UPDATED DESIGN OF THE ITALIAN SUPERB FACTORY INJECTION SYSTEM

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Abstract

The ultra high luminosity B-factory (SuperB) project of INFN [1, 2] requires a high performance and reliable injection system, providing electrons at 4 GeV and positrons at 7 GeV, to fulfill the very tight requirements of the collider. Due to the short beam lifetime, continuous injection of electrons and positrons in both High Energy Ring (HER) and Low Energy Ring (LER) is necessary to keep the average luminosity at a high level. An updated version of the injection system, optimized at higher repetition frequency is presented. This scheme includes a polarized electron gun, a positron production scheme with electron/positron conversion at low energy 0.6 GeV, and a 1 GeV damping ring to reduce the injected emittance of the positron beam.

INTRODUCTION

The Main Rings (MR) parameters relevant for injection are listed in Table 1. The very low beam lifetime requires continuous injection at high repetition rate in order to keep the luminosity almost constant at the peak value.

Charge per bunch required at injection

Injecting at 50 Hz with a single bunch per pulse, each one of the 978 bunches will be refilled after Δt = 20 s, with a number of particles $\Delta N \cong N \cdot \Delta t / \tau = N \cdot 0.08$. The average relative loss will be the half $\langle \Delta N / N \rangle \cong 4\%$. Since the luminosity is proportional to the square of the bunch current the average luminosity relative loss with respect to the peak value will be $\Delta L / L_{peak} \cong 2 \langle \Delta N / N \rangle \cong 8\%$.

Injecting in the main rings few bunches per pulse with 4 ns bunch spacing, say 5, we can keep the peak luminosity reduction within 2% and reduce the number of injected positrons per bunch below 1×10^9.

SYSTEM DESCRIPTION

The injection system described in [1, 3] is based on the following assumptions: S-band linac operating at 50 Hz, injection in each ring at 25 Hz, with 5 bunches per pulse, and both beams stored in the Damping Ring (DR) in turn.

Now we are proposing a new layout, illustrated in Fig. 1. The main difference with respect to the previous scheme is the fact that only the positron beam is stored in the DR while the electron beam is directly accelerated and injected. In this way the positrons can be stored in the damping ring for the time between two injection pulses (before it was half this time) achieving the same emittance damping factor at twice the repetition frequency. Therefore it is possible with a 100 Hz linac to inject at 50 Hz in each ring using a single bunch per pulse to make the current per bunch very uniform along the ring.

Table 1: Main Rings Parameters Relevant for Injection

	LER	HER
Particle	e^-	e^+
Energy (GeV)	4.18	6.70
Number of bunches	978	978
Particles/bunch	6.6×10^{10}	5.1×10^{10}
Charge/bunch (nC)	10.6	8.2
Charge/bunch (nC) required for injection (1 bunch/pulse, 50 pps)	0.79	0.65
Horizontal emittance (nm)	2.5	2.0
Vertical emittance (pm)	6.2	5.0
Relative energy spread	7.3×10^{-4}	6.4×10^{-4}
Lifetime (s)	269	254
Polarization	~80%	0

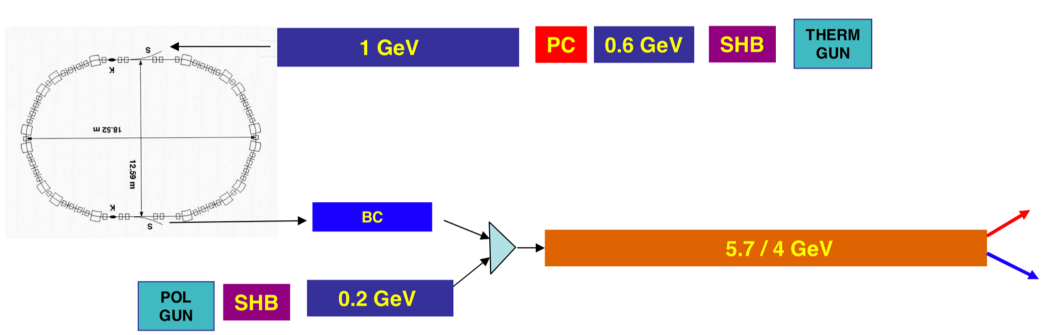

Figure 1: New injection system layout.

A “high current” electron gun is used for positron production. A single electron bunch (or a short train of up to 5 bunches), with 10 nC charge is produced at 50 Hz and passed through a sub-harmonic bunching system to reduce the bunch length from 1 ns FWHM down to 10 psec. The bunching system consists of 2 standing wave cavities operating at 238 MHz and 476 MHz, the 12th and the 6th sub-harmonics of the 2856 MHz, followed by an S-band buncher. The frequency of 476 MHz is the same as the DR and main rings frequency in order to synchronize the injected bunches.

The bunch is accelerated at 0.6 GeV in a S-band 50 Hz linac and focused on the positron converter. e^+/e^- conversion is done at low energy, as in the previous scheme [1], using a high efficiency system described in a following section.

After the converter an L-band linac accelerates the positron bunch up to 1 GeV for injection into the DR.

The bunch is stored for 20 ms in the DR, corresponding to ~ 3 betatron damping times, and then extracted. A bunch compressor reduces the bunch length at the entrance of the linac in order to minimize the bunch energy spread for HER injection [1].

A 6 GeV S-band linac accelerates the bunch up to the nominal HER energy.

Electrons are produced using a polarized gun like the one used by the SLC collider at SLAC [4]. The possibility to use the SLAC gun itself, presently available, is under consideration. A polarization of 80% has been routinely achieved. The bunch length is reduced down to 10 ps FWHM by means of two sub-harmonic bunching systems. Further optimization will be needed to fit the low charge, short bunch operation mode required. The normalized emittance at the gun exit is $1.5\cdot10^{-5}$ m, three times smaller than the value required for MR injection. The emittance increase due to the bunching process depends on the bunch charge. In our case the required charge per bunch is only 0.8 nC, a factor ~ 20 below the nominal emitted charge per bunch, and therefore we expect that even with some blow-up the final emittance will satisfy the injection requirements. After the bunching systems the electron bunch is accelerated in a 50 Hz 0.2 GeV S-band linac before merging in a combiner magnet with the positron line at the exit of the bunch compressor. Acceleration up to the LER energy is performed in the same 6 GeV linac used for positrons, which is operated at 100 Hz alternating one positron pulse with one electron pulse.

LINAC

In this scheme there are three sections made of room temperature S-band linac. The main S-band linac parameters are listed in Table 2. In the electron mode 12 out of 40 RF stations of the 6 GeV linac are switched off to accelerate the beam at 4.2 GeV.

The positron converter is followed by a 1 GeV L-band linac that allows a large positron capture and transport efficiency. L-band, room temperature linacs are unusual in the field of particle accelerators. One is in operation at the University of Osaka [5], another one is foreseen for injection into the SuperKEKB collider [6]. Both are based upon the use of 30 ÷ 40 MW Klystrons and SW two meter length copper sections, with average gradient of 12÷13 MV/m. The parameters for the L-band linac section are shown in Table 3.

Table 2: S-band Linac Parameters

Section	1	2	3
Energy (GeV)	0.6	0.2	6.0
Repetition rate (pps)	50	50	100
Length (m)	30	10	270
Number of klystrons	3	1	40
Klystron peak power (MW)	50	50	60
Number of sections	9	3	80
Gradient (MV/m)	23	23	25

For the 6 GeV linac we have a possible solution with C-band sections, in alternative to the S-band one reported in Table 2. C-band linac sections are being developed and tested at LNF with good performance [7]. This solution, listed in Table 3, would be some 6÷7 % more expensive than the S-band but would require a shorter tunnel. Therefore it will be preferred only if the shorter tunnel gives important advantages for the SuperB complex layout. At present we have a layout solution with S-band linac that fits in the approved site at Tor Vergata University Campus (Rome).

Table 3: L-band and C-band Linac Parameters

Section	L-band	C-band
Energy (GeV)	1.0	6
Repetition rate (pps)	50	100
Length (m)	100	170
Number of klystrons	20	50
Klystron peak power (MW)	40	50
Number of sections	40	100
Gradient (MV/m)	12.5	40

POSITRON PRODUCTION

The positron source design [8] allows taking into account a low energy drive electron beam (0.6 GeV). For this it was necessary to optimize the e^+ production yield and the capture efficiency to fit the damping ring acceptance. The first was maximized at 1.7 e^+/e^- for a tungsten target of ~ 1 cm (3 radiation lengths). Moreover the total flux takes advantage from the high bunch charge delivered by the electron gun (~ 10 nC).

As far as the capture is concerned a high efficiency system, consisting of a 20 cm Adiabatic Matching Device and of large iris L-band cavities has been proposed. At the same time also the efficiency of a ‘standard’ capture in S-band was estimated. To reduce the longitudinal emittance a first deceleration cavity was considered. A new idea was also proposed by introducing a L-band cavity operated in TM020 mode for deceleration. This increases the bunching efficiency preserving the transverse acceptance given by the large iris diameter (30 mm). The design of this cavity is in progress at LAL.

In the deceleration case, after the capture section and in an energy range of ± 10 MeV, a longitudinal capture efficiency of respectively 8 and 29 % is obtained for the S-band and the L-Band TM020 deceleration cases. This completely fulfills the requirements of the SuperB injector. Due to the capture efficiency it will be also possible to lower the required drive beam charge, preserving the efficiency of the electron gun.

DAMPING RING

The damping ring has been already described in [1], and the main parameters are shown in Table 4. Here we discuss the DR acceptance, which is crucial for the positron conversion rate.

Table 4: Damping Ring Parameters

Energy (GeV)	1.0
Circumference (m)	51.1
Horizontal emittance ε_{0x} (nm)	23
Vertical emittance ε_{0y}, κ=.01 (nm)	0.2
Betatron damping time (ms)	7.3
Relative energy spread	$6.2\text{x}10^{-4}$
Momentum compaction	$5.7\text{x}10^{-3}$
RF frequency	475
RF voltage (MV)	0.5
Bunch length (mm)	4.8

DR injection acceptance

We assume a beam stay clear of 25 mm radius and a maximum oscillation amplitude, including betatron and synchrotron oscillations, of x_{max} = 15 mm in order to leave a safety margin for orbit and energy errors. The maximum accepted betatron amplitude is:

$$A_x = x_{max}^2/\beta_x = 1\ 10^{-5}\ \text{m}.$$

The equivalent rms beam size is $\sigma_x = x_{max}/3$ corresponding to an emittance $\varepsilon_i = A_x/9 = 1.1\ 10^{-6}$ m. The maximum accepted relative energy deviation is $\Delta E/E = 1.5\ 10^{-2}$, well below the RF acceptance at 0.5 MV voltage $\Delta E/E = 2.5\ 10^{-2}$. Both the transverse and energy acceptance are well below the dynamic aperture [1].

Given the positron injected emittance ε_i the emittance of the beam extracted from the DR and accelerated to the HER energy is:

$$\varepsilon_i^{HER} = \left[(\varepsilon_i - \varepsilon_o)e^{-\frac{2t}{\tau}} + \varepsilon_o\right] \cdot E_{DR}/E_{HER}$$

In the horizontal plane the emittance at HER injection is ε_i^{HER} = 4.1 nm and in the vertical plane, assuming a coupling of 1% in the DR, it is 0.72 nm.

INJECTION INTO MAIN RINGS

A detailed description of the main rings injection is given in [1]. Since we inject with colliding beams we want to keep the betatron oscillation of the injected beam as low as possible to avoid any perturbation to luminosity and detector backgrounds. The value of the betatron function in the ring at inection is large to reduce the contribution of the septum thickness. The main rings configuration has non-zero dispersion at injection point and the injected beam has an energy offset. This allows smaller oscillations of the injected beams at the interaction point, where dispersion is zero. The parameters of the injected beams and the maximum betatron oscillation in the ring x^{inj}_{max}/σ_x, calculated from the linear optics, are shown in Table 5. The maximum of the injected beams oscillation is well within the ring acceptance $A_x/\sigma_x = 30$; this should provide enough safety margins also when beam-beam and nonlinear effects are taken into account.

Table 5: Main Rings Injection Parameters

	LER	**HER**
Injected emittance ε_{ix} (nm)	5.5	4.1
Injected energy spread	$1.3\cdot10^{-3}$	$8\cdot10^{-4}$
x^{inj}_{max}/σ_x	15	12

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