DESIGN OF THE TRANSFER LINE-2 FOR THE CTF-3 AT CERN

Amalendu Sharma, Abdurrahim, A.D. Ghodke, Gurnam Singh
IOAPDD, Raja Ramanna Centre for Advanced Technology, Indore (M.P.)

Abstract

The design of the Transfer Line-2 (TL-2), which will transfer an electron beam from the Combiner Ring (CR) to CLEX area (CLIC experimental area) of CTF-3 (CLIC Test Facility-3) at CERN, is presented in this paper. This line will be used to control the bunch length and Twiss parameters at the entrance to the CLEX area. The line will have a wide tunability of R_{56} parameter, ranging from –0.35m to +0.35m. This has been designed considering the constraints imposed by the building geometry and the magnetic elements to be used. The design optimization of the line has been done up to second order for the entire R_{56} range, keeping T_{566} practically zero and emittance dilution below 10%.

INTRODUCTION

CLIC (Compact Linear Collider) at CERN is based on the new scheme of RF generation at 30 GHz. The RF generation scheme is based on the frequency multiplication and bunch compression of the drive beam. The CTF-3 is to demonstrate the feasibility of such a scheme to provide the 30 GHz RF power source with CLIC nominal peak power and pulse length. The electron beam at nominal energy of 150 MeV after frequency multiplication will be extracted from the Combiner Ring (CR) and it will be transported to CLEX area with required bunch length compression by the TL-2. The general description and layout of the CLIC and CTF-3 can be found in references [1, 2, and 3]. Here in RRCAT, we have carried out the optics design of the TL-2, with required tuning range to handle the bunch length control before delivering the beam in CLEX area. In this paper we have provided the basic theory of bunch length control in the magnetic optics and design of TL-2.

BUNCH LENGTH COMPRESSION

Bunch length compression is possible by establishing the energy time correlation in the bunch by a RF field and then passing it through the magnetic channel to establish the required length energy correlation [4]. When bunch passes through the RF field, the energy time correlation is given by

$$z_1 = z_0 \quad (1)$$

$$\delta_1 = \left(1 - \frac{qV_{RF}}{E_0}\sin\phi_s\right)\delta_0 + \left(\frac{qV_{RF}}{E_0}\cos\phi_s\right)kz_0 \quad (2)$$

Here z gives the longitudinal position of the particle with respect to reference (synchronous) particle. V_{RF}, q, δ and ϕ_s carry their usual meanings. Subscripts 0 and 1 are used for entrance and exit of the cavity. In the approximation used here, it is assumed that cavity has zero length and thus z does not change. The equation 2 can be written as

$$\delta_1 = R_{65}z_0 + R_{66}\delta_0 \quad (3)$$

Here R_{ij} is the element of 6x6 first order transfer matrix. After that the particle passes through the magnetic channel, which has opposite effect of the cavity, i.e. the δ remains unchanged and z is modified. For a magnetic channel, the first order relations can be written down as

$$z_2 = z_1 + R_{56}\delta_1 \quad (4)$$

$$\delta_2 = \delta_1 \quad (5)$$

Z_2 and δ_2 are the longitudinal position and momentum deviation after the magnetic channel. Here R_{56} depends on the dispersion distribution inside the dipole magnets of the magnetic channel. It is given by (in sign convention of MAD-8 [5])

$$R_{56} = -\int \frac{\eta ds}{\rho} \quad (6)$$

Therefore by controlling the dispersion distribution inside the dipole magnets, R_{56} parameter can be controlled and by selecting the proper values of R_{65}, R_{66} and R_{56}, the required bunch length compression can be obtained. Introducing second order terms in the analysis, the equation 4 will be modified as

$$z_2 = z_1 + R_{56}\delta + T_{566}\delta^2 \quad (7)$$

Here T_{ijk}- is the element of the second order transfer matrix. In the present paper we outline the design of the TL-2, which has a wide tuning range of the R_{56} parameter to control the bunch length and in whole tuning range second order term T_{566} is compensated.

OPTICS DESIGN OF THE TL-2

General Layout

The beam parameters of TL-2 are provided in the table-1. The line is to be accommodated in the existing LPI-complex (LEP Pre Injector complex), which has several geometrical constraints and the magnets to be used here to be selected from a stock of already magnets available at CERN. These constraints poses a challenge in the design of the line with such wide tuning range of R_{56} parameter (from -0.35m to +0.35m) with T_{566} corrected to zero and emittance dilution below 10%. The layout of the complete line inside the building is shown in the figure-1. Parameters and numbers of the available magnets are shown in the table-2.

The design of the line can be broken in three modules. Following sections describe the details of each module of this line.

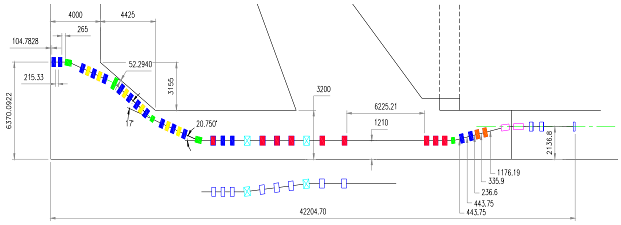


Figure 1: Layout of TL-2

Table 1: Beam parameters of the TL-2

Parameters	@ entrance	@ Exit
Nominal energy (MeV)	150	150
Peak energy (MeV)	300	300
β_x, β_y (m)	8.1, 3.5	4-5, 4-5
α_x, α_y	0.12, 0.31	0.0, 0.0
η_x (m), η'_x	0.0, 0.0	0.0, 0.0
η_y (m), η'_y	0.0, 0.0	0.0, 0.0
ε_x normalized (mm-mrad)	100	110
ε_y normalized (mm-mrad)	100	110
δ in %	1.0	1.0
σ_z (ps)	8.3	1.3

Table 2: Parameters of the available magnets

	Dipole Type-1	Dipole Type-2	Stnd. Quad	Slim Quad	TSL Quad	Sextupole
Mech. length (m)	0.770	0.520	0.592	0.384	0.430	0.350
Mech. width (m)	0.794	0.794	0.819	0.340	0.650	0.420
Effective length (m)	0.518	0.268	0.380	0.300	0.295	0.246
Aperture (mm)	100´45	100´45	184	100	101	167
Strength	1.3 T	1.3 T	5.4 T/m	8 T/m	10.6 T/m	44 T/m2
Number	02	03	26	02	16	12

Module-1

Module-1 of this line is from the extraction septa of the CR to first horizontal dipole magnet. This is an achromat. The septa and the dipole magnet bend the beam in opposite direction and therefore this achromat has an phase advance of 2π in the horizontal plane. The design of this module is governed mainly by the constraints, imposed by the building and the sections of CR in the vicinity of the extraction point. Due to this, the locations for placing the quadrupoles are restricted and all the quadrupoles being operated close to their highest strength result in a rapid rise of β-functions at the exit of this module. All these restrictions lead to a very low flexibility in this module.

Module-2

Module-2 fulfils various requirements of the transfer line. It controls large β-functions, resulting from the module-1 and provides a 6m long dispersion free region for tail clippers. It has a vertical achromat to send the beam 50cm down wards as the LPI-complex and CLEX area have different floor levels. Besides it has a quadrupole triplet for obtaining required Twiss parameters at the entrance of the module-3.

Module-3

Module-3 is the tunable R_{56} arc and a quadrupole doublet for matching the Twiss parameters at the end of the line. The design of this module also is restricted by the existing building geometry. The tunable R_{56} arc of this module has been designed with four dipole magnets and two quadrupole doublets and two quadrupole triplets. The first and last dipole magnets of ±20.75° bend angle form the entrance and exit of this achromatic arc, hence the contribution of these magnets in R_{56} is constant. The other two-dipole magnets, of ±17° bend angle, are used to tune the R_{56} parameter. For tuning the R_{56} in the arc, the quadrupole strength goes very high and thus higher order chromatic terms have larger magnitudes, which require strong sextupoles to compensate them. Therefore the arc has been designed with mirror symmetry to lower down the higher order geometrical aberrations as well as to reduce the number of the power supplies. For obtaining a particular value of R_{56} parameter, dispersion and its derivative at the entrance of the second dipole magnet of the arc are chosen in such a way, so that the dispersion becomes sufficient at the sextupole locations to lower down their strength for correcting the T_{566} parameter. The optimization of this line is done with MAD-8 program, which requires a good starting guess value for solution. To obtain a good starting guess values for the solution, a computer program in C has been written assuming quadrupoles as thin lenses [6]. The lattice function and dispersion at the three extreme values of R_{56} (-0.35m, 0.00 and +0.35m) are shown in the figure-2.

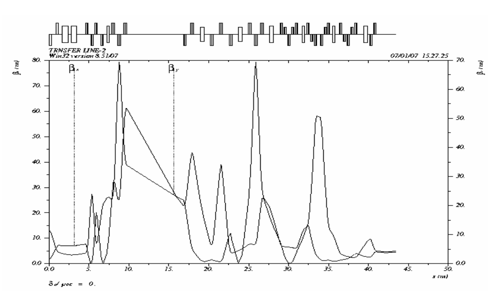


Figure 2a: Lattice function for R_{56} = -0.35m

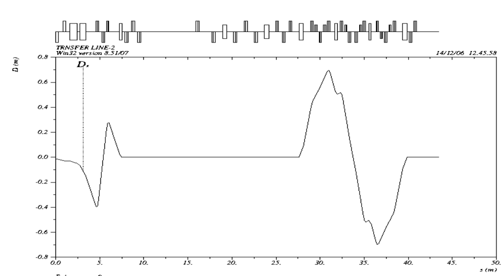


Figure 2b: Dispersion function for R_{56} = -0.35m

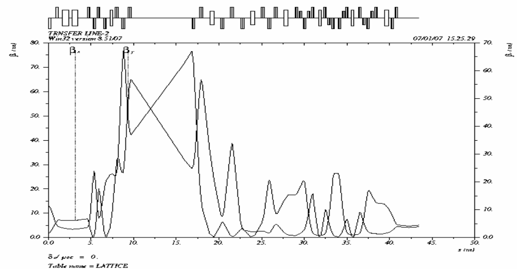


Figure 2c: Lattice functions for R_{56} = 0.00m

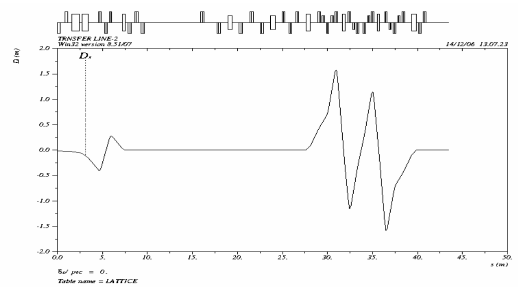


Figure 2d: Dispersion function for R_{56} = 0.00m

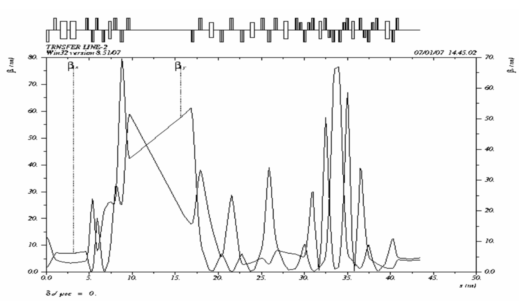


Figure 2e: Lattice functions for R_{56} = +0.35m

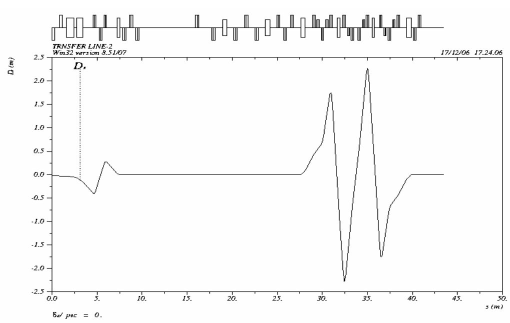
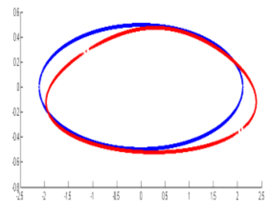
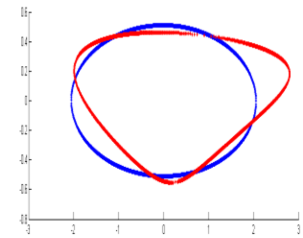


Figure 2f: Dispersion function for R_{56} = +0.35m

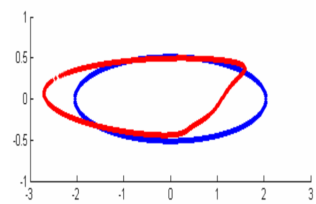
For correction of the T_{566} parameter, the six sextupoles, driven by three power supplies are incorporated in the tunable R_{56} arc of the module-3. The complete symmetric optical solution with I-transformer between the sextupoles is not possible in whole tuning range due to matching requirements at the exit. The line has only two quadrupoles at the end for matching the Twiss parameters. Thus for minimizing the phase space distortion due to sextupoles, a distribution of β-functions at the location of the sextupoles with proper phase advance is obtained, so that the sextupolar kicks cancels partially. This distribution is achieved by suitable choice of Twiss parameters at the entrance of the module-3. In this way we are able to improve the situation at R_{56} = 0.00 and -0.35m. The work at other extreme of R_{56} and also improvement in the solutions achieved are in progress. Figure-3 shows the phase space distortion due to sextupoles at the R_{56} = 0.00 and -0.35m.



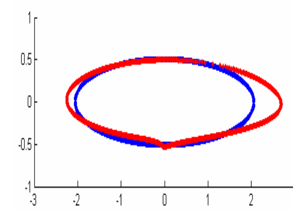
X-Plane at R_{56} = -0.35m



Y-Plane at R_{56} = -0.35m



X-Plane at R_{56} = 0.00m



Y-Plane at R_{56} = 0.00m

Figure 3: Phase space distortion due to T_{566} correction.

CONCLUSION

Transfer line-2 from the CR extraction point to CLEX area has been designed to achieve with R_{56} varying from -0.35m to +0.35m with constraints due to building layout and choice of magnets. The sextupole scheme is under study.

ACKNOLEDGEMENT

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