Beam Transport Lines at BESSY-II*

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Abstract

The injection system for the BESSY-II storage ring consists of a 50 MeV microtron and a synchrotron booster which ramps the electron beam to the final operation energy of max. 1.9 GeV. The requirements to be met by the transfer lines from the microtron to the booster and from the booster to the storage ring are discussed and the respective magnetic structures are presented. A "genetic" fitting algorithm to optimize the quadrupole settings in the transfer lines is briefly discussed.

I. Introduction

The electron beam from a 100 keV diode gun is preaccelerated up to 50 MeV by a conventional racetrack microtron and is injected on-axis into the booster synchrotron using a "fast" kicker in combination with a horizontal septum magnet (393 mrad). At full energy (E_{max}=1.9 GeV) three bumper magnets push the closed orbit close to the extraction septum (196 mrad) and a "fast" kicker (1.8 mrad) extract the beam. Injection into the storage ring is done using two septa with a total deflecting angle of 133 mrad. The storage ring comprises alternating low-beta ($\beta_{x,z}$ ~1 m) and high-beta (β_x ~17 m) straight sections. Four kicker magnets in a high-beta straight section produce the required horizontal closed orbit shift of 17 mm towards the septa [1]. To ensure good transmission and high injection efficiency, several design constraints have to be fulfilled by both transport lines. Apart from geometrical aspects and beam optics requirements, limitations in the possible strength and length of the optical elements must be taken into account.

II. Injection Line (Microtron → Booster)

The injection line geometry has to fit within the given radiation protection walls and must leave sufficient space for access as well as for the diagnostic equipment and the high voltage gun environment. A top view of the proposed magnetic structure which meets these demands, is shown in figure 1.

There is an achromatic structure just after the microtron. Keeping the dispersion low allows to decouple lattice functions and dispersion in the following triplet telescope. The matching section consists of 8 independent quadrupoles to fit 6 optical parameters. The large number of quadrupoles guarantee a high degree of flexibility in matching a wide range of possible starting values from the microtron. The linear lattice functions are plotted in figure 2. The maximum beta functions in both planes are less than 20 m which corresponds to a envelope of $1\sigma \leq 3.7$mm, keeping the magnet apertures small. The main parameters are listed in table I.

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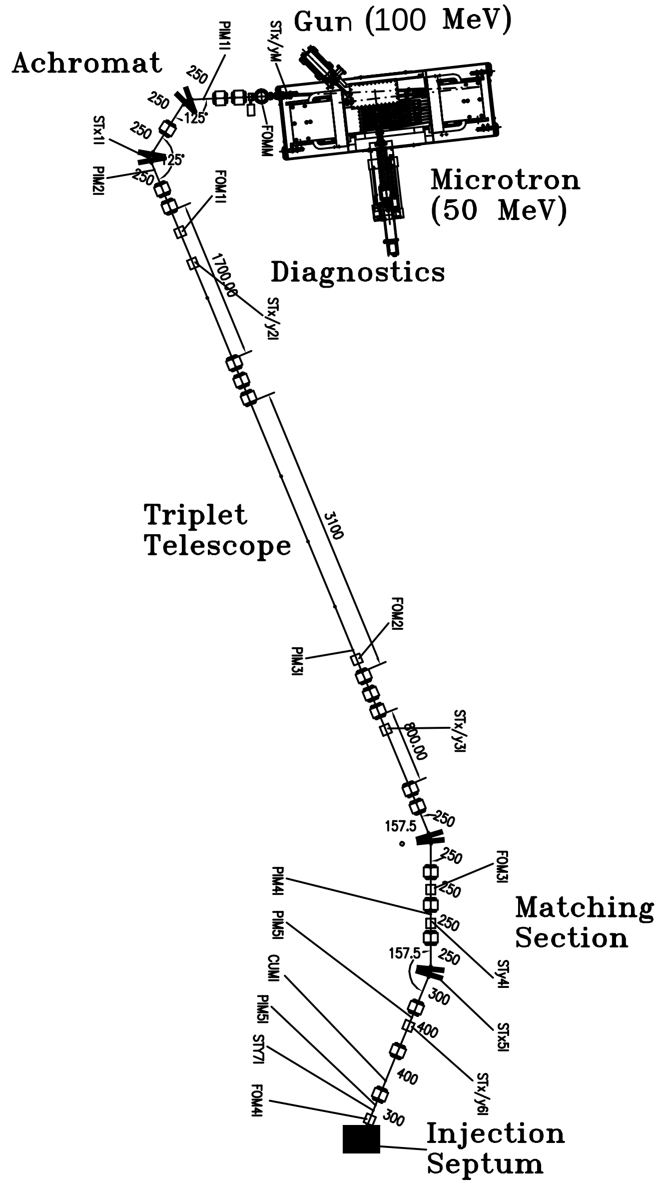

Figure. 1. Lattice and diagnostics of the injection line.

III. Transfer Line (Booster → Storage Ring)

In addition to the optical matching conditions the following requirements for the full energy transport line have to be met.

- The deflecting angles of the booster extraction system and the storage ring injection system are fixed.
- The transfer line must be partly parallel to an underground tunnel which may be used to provide a test beam for detector studies ('Zeuthen-Tunnel').

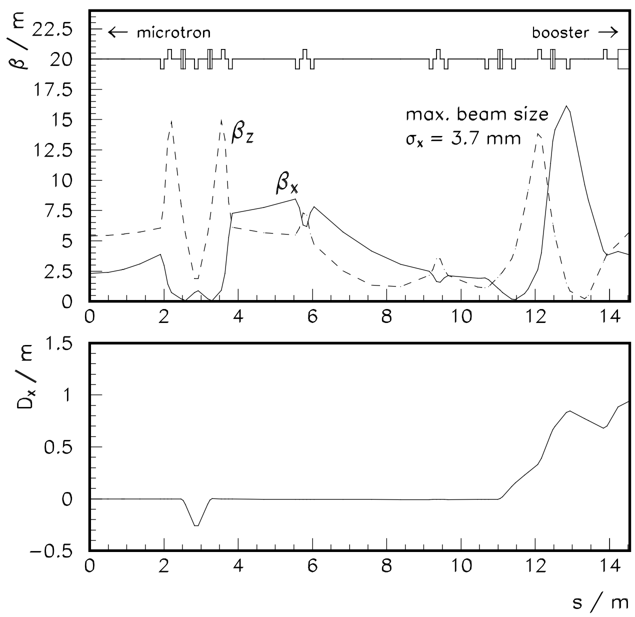

Figure. 2. Optical functions of the injection line.

Max. energy	50 MeV	
Total length	14.54 m	
No. quads/families	16/14 (aperture: Ø=25 mm)	
No. sector dipoles	4 ($2 \times 22.5°$, $2 \times 55°$)	
Max. quad strength	g $\leq$ 10 T/m	
Vacuum chamber Ø	25 mm	
Max. beam size	$\sigma_x \simeq 3.7$ mm	
Optical functions	Microtron exit	Injection into Booster
β_x	2.3 m	3.84 m
α_x	0	1.44
β_z	5.4 m	5.72 m
α_z	0	-1.7
D_x	0	0.94 m
D'_x	0	-0.26
$\varepsilon_{x,z}$ @50MeV	$5 \cdot 10^{-7}$radm	$2 \cdot 10^{-7}$radm
$\Delta E/E$ @50MeV	$\pm 2 \cdot 10^{-3}$	$\pm 2 \cdot 10^{-3}$

Table I
Main parameters of the injection line.

- Sufficient space for optional quadrupoles and an additional vertical dipole magnet to bend the electron beam into the 'Zeuthen–Tunnel' must be provided.

Figure 3 shows the geometrical layout of the proposed transfer line. The beam line consists of three quadrupole triplets separated by two identical rectangular dipoles with a deflecting angle of 384 mrad each. A quadrupole doublet in front of and one singlet behind the radiation protection wall in combination with a vertical dipole are assigned to the test beam optics.

Figure 4 depicts the optical functions of the transfer line. The first quadrupole triplet keeps the beta functions below 40 m according to a maximum beam size of $\sigma_x \leq 3.5$ mm. The last two triplet structures form the matching section. Matching a wide range of Twiss parameter values is possible for different starting

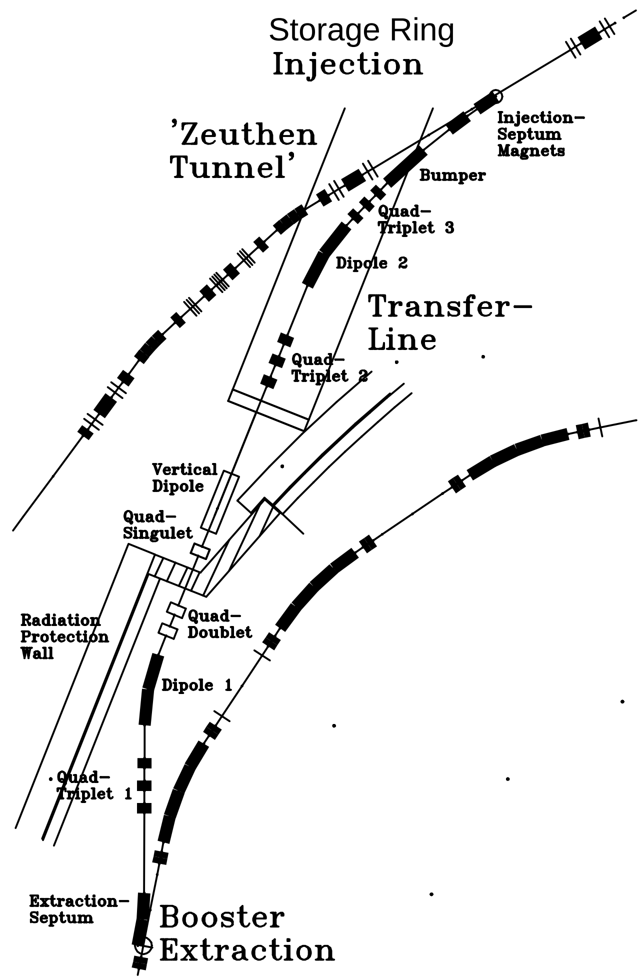

Figure. 3. Layout of the transfer line (top view).

parameters from the booster synchrotron and momentum deviation of the order of 1%. The main parameters of the transfer line are summarized in table II.

IV. Optimizations with "Genetic" Algorithms

Designing a transfer line is a typical optimization problem. Once the gross features are clear, the fine tuning is usually done using a fitting algorithm, which minimizes a target function (e.g. the difference between the desired optical functions and those actually found). If this function depends on many parameters (e.g. strengths of quads), the fitting algorithm may not converge or may get caught in a local minimum far away from the best solution.

"Genetic" algorithms are as simple as efficient [2]. They are able to escape local minima and find the best solution to very complex problems. Genetic algorithms are essentially a specialization of Monte Carlo optimization techniques. Instead of one random walker in the parameter space, there is a whole *population* of them. Each *individual* i represents a set of n parameters which determine the target function $f(p_1^i, \ldots, p_n^i)$ to be minimized.

After each step, a certain number *fittest* individuals (those yielding the lowest f) is selected. The less fortunate individuals are rejected and displaced by new parameters sets (*descendants*)

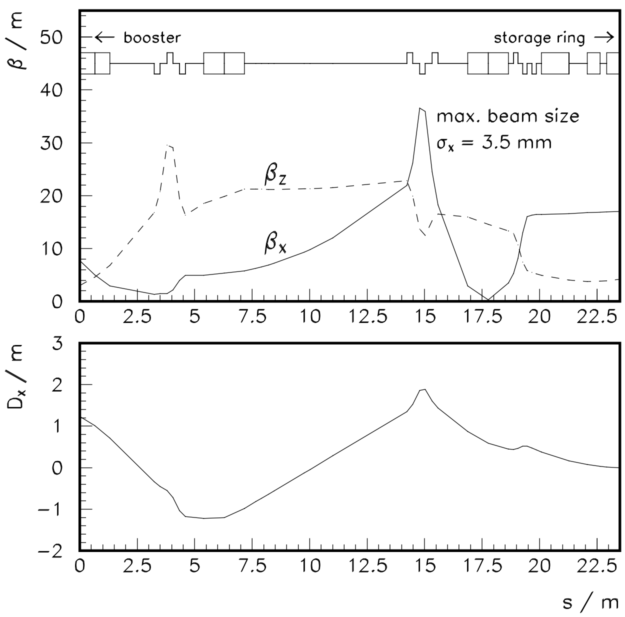

Figure. 4. Optics of the transfer line.

Max. energy	1.9 GeV	
Total length	23.48 m	
No. quads/families	9/9 (aperture: Ø=30 mm)	
No. dipoles	3 ($2 \times 22^{\circ}$, $1 \times 7.66^{\circ}$)	
Max. quad strength	$g \leq 30$ T/m	
Vacuum chamber Ø	30 mm	
Max. beam size	$\sigma_x \simeq 3.5$ mm	
Optical functions	Booster Extraction	Storage Ring Injection
β_x	7.72 m	17.03 m
α_x	2.26	-0.04
β_z	2.99 m	4.16 m
α_z	-1.02	-0.32
D_x	1.23 m	0
D'_x	-0.26	0
ε_x @1.9GeV	$1.7 \cdot 10^{-7}$radm	$6.5 \cdot 10^{-9}$radm
$\Delta E/E$ @1.9GeV	$\pm 6.1 \cdot 10^{-4}$	$\pm 7.8 \cdot 10^{-4}$

Table II
Main parameters of the full energy transfer line.

which are a random step away from the selected ones (*parents*). The function is evaluated with the new parameters and the process repeats itself.

Genetic algorithms may vary in the way, a random step (a *mutation*) is done. Generally, random steps should lead in any direction and should be small to allow for fine tuning, but sometimes large to find a complete new solution.

This strategy has been applied to both the injection line and the transfer line. Given their geometrical position, the strengths of all quadrupoles was fitted without starting anywhere near the solution (in the case of the injection line, the quads in the achromat region were kept fixed, but the task of varying more than ten parameters to fit six optical functions is nevertheless formidable).

If the problem has more than one solution, the algorithm may end up with quite different individuals. As an example, different solutions for the injection line are shown in figure 5. Apart from the fact that the human-aided design (figure 2) is aesthetically more appealing, the random strategy was able to find satisfactory solutions and may be applicable to other problems in accelerator physics.

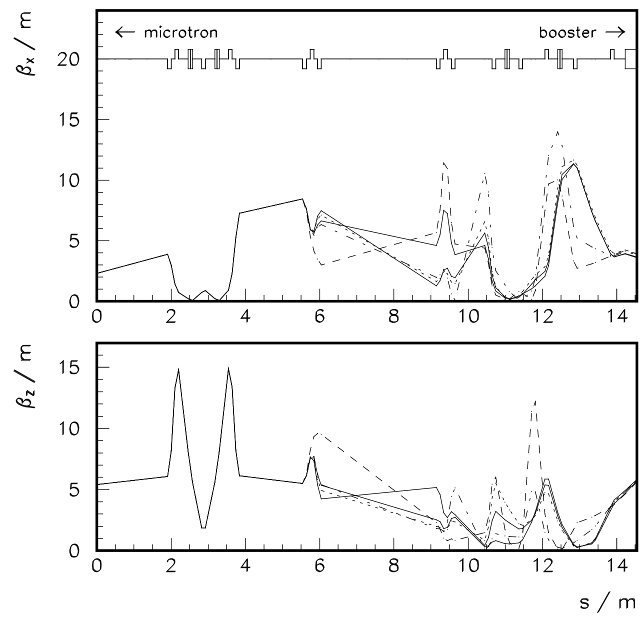

Figure. 5. Injection line optics generated by ”Genetic” algorithms.

References

[1] Ch. Geyer, D. Krämer, *Injection and Extraction of the BESSY II Booster and Storage Ring*, Proceedings of 1994 IEEE Particle Accelerator Conference, London

[2] D. E. Goldberg, *Genetic Algorithms in Search, Optimization and Machine Learning*, Addison–Wesley, Reading, MA, 1989