.

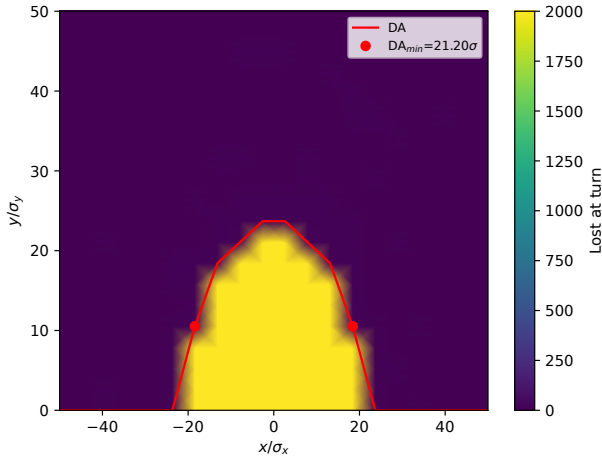


Figure 3: Dynamic aperture for the polarizer ring design based on 60° arc cells.

Furthermore, polarization build-up for a machine with imperfections has been studied. Magnet offsets with an rms of 0.3 mm and rolls with an rms of 0.3 mrad have been applied to all bending and quadrupole magnets, but not to wigglers. The resulting closed orbit perturbations have not yet been corrected. Relative strength errors of 10^{-3} have been applied to all quadrupoles and bending magnets. Equilibrium polarization levels and build-up times have been estimated from the Derbenev-Kondratenko-Mane formula taking radiative depolarization into account and yielding a polarization level P_{dk} and time constant τ_{dk} , and taking in addition depolarization caused by spin resonances into account [5]. With a depolarization time constant due to spin resonances of τ_{dep} ,

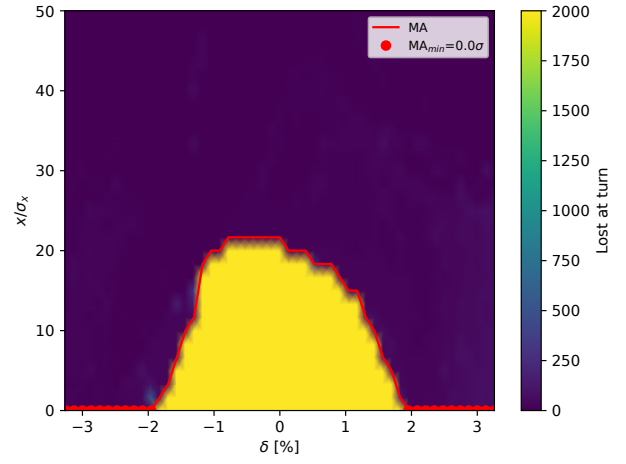


Figure 4: Momentum acceptance for the polarizer ring design based on 60° arc cells.

the equilibrium polarization and time constant become:

$$P_{\text{eq}} = \frac{P_{\text{dk}}}{1 + \frac{\tau_{\text{dk}}}{\tau_{\text{dep}}}} \quad \text{and} \quad \tau_{\text{pol}} = \frac{\tau_{\text{dk}}}{1 + \frac{\tau_{\text{dk}}}{\tau_{\text{dep}}}}.$$

Equilibrium polarization levels with depolarization due to spin resonances and from the Derbenev-Kondratenko-Mane formula are presented in Fig. 5. One observes that polarization levels are appropriate for many cases, but there are still a significant number of cases with insufficient equilibrium polarization. Further studies are required to understand whether closed orbit correction, in particular, in the vertical and, possibly a modest change of the beam energy to adjust the spin tune allow to increase the equilibrium polarization.

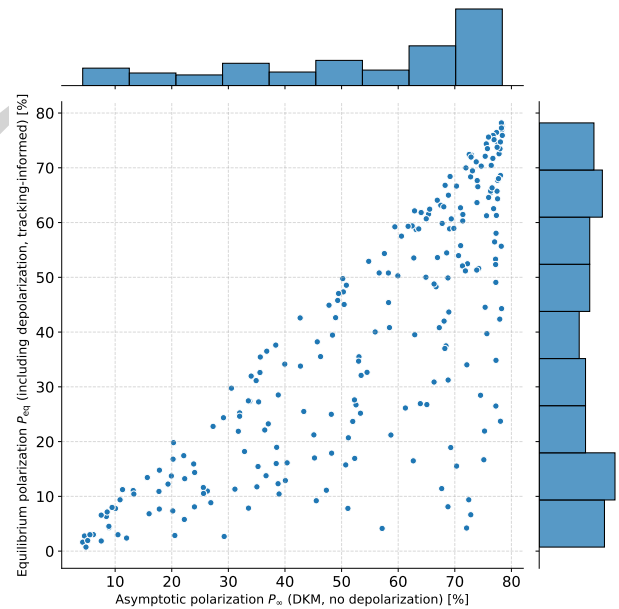


Figure 5: Polarization build-up characteristics for the polarizer ring design with 60° arc cells with imperfections.

Table 1: Main Characteristics of the three FCC-ee Polarizer Ring Proposals

Parameter	Design 1	Design 2	Design 3
Circumference [m]	345.3	349.0	237.0
Phase advance per arc FODO cell	60°	90°	60°
Tunes horizontal/vertical	11.73/11.78	16.65/15.63	11.75/11.76
Energy loss per turn [MeV]	0.524	0.509	0.819
Equilibrium polarization (perfect machine)	78.42 %	78.02 %	84.95 %
Polarization build-up time (perfect machine) [s]	3640	3784	1330
Equilibrium horizontal emittance with wiggler [nm]	19.56	5.45	35.26
Horizontal/Vertical Damping time with wiggler [ms]	12.71/12.57	13.14/13.09	5.63/5.52

A Polarizer Ring Design with a larger Phase Advance per FODO Arc Cell

The motivation of increasing the phase advance per arc cell was to reduce the equilibrium emittance. Thus a design of a lattice with 90° FODO cells was studied.

The main characteristics of the resulting ring are given in Table 1. As expected, the equilibrium emittances were reduced significantly with little impact on the synchrotron radiation time constant and polarization build-up characteristics and the radiation damping time constant.

Chromaticity correction was again based on two pairs of sextupoles spaced by betatron phase advance 180° and generates significant off-momentum betatron beating. The DA was slightly reduced. The MA was strongly reduced, such that further optimizations would be necessary to allow injection of the expected positron beams with sufficient efficiency.

A Polarizer Ring Design with shorter Circumference

For this option, the motivation of decreasing the size of the machine and to increase the magnetic field of the bending magnets was to improve the polarization built-up characteristics.

The main characteristics of the resulting ring are given in Table 1. As expected, the higher magnetic fields of the bending magnets and the shorter circumference allowed to speed up polarization build-up and increase equilibrium polarization at least for a ring without imperfections. The larger bending fields lead to increased equilibrium emittances and faster synchrotron radiation damping.

The same chromaticity correction scheme than for the other two designs has been implemented resulting again in significant off-momentum betatron beating. Both the DA and the MA are slightly reduced with respect to the first design. Further studies with realistic parameters for injected positron beam are needed to clarify whether further optimizations are required.

with different circumferences and phase advances per cell. First estimates of basic properties have been given. Without considering imperfections, the Dynamic Aperture (DA) and Momentum Acceptance (MA) of designs 1 and 3 seem sufficient for injection of the positron beam accelerated from the conversion target without prior emittance reduction in the damping ring of the FCC-ee injector complex. The polarization build-up rates are still at the lower end of the requirements for the first two designs with larger circumferences and lower magnetic fields of the bending magnets. A third design with smaller circumference and higher magnetic fields allowed to speed up polarization build-up, but would profit from further optimisations to increase the MA.

Work on increasing the MA and DA by, e.g., optimising the working point and other chromaticity correction schemes is planned. This is mandatory in case the third design with enhanced polarization build-up properties is adapted with injection of the positron beam directly from the positron linac without pre-damping using the damping ring.

The equilibrium emittances of all polarizer ring designs presented are too large for acceleration in the high energy linac and injection into the FCC-ee High Energy Booster (HEB). Thus, in case one of these designs is selected, the bunches have to be damped in the damping ring after polarization build-up and before further acceleration.

Studies on different lattice types aiming at designing a ring with sufficient polarization build-up rates, large DA and MA, and small equilibrium emittances suitable for direct acceleration to the HEB injection energy are ongoing. If this attempt is successful, energy calibration bunches would not require damping in the damping ring neither before nor after polarization build-up.

Integration studies of the polarizer ring into the FCC-ee injector complex have to take place together with the ones for the damping ring. For example, for practical reasons operating the polarizer and the damping ring at the same energy is preferable, but has some impact on achievable polarization build-up properties.

CONCLUSIONS AND OUTLOOK

First studies on a low energy polarizer ring for FCC-ee led to three different designs, all based on FODO arc cells,

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