BEAM DYNAMICS STUDIES FOR THE INJECTION SYSTEM OF A HIGH LUMINOSITY FLAVOUR FACTORY

D. Pellegrini, CERN, Geneva, Switzerland and EPFL, Lausanne, Switzerland
S. Guiducci, M.E. Biagini, INFN-LNF, Frascati, Rome, Italy

Abstract

The requirements, in terms of average luminosity and lifetimes, of high luminosity e^+e^- colliders such as the flavour factories, pose stringent constraints to the design of the injection complex. For the SuperB B-factory project at Tor Vergata, Italy, a design was developed to deliver full energy bunches (4.2 GeV e^- and 6.7 GeV e^+) to the main rings every 30 ms aiming at a high and nearly constant luminosity [1]. The system included a polarized electron gun, a positron production system, linac sections, a Damping Ring (DR) and transfer lines connecting to the collider Main Rings (MR). After the decision, due to budget issues, to rescale the project to a lower energy (2.3 GeV/beam) for a tau/charm flavour factory, the same design principles have been applied. In this paper the study of the beam dynamics from the DR to the MR entrance is presented, including optimization of the transfer lines and of the bunch compressor. A start to end simulation shows that the beam quality satisfies the injection requirements, even in the presence of energy errors and collective effects like CSR and wakefields.

INTRODUCTION

The baseline of the injector of the SuperB B-factory described in [2] is based on simple and well tested solutions, which make use of components available on the market. The charge required for injection into main rings is 300 pC/bunch in 5 bunches for both electrons and positrons. The electron gun can reach 10 nC per bunch with a polarization larger than 80 %. Full charge electron bunches are used for the positron production: after acceleration in Linac L1 up to 1.5 GeV they impinge on a tungsten target. Positrons are captured and accelerated in the Linac L2 up to 1.1 GeV. Both beams are stored in the DR for emittance damping as described in [1], positrons are stored for 20 ms and electrons for 10 ms only.

The linacs are operated at 100 Hz and the injection cycle is 30 ms for each beam. This timing scheme allows to accelerate a beam pulse for a SASE FEL facility, during the store time of the positrons in the DR, without affecting the injection rate for SuperB. At the DR extraction the bunches are too long to be accelerated by the S-band main linac. A single-stage bunch-length compressor has been fitted before the main linac and the compression ratio has been optimised in order to minimize the energy spread at the injection in the main rings.

After the full energy acceleration in the main linac (4.2 GeV e^- and 6.7 GeV e^+), the electron beam is transported to the low-energy main ring (LER) by a transfer line with an angle of ~ 150 degrees. The transfer line for the high-energy ring is nearly straightforward. The design transfer line from the linac to LER, which is the most difficult one, is presented in the following.

The design, the optimization and the tracking of particles from the DR up to the LER injection cell, have been done with the code *elegant* [3].

BUNCH COMPRESSOR

The bunch compressor utilizes an S-band cavity of the same type of the main linac, operated at the zero-crossing phase. A dipole splits the electron and positron beams in two chicanes. The final dipole of the chicanes is used to recombine the beams on the same orbit.

The optimization aims to minimize the momentum spread at the end of the main linac which is influenced by the bunch length during the acceleration in the main linac, and by the momentum spread induced by compressor itself. The energy spread of the electron beam at the end of the main linac as function of the RF voltage and of the chicane angle is presented in Fig. 1. The optimization aims to achieve an energy spread of ~ 1.5 ‰ for both electrons and positrons for the same parameters. In fact the momentum-chirping cavity is shared by both beams, and the two symmetrical chicanes use the same magnets. The bunch compressor parameters and the beam parameters at the end of the linac are shown in Table 1.

The simulation takes into account the coherent synchrotron radiation CSR in the chicane. As foreseen by analytical computations [4, 5], this effect is negligible for the relatively long and weakly-charged bunches of the SuperB injector.

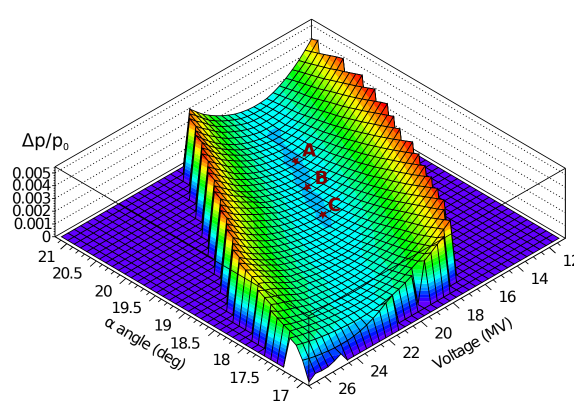

Figure 1: Energy spread of the electron beam at the end of the main linac as function of the parameters of the bunch compressor.

ISBN 978-3-95450-122-9

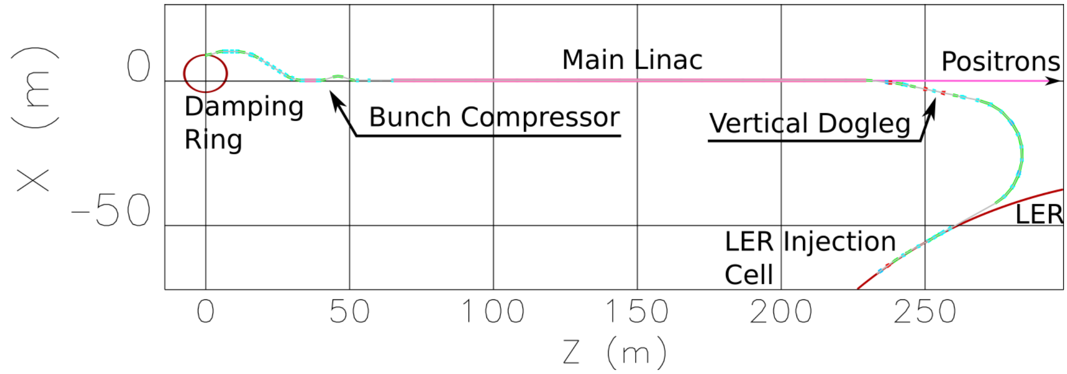

Figure 2: Layout of the electron injector from the DR extraction to the LER injection cell.

Table 1: Bunch Compressor and Beam Parameters at Linac End

	Electrons	Positrons
Voltage	18.5 MV	
R_{56}	-0.86 m	
$\Delta p/p_0$	1.51 ‰	1.18 ‰
bunch length	590 μm	600 μm
ε_x	5.52 nm	4.22 nm
ε_y	48 pm	760 pm

MAIN LINAC

The main linac consists of 82 cavities (e^- are extracted after 46 of them), operating at 2856 MHz with an average gradient of 23.5 MV/m. Focusing is provided by 44 quadrupoles, one each two cavities, arranged in a FODO lattice.

The proposed orbit correction scheme consists of 21 BPMs and 21 correctors. The distances between a BPM and a corrector, and between a corrector and the next BPM are 1 cavities and 3 cavities respectively. This scheme allows an effective correction of the orbit and a good control of the emittance blow up coming from the element misalignments.

Short-range wakefields, both transverse and longitudinal, have been simulated. While the former have a negligible effect, the latter induce a small energy spread along the bunch, which can be compensated advancing the linac phase by 1° [5].

LINAC-LER TRANSFER LINE

The design of the transfer line for the electron transport from the main linac to the LER injection cell has been driven by tight geometrical constraints. The full energy electron beam (4.18 GeV) passes through a vertical dogleg of about 1 m displacement, a 149° horizontal arc and

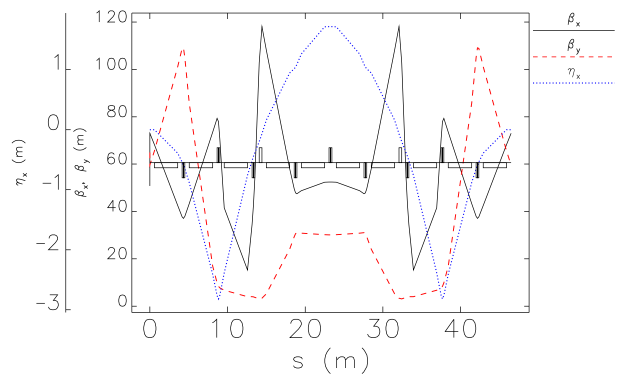

Figure 3: β functions and dispersion for the proposed bending section.

arrives with a small vertical angle to match the tilt of the LER. The layout of the transfer line within the whole complex is shown in Fig. 2. Further details about the design can be found in [5, 6].

The small curvature radius ($\sim$ 30 m) of the bending section requires a strong focussing in order to contain the dispersion and the R_{56} which causes bunch lengthening. Different lattices have been investigated [6], the proposed one inverts the dispersion in the central part of the arc (see Fig. 3), this allows a reduction of R_{56} to better fit the bunch into the ring longitudinal acceptance.

As shown in Table 2, for energy errors below ± 3 ‰, the bunch inside the ring (after the injection kicker) is within the ring horizontal aperture of 25 σ_x^{sto}.

Figures 4 and 5 show the horizontal and longitudinal phase space for the electron beam tracked along the whole injector and compared with the LER acceptances. The crab waist scheme with crab sextuples on ensures that the beam will damp down to the equilibrium emittance without an initial emittance blow up due to beam-beam effect [2].

TAU-CHARM FACTORY INJECTION SYSTEM

Tau-Charm injection system delivers continuously low emittance beams to the main rings at a maximum energy of

Table 2: Size of the horizontal invariant and offset values, for deviations of the injection energy from the reference value. The offset values of the injected bunch are referred to the unperturbed stored orbit and ensure that losses at septum are $< 1.3\,\%$. The invariant value represent the aperture required to collect 99.7% of injected particles

Energy Offset	Offset Value	Invariant 99.7%
5 ‰	34.1 mm	$34.3\ \sigma_x^{sto}$
3 ‰	29.5 mm	$23.9\ \sigma_x^{sto}$
1 ‰	28.4 mm	$19.1\ \sigma_x^{sto}$
0 ‰	27.5 mm	$17.8\ \sigma_x^{sto}$
−1 ‰	28.4 mm	$19.6\ \sigma_x^{sto}$
−3 ‰	31.4 mm	$23.0\ \sigma_x^{sto}$
−5 ‰	35.6 mm	$27.5\ \sigma_x^{sto}$

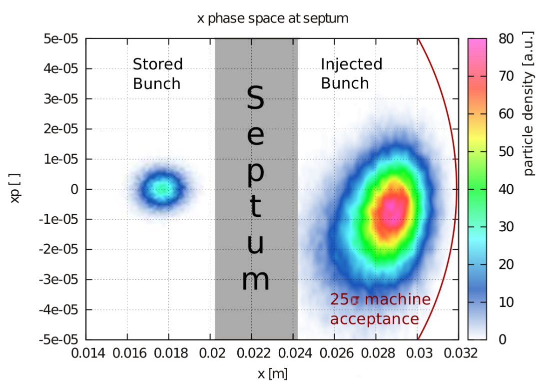

Figure 4: Injected and stored x-phase space of the bunches at septum. The energy error is +3 ‰ with respect to the reference.

2.3 GeV in order to keep nearly constant beam current and luminosity. The layout is based on the design of the SuperB injection system. It is foresee to use the same design for the linac and damping ring, reducing the number of elements in the main linac according to the lower energy.

The main difference with respect to the SuperB design is that the damping ring will collect only positrons. The electrons are accelerated through Linacs L1, L2, L3 up to 2.3 GeV and then transported to the Electron Ring with a transfer line. A pulsed magnet is used to bypass the positron source. For positron production the electrons are accelerated up to 0.6 GeV in Linac L1 and focused on a tungsten target. After the converter, the positrons are collected, accelerated up to 1.0 GeV in Linac L2 and stored in the damping ring for 30 ms, corresponding to ~ 4 damping times. The three linacs are operated at a repetition frequency of 100 Hz. The injection repetition cycle is 40 ms for each beam, corresponding to 25 Hz. The timing scheme allows to accelerate two beam pulses for an FEL facility during the store time of the positrons in the DR, without affecting the injection rate for the Tau-Charm.

Even for the Tau-Charm a bunch compressor will be placed at the DR exit. The optimization performed for SuperB will be repeated to find the best parameters at the lower energy.

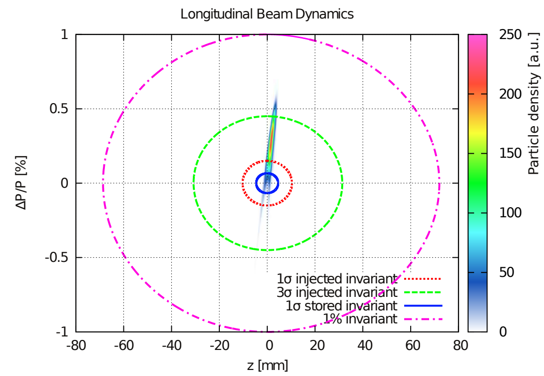

Figure 5: Longitudinal phase space of the injected bunch at septum with a 3 ‰ energy deviation transported in the presented transfer line. The ellipses represent (from inner to outer) the size of the stored bunch, 1σ and 3σs invariants of the bunch injected at reference energy and the 1% acceptance of the ring design.

CONCLUSIONS AND OUTLOOK

The details of the beam dynamics in the SuperB injector have been investigated. The tracking of the electron beam from the Damping Ring to the injection cell of the LER proved that the current parameters of the machine allow to satisfy the injection requirements necessary for the high luminosity. The design of the transfer line from linac to LER requires a final energy error smaller than ± 3 ‰.

The same design principles used for the SuperB injection system have been applied to the Tau-Charm and the beam dynamics studies can easily be adapted to a lower energy.

REFERENCES

[1] M. E. Biagini, P. Raimondi, and J. Seeman *eds.* "SuperB Progress Report - Accelerator" INFN - Laboratori Nazionali di Frascati, December 2010. url: http://arxiv.org/abs/1009.6178v3.

[2] S. Guiducci *et al.* "Baseline design of the SuperB factory injection system" In: Proceedings of IPAC2012. New Orleans, USA, 2012.

[3] M. Borland. "elegant: A Flexible SDDS-Compliant Code for Accelerator Simulation" In: Advanced Photon Source LS 287, 2000.

[4] Ya. S. Derbenev, J. Rossbach, E. L. Saldin and V. D. Shiltsev "Microbunch Radiated Tail-Head Interaction" In: Tesla FEL Report 5 (1995).

[5] D. Pellegrini "Beam Dynamics studies and optimization of the SuperB injection system" Master Thesis Universitá degli Studi di Padova and INFN-LNF, 2012.

[6] D. Pellegrini and S. Guiducci "Beam dynamics studies and design of the LINAC-LER transfer line for the electron Injector of SuperB" Technical note INFN-12-24/LNF, 2012.

ISBN 978-3-95450-122-9