3.5 GeV SUPERCONDUCTING STACKING RING FOR COMPTON BASED POLARIZED POSITRON SOURCE OF CLIC

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Abstract

This paper describes a superconducting storage ring dedicated to positron accumulation as part of a polarized positron source based on Compton scattering in a Compton storage ring (CR). The superconducting stacking ring (SR) can provide a synchrotron damping time of order 250 μs. Together with a novel combined injection scheme in the longitudinal and transverse plane, such a ring may solve the problem of accumulating a positron beam of $4 \times 10^9 e^+$ /bunch and 312 bunches which is the beam charge required for CLIC.

INTRODUCTION

Compton scattering of an electron beam off a high-power laser pulse in a so-called Compton Ring [1] is a promising option to realize a polarized positron source for a future linear collider such as CLIC. Due to practical limits on the laser pulse energy and the electron bunch charge the number of positrons produced per beam-laser collision is limited to at most a few 10^7 positrons per pulse. The CLIC design bunch charge is 100 times higher. Therefore, a Compton-based source must obtain the target bunch population by accumulating a large number of positron arriving in a number of bursts from the CR [2, 3, 4], with intermediate damping of the scattering electron beam and of the accumulating positrons.

Simulations of a Compton positron source indicate that a yield of a few 10^7 positrons per pulse is possible, with a longitudinal rms emittance around 0.2–0.3 meV-s, and a transverse normalized rms emittance of 8×10^{-3} rad-m [5]. To obtain a high degree of polarization high-energy positrons have to be selected. An energy selection providing a beam polarization larger than 60% also decreases the transverse rms emittance, by an estimated factor 2–4, and discards more than 70% of the produced positrons. The total gamma yield from the CR has to be adjusted accordingly. This effect can be taken into account in the Compton ring design.

The present layout of a CLIC polarized positron source based on Compton backscattering is shown in Fig. 1.

STACKING RING

As we have seen the stacking ring must accumulate positrons during a few thousand turns. It was initially proposed to perform the injection in the longitudinal phase space, for which a fast longitudinal damping time of order 100 μs and a large SR energy acceptance of order $\pm 10\,\%$ are needed. Using a combined longitudinal-transversal injection would allow decreasing the required SR energy acceptance down to more realistic values of order of 3.5 % [7].

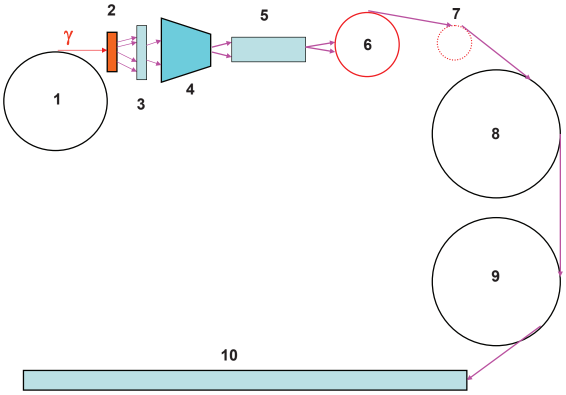

Figure 1: Layout of the Compton based positron source. 1: Compton ring; 2: conversion target; 3: positron selection; 4: adiabatic matching device; 5: pre-accelerator; 6: stacking ring; 7: time diagram transformer; 8: pre-damping ring; 9: damping ring; 10: main accelerator.

To obtain a positron beam damping of a few hundred turns in the SR the beam energy loss per turn must be large. For this reason in [7] a superconducting SR with an energy loss of about 20 MeV was proposed. Unfortunately, this scheme faces a serious technological issue with synchrotron radiation: If the beam current stacked in the SR is equal to the CLIC pulse current of $I_\mathrm{p} = I_\mathrm{stack} \approx 1.28\,\mathrm{A}$, with energy losses of order of several MeV per turn the power load on the vacuum chamber becomes unreasonably large.

To overcome this problem, we here propose a special operation mode of the positron complex. In this operation mode the positron beam is stacked in the SR with a bunch separation equal to n_bb times the nominal CLIC spacing (0.5 ns), which allows reducing the stacked current in inverse proportion to the separation $I_\mathrm{stack} = I_\mathrm{p}/n_\mathrm{bb}$. In other words the target positron intensity of the single CLIC pulse is being accumulated in the pre-damping ring (PDR) during several successive stacking cycles (8 cycles for the proposed lattice; the number of cycles equals the ratio of the generation cycles of the CR to the CLIC repetition rate, which is 50 Hz). In addition, the chosen SR circumference is three times longer than the CLIC pulse; the pulse transformation is performed by three-turns injection from the SR into a so-called time-diagram transformer (TDT). After stacking and damping of the required bunch population, the positron train is quickly extracted from the SR to the TDT and just after filling the TDT sent further to the PDR, shifting successive trains by a single PDR RF bucket.

To obtain the damping time of order 100μ s a SR with a positron energy of E_{e^+} =5 GeV was proposed in [7]. For such an energy, after extraction from the SR one needs to decelerate the positrons down to the PDR beam energy $E^{e^+}_{\rm PDR} = 2.86$ GeV and this need is a serious drawback of the proposed ring.

We can decrease the SR energy, while maintaining reasonable bending field, if we change the SR layout to the one presented in Fig. 2

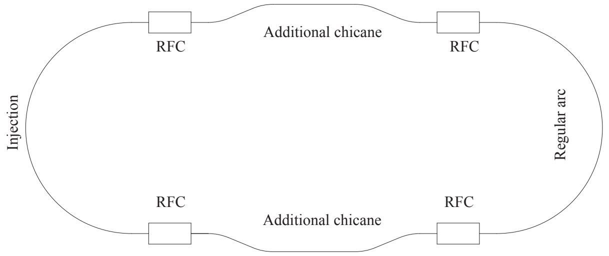

Figure 2: Optimized SR layout. IA: injection arc; RA: regular arcs; AC: additional chicanes; RFC: RF-sections.

Two chicanes in the long straight sections allow us to increase the beam energy losses by a factor $b = (2\pi + \varphi_{\rm chic})/(2\pi)$, where $\varphi_{\rm chic}$ is the total bending angle of the chicanes. Besides, such a ring scheme enables the control of the momentum compaction factor and, thereby, decreases the required RF voltage.

The parameters of the corresponding stacking ring design were chosen as follows:

- ring circumference $C_{\rm SR} \approx 143.9$ m (120 positron bunches on the ring orbit);
- positron energy $E_{e^+} = 3.5$ GeV;
- bending field $B_0 = 6$ T;
- total bending angle of the chicanes $\varphi_{\rm chic} = 136°$;
- momentum compaction factor $\alpha_1 = -0.001$;
- RF voltage $V_{\rm rf} = 25$ MV; and
- dispersion at the injection azimuth $\eta_{\rm i} = 1$ m.

The SR lattice consists of two long straight sections with additional chicanes and RF-cavities. Besides, it is assumed that the positron beam extraction is also performed in one of the long straight sections.

The two SR arcs consist of eight regular arc cells and two arc cells with long drift spaces in which, e.g., the positron beam will be injected after pre-acceleration. The dispersion function at the injection point is $\eta_{\rm inj} = 0.975$ m. The super period number is two. The beta and dispersion functions of a single super period are shown in Figs. 3, and 4.

Several sextupole families are used to correct the chromatic effects. The chromatic correction provides for a large energy acceptance and allows injecting into the ring with a 3.5 % pulse deviation from the reference ring energy.

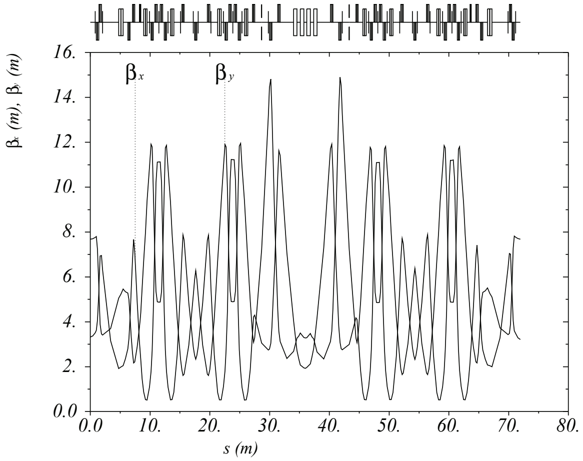

Figure 3: SR beta functions for a single super period.

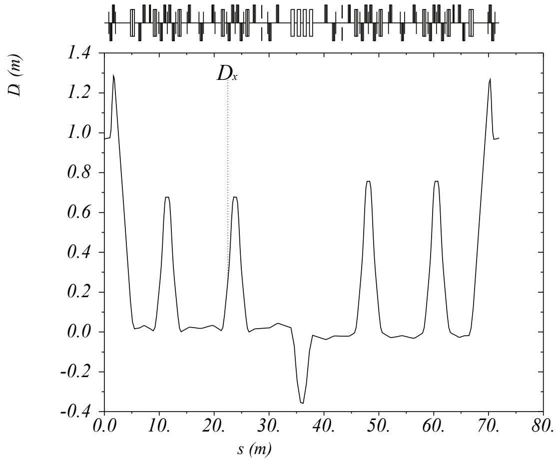

Figure 4: SR first-order dispersion for a single super period.

The main stacking ring parameters are listed in Table 1.

SIMULATION OF BEAM DYNAMICS IN THE STACKING RING

The off-energy dynamic aperture (DA) of the designed SR is illustrated in Fig. 5. The DA simulation was performed with the MAD-X code, tracking particles over 10,000 turns. Synchrotron radiation was not included.

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Table 1: Main stacking ring parameters

Parameter	Unit	Value
Positron energy	GeV	3.5
Ring circumference	m	143.90
Betatron tuning Q_x, Q_y		10.23; 5.30
Momentum compaction factor		-0.001
Dispersion at injection azimuth	m	0.975
Harmonic number		960
Number of bunches in orbit		120
Bunch-to-bunch spacing	ns	4
RF frequency	MHz	2000
RF voltage	MV	25
Damping times	μ s	
– transverse		490
– longitudinal		250
Ring energy acceptance	%	4
Energy loss per turn	MeV	9.4
Mean power load	kW	200

Thanks to the large DA of the SR one can inject positron beams with a large emittance up to a few thousand micrometer (normalized).

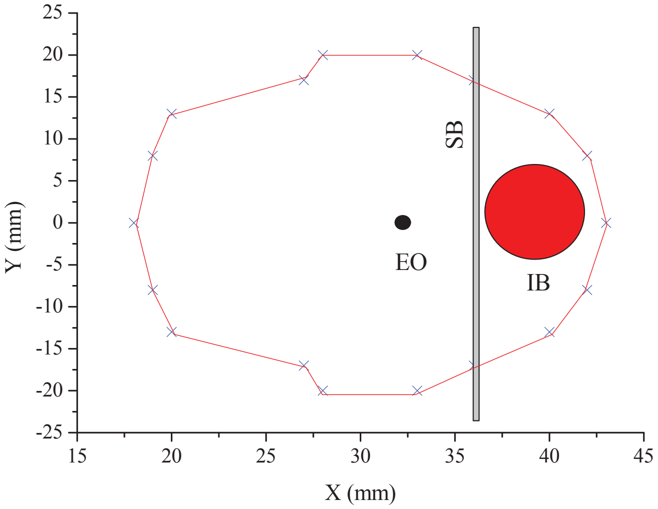

Figure 5: Simulated SR dynamic aperture over 10,000 turns at a momentum offset of $\Delta p/p_0 = 3.5\,\%$ (without synchrotron radiation). The red aperture lining demarcates the region of stable particle motion. .

The longitudinal beam oscillations at injection during a single synchrotron period (synchrotron frequency $Q_s \approx 0.03$) are visualized in Fig. 6. The following parameters were used for the injection simulations:

- rms normalized transversal emittances $\epsilon_x = \epsilon_y = 2000 \times 10^{-6}$m × rad;
- rms longitudinal emittance $(\Delta p/p_0)_{\rm rms} \times \sigma_s = 0.15\% \times 1\,\rm mm$ (approximately corresponding to the beam energy spread after acceleration from 15–20 MeV to 3.5 GeV);
- Longitudinal shift of the injected beam center $\Delta p/p_0 = 0.034$;
- a final septum thickness of $0.5\,\rm mm$ (36.2–$36.7\,\rm mm$).

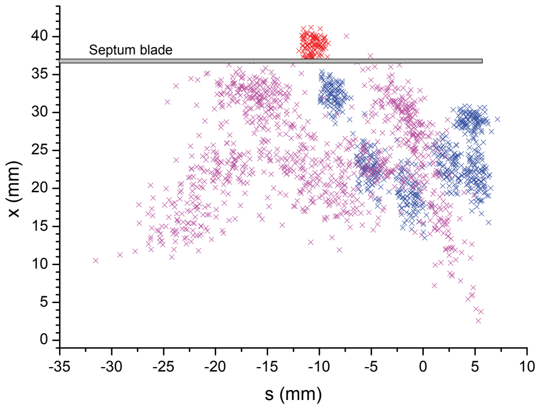

Figure 6: Beam particles at injection (red symbols), on the first couple of turns (blue symbols), and at the end of the first synchrotron period (magenta symbols).

The distribution of the injected beam is assumed to be a truncated Gaussian (extending to 2.5σ in the two transversal planes and to 1.5σ in the longitudinal). The simulation shows that from every 1000 particles injected, 48 particles are lost during the first synchrotron period, and that no further losses occur afterwards. So, the overall injection efficiency is close to 95 %.

CONCLUSION

The proposed superconducting stacking ring could be a solution to the problem of positron stacking under the condition of quasi-continuous positron generation. The CR operation mode with high repetition rate allows for the design of a stacking ring with realistic parameters. The design procedure and the simulations performed indicate that the SR beam energy can be 3.5-5 GeV, and that a high stacking efficiency of 95% can be achieved, with acceptable power load of the synchrotron radiation.

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