T.3: Optics Design of a Bunch Compressor Transfer Line for CLIC Test Facility at CERN

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1. Introduction

Several of the recent accelerator projects employ electron bunch compressors at one or another stage. These accelerator projects are related to future electron positron colliders, free electron lasers (FELs), or generation of very high frequency RF power for two beam accelerators. The interest in very short electron bunches for these projects is driven mainly by the desire to obtain high luminosity in colliders, high peak intensity of the emitted radiation in FELs, and to get a very high conversion efficiency from electron beam power to the RF power in two beam accelerator concept. Therefore, in the last one or two decades, design and optimization of electron bunch compressors have become an active area of research in beam dynamics.

CLIC (Compact LInear Collider) project at CERN is an upcoming electron positron collider in the TeV energy range [1]. This collider will be based on high gradient linear accelerator operating at high RF frequency. Here, high RF frequency will be generated using an another electron beam known as "drive beam". To demonstrate this scheme of acceleration, CTF (CLIC Test Facility) has been developed at CERN [2]. Under the DAE-CERN collaboration, RRCAT participated in the beam optics design for a bunch compressor transfer line (known as Transfer Line-2) for this test facility (CTF3) [3]. In this article, basics of bunch compression scheme are discussed in the next section. In Section 3, a brief overview of CTF and CLIC is provided, and subsequent sections deal with the optics design and optimization of Transfer Line-2 (TL-2) of this test facility.

2. Bunch compression

2.1 Basic Scheme

Electron bunch length can be compressed using the concept of path length dependence of an electron on its momentum in a magnetic optics. In accelerator facilities such as mentioned in the above section, generally the electron beam has a very high energy, i.e., the electron beam is an ultra-relativistic beam. In this ultra-relativistic domain, change in energy practically does not change the velocity of an electron, and all the electrons in a bunch travel with almost same velocity. Due to this phenomenon, travel time of an electron almost depends only on the covered path length. If an electron, which is leading the bunch centre travels a longer path than the bunch centre, and electron which is lagging behind the bunch centre follows a shorter path, then electrons in this bunch come closer to each other and bunch length is reduced. When an electron bunch traverses through a dipole magnet, the trajectories of different electrons become different according to their momentum. It is shown in Fig. T.3.1. The deviation in trajectory from the design path due to fractional momentum offset is known as 'dispersion', i.e. $D=\Delta x/\delta$, where D is the dispersion, Δx is the deviation in trajectory of an electron from the design path and δ shows the fractional change in momentum $(\Delta p/p)$ of an electron from the design value. The different path lengths for different electrons, which have momentum spread can be generated by introducing dispersion in the magnetic optics. But this optics will be able to compress the bunch length only if electron bunch has a correlated momentum spread, i.e., in a bunch, all the electrons having higher momentum than the design momentum are either in a leading position from the bunch centre or are lagging behind the bunch centre. Reverse is true for all the electrons having lower momentum than the design value. Also, the farther the electron is from the bunch centre, its momentum deviation from the design value should increase. Therefore, electron bunch compression is a two step process [4], first is the generation of the desired correlation between the position and momentum, and then the second step is the utilization of this correlation to compress the bunch length by passing this bunch through an optics (beam transfer line) where a correlation between path length and momentum can be generated.

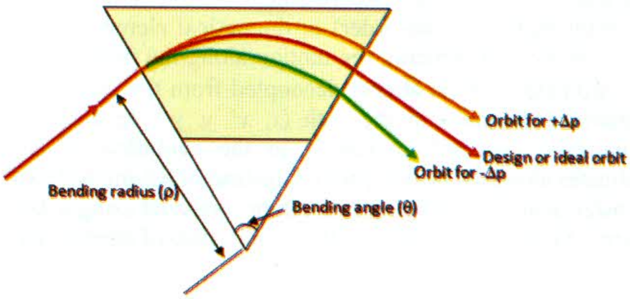

Fig. T.3.1 Deviation in trajectories inside a dipole magnet due to different momentum of electrons

In accelerator physics, the state of an electron (i.e. its co-ordinates and momentum) is defined by taking the reference point as the position and momentum of a desired design particle (also known as synchronous particle). This synchronous particle has certain momentum (energy) and traces a certain curve due to its course of motion. This energy is the design energy (central energy) of the accelerator or beam transport system and the traced curve is the design path (or orbit). The desired design path is generated by carefully optimized magnetic field distribution along the direction of motion using different dipole magnets. The state of an electron has six co-ordinates, in which two co-ordinates describe the instantaneous horizontal and vertical displacements (*x, y*) of the electron with respect to this design path. Two co-ordinates show the instantaneous angles (*x', y'*) made by the trajectory of the electron with respect to the design path in horizontal and vertical direction, respectively. One of the co-ordinates gives the distance (or arrival time difference) along the design path with respect to the instantaneous position (or time) of the synchronous particle (*z* or *t* or *ct*). This is also called as a longitudinal position (design path is in general shown using symbol *s*). The sixth co-ordinate ($\Delta p/p$) is the deviation in momentum relative to the momentum of the synchronous particle (denoted by symbol δ). To keep the electron bunch confined around the design path, focusing action is required. This is achieved by a suitable arrangement of quadrupole magnets along the design path. To manipulate the energy of an electron, electric field generated in an RF cavity is used. When an electron with certain initial co-ordinates (x, x', y, y', z, δ), passes through an optical element, its co-ordinates get modified or changed. The map between these coordinates at the exit of an element to the entry of the element in linear dynamics can be represented using transfer matrix of the element. This can be written as

$$\widetilde{\boldsymbol{X}}_{exit} = \widetilde{\mathbf{R}}\widetilde{\boldsymbol{X}}_{entrance} \quad [1]$$

Here $\widetilde{\boldsymbol{X}}$ is the column vector of all the six co-ordinates. Subscripts refer to the location of co-ordinates i.e. at the entrance and exit of the optical element. Matrix $\widetilde{\mathbf{R}}$ is the map (transfer matrix of 6x6 order) of the optical element under consideration. In general, the motion along the design path (co-ordinates z, δ) is almost decoupled from the motion in transverse direction to the path (x, x', y, y'). In a bunch compressor, general interest is in the evolution of co-ordinates along the design path i.e. instead of having full 6x6 transfer matrix, initially motion can be analyzed using a 2x2 matrix. So most of the time, in this article, map of interest will be

$$\begin{bmatrix} z \\ \delta \end{bmatrix}_{exit} = \begin{bmatrix} R_{55} & R_{56} \\ R_{65} & R_{66} \end{bmatrix} \begin{bmatrix} z \\ \delta \end{bmatrix}_{entrance} \quad [2]$$

Here *R* is used to show the elements of the transfer matrix. Map of a complete optics can be obtained by successive matrix multiplication of all the transfer matrices of individual elements.

In a bunch compressor, the first step, i.e. generation a correlation between momentum and position of an electron is carried out by an RF field. Synchronous particle is kept at the zero phase of RF field. The particles, which are at positive phase will get positive momentum deviation, and electrons which are at negative phase of RF will get negative momentum deviation. Under the thin element approximation, the longitudinal position (*z*) of the electron does not change while traversing through the cavity. However, the momentum changes according to phase at which electron arrives in the cavity, i.e., according to z and RF peak voltage. Thus for a cavity, R_{55} is one and R_{56} is zero, R_{65} and R_{66} depend on voltage and synchronous phase. The matrix for a cavity with the explicit expression of its all the four elements is given below:

$$\widetilde{\mathbf{R}}_{cavity} = \begin{bmatrix} 1 & 0 \\ -\frac{qVk_{RF}}{E_s}cos\phi_s & 1-\frac{qV}{E_s}sin\phi_s \end{bmatrix} \quad [3]$$

Here, q is the charge on electron, V is the peak RF voltage, ϕ_s is the synchronous phase, E_s the energy of synchronous particle (design energy) at the entrance of RF cavity, and k_{RF} is the magnitude of RF wave vector. Zero or π synchronous phase gives $R_{65}=qVk_{RF}/E_s$, and $R_{66}=1$. In this case, the central energy of the bunch remains unchanged. The distribution of electrons in a bunch in the space spanned by RF phase ϕ and momentum deviation δ (known as longitudinal phase space) is shown in Fig. T.3.2 for uncorrelated as well as correlated cases.

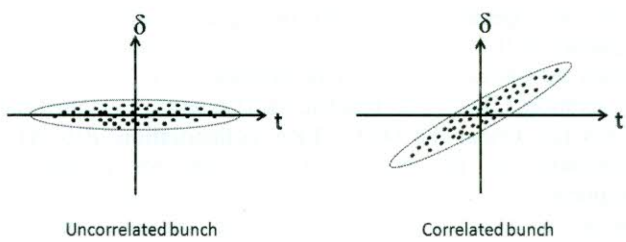

Fig. T.3.2 Electron distribution within an uncorrelated and correlated bunch in longitudinal phase plane

Introduction of the dispersion in an optics generates different trajectories for electrons with different momentum. Due to different trajectories, the path lengths also become different. This path length can be written down using geometrical relations as following (under linear approximations)

$$R_{56} = \frac{\Delta L}{\delta} = \int \frac{Dds}{\rho} \quad [4]$$

Here *p* is the radius of curvature of the design path, produced by the dipole magnet and ΔL is the difference in path lengths between the design path and path of an off-momentum electron. Integration is along the design path inside the dipole magnets. Therefore, similar to RF cavity, the map for a dipole magnet can also be written down as

$$\widetilde{\mathbf{R}}_{dipole} = \begin{bmatrix} 1 & R_{56} \\ 0 & 1 \end{bmatrix} \quad [5]$$

In optics, the dispersion is generated using a dipole magnet. Hence, the main contribution to the path length dependence on momentum comes from the dipole magnet. Due to various requirements in optics, in general, in all the applications of a bunch compressor, the downstream path from the compressor should not depend on the momentum, i.e., downstream to bunch compressor, dispersion should vanish (this type of optics in accelerator jargon is known as *'achromat'*). Therefore any bunch compressor optics in general has at least two dipole magnets.

Overall bunch compression in a bunch compressor can be obtained, using transfer matrices for both the steps, i.e., using Eq. 3 and 4.

$$\begin{bmatrix} z \\ \delta \end{bmatrix}_{exit} = \begin{bmatrix} 1 + R_{56}R_{65} & R_{56}R_{66} \\ R_{65} & R_{66} \end{bmatrix} \begin{bmatrix} z \\ \delta \end{bmatrix}_{entrance} \quad [6]$$

Here, the subscripts 'exit' and 'entrance' refer to the bunch compressor entrance and exit, rather than a single element. Above expression tells about the particular electron in a bunch by considering its position and momentum deviation with respect to the synchronous position and momentum. For complete bunch, considering distribution in position and momentum, the final bunch length is given by

$$\sigma_{exit} = \sqrt{(1 + R_{56}R_{65})^2 \sigma_{entrance}^2 + R_{56}^2 \delta_{entrance}^2} \quad [7]$$

Here, σ is the bunch length and δ is the standard deviation of the distribution in momentum offset. This expression shows that the minimum bunch length can be obtained when $R_{56}=-1/R_{65}$. The minimum bunch length is given by $\sigma_{exit,min} = |R_{56}\delta_{min}|$. It seems that very small value of R_{56} can lead to a very short bunch length. But the smaller value of R_{56} demands a larger value of R_{65} (in magnitude) and therefore, the momentum spread of the bunch becomes larger. Larger momentum spread can lead to beam losses during beam transfer in the line, and also it leads to a significant contribution from the higher order terms in the beam dynamics. Therefore, selection of values for R_{56} and R_{65} should be done carefully.

2.2 General optics for bunch compressors

For a fixed value of R_{56}, in general two types of optics are in use for bunch compressors. One is chicane optics, in which four dipole magnets are arranged in a way to have the exit beam on the same axis as of the incoming beam (Fig. T.3.3) [5] and second is the dog-leg optics (Fig. T.3.4) [6], in which there is a lateral shift in the beam after the compressor.

In chicane optics, there is no quadrupole magnet. On the other hand, in the case of a dog-leg optics, there are only two dipole magnets. Satisfying the achromatic condition in both the optics gives a fixed value of R_{56}, and therefore tuning in the optics for different bunch length compression is not possible. The value of R_{56} in a chicane optics and in a dog-leg optics is given by Eq. 8 and 9, respectively, given below

$$R_{56} \approx -2\theta^2 \left(L_{12} + \frac{2}{3} L_{bm} \right) \quad [8]$$

$$R_{56} \approx \frac{L_{bm}}{3} \theta^2 \quad [9]$$

The parameters used in these equations are shown in Figs. T.3.3 and T.3.4. For getting larger value of R_{56}, wiggler based optics is also used [5]. For making the optics with ability to tune the R_{56}, S-arc optics and chicane optics with inclusion of quadrupole magnets may be the possible configurations, while fulfilling the achromatic condition. In these optics, quadrupole magnets can be used to shape the dispersion function inside the dipole magnets, which are in the middle of the optics, while dispersion in first and last dipole magnet can be matched to meet the achromatic condition. For TL-2, the optics design is based on S-arc configuration.

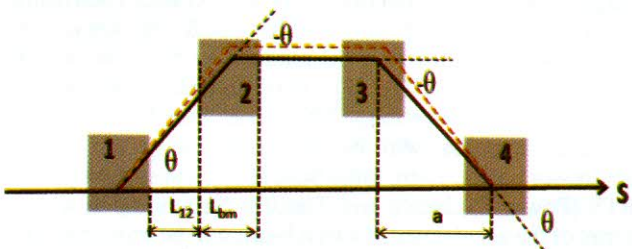

Fig. T.3.3 Chicane optics using fur dipole magnets (black curve shows the design trajectory and dotted curve shows the trajectory for an off-momentum electron).

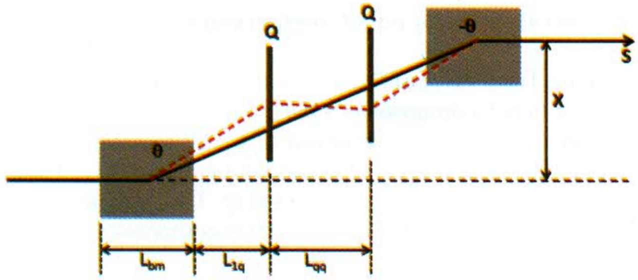

Fig. T.3.4 : Dog-leg optics using two dipole magnets and two quadrupole magnets, shown by letter Q (black curve shows the design trajectory and dotted curve shows the trajectory for an off-momentum electron).

3. Brief Overview of CLIC and CTF3 acceleration scheme

CLIC is a future electron positron collider of CERN for 3 TeV centre of mass energy. Presently operating collider, LHC at CERN is a hadron machine. Hadrons have composite structure of quarks, while electron and positron are fundamental particle according to present 'standard model'. Due to fundamental nature of these particles, the precise measurement of parameters during collision is possible. But acceleration of electron (and positron) to a very high energy is not possible in a circular accelerator due to large energy loss in the form of synchrotron radiation. Therefore, this future electron positron collider is based on the linear accelerators (Linacs). To reach a very high energy in linear accelerators, required length becomes huge. To reduce the length, operating frequency of RF structure as well as the field gradient in RF structure should be very high. To generate the high frequency (12 GHz), high gradient (100 MV/m) field in RF structure, CLIC is using the concept of drive beam. In this scheme, using a 973 MHz RF Linac, electron beam with high charge in the electron bunches will be accelerated. Then using a Delay Loop (DL) and Combiner Ring (CR), the separation between the bunches will be reduced to 83.3 ps, which corresponds to 12 GHz [1]. This process is known as 'frequency multiplication'. Then the bunch length of individual bunches will be shortened using the bunch compressor optics. Then, these bunches will pass through the PETS (Power Exchange and Transfer Structure), in which energy of the accelerated electron beam will be transferred to these structure and beam will be de-accelerated. The RF power generation efficiency increases with shorter bunches. The RF power generated is transferred to the main acceleration cavities, where main electron beam for collider will be accelerated. CTF3 can be considered as a small scale CLIC drive beam facility to demonstrate this two beam acceleration concept [2]. This test facility will also be used to test the various RF components of CLIC.

4. Optics Design of TL-2

Layout of the CTF3 is shown in Fig. T.3.5 [7]. The drive beam accelerator (Linac) operates maximum up to 300 MeV of beam energy with a nominal operating energy of 150 MeV. The pulses of electron bunches interleaved by a DL and CR for frequency multiplication. The extracted beam from CR is transported through TL-2 to CLEX area (CLIC EXperimental area), where PETS are located. The transfer line TL-2 is used to compress the bunch length as well as optical matching to CLEX area. Therefore, this line joins the CR extraction point to CLEX. The facility had to be installed in the already available building of LEP pre-injector. Magnets were also available and design of TL-2 should use these magnets. Being a test facility, the required tuning range of R_{56} is also wide i.e. from -0.30 m to +0.30 m. The bunch length has to be compressed to 1.5 ps from 8.3 ps i.e. nearly a bunch compression up to 5.5 times. Design of a transfer line with such a wide tuning range of R_{56}, with the building (geometric) and magnetic constraints was a challenge. The major design parameters of this line are provided in Table-1.

The geometrical layout of the building, where this line was to be installed is shown in Fig. 6. Point 'E' in the figure is the extraction point of CR. The beam is extracted using two septa magnets towards the wall 'AB'. The line should deliver the beam to CLEX area from the point 'D' (on wall 'BC') of the building. To accommodate a line in this building with wide tuning of R_{56}, a modular design approach was adopted. Details of this modular design are given in the next section.

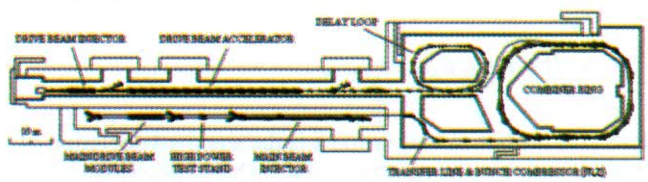

Fig. T.3.5 : Layout of the CTF3

Table 1 Design parameters of TL-2

Parameter	Design value
Maximum beam energy	300 MeV
Nominal beam energy	150 MeV
Charge per bunch	2.33 nC
Beam emittance (π mm-mrad)	100 (normalized) in both the planes
Bunch length (at start and end)	8.3 ps and 1.5 ps
Momentum spread	1% RMS
Horizontal β at start and end	4.43 m and < 20 m

Vertical β at start and end	7.79 m and < 20 m
Dispersion at start and end	0.00 m and 0.00 m
Floor levels at start and end	1.35 m and 0.85 m
R_{56}	-0.30 m to +0.30 m
T_{566}	0.00 in entire range of tuning

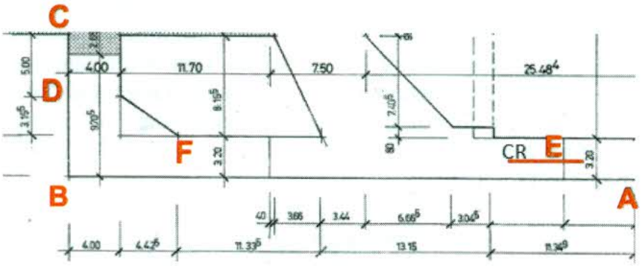

Fig. T.3.6 Layout of the building where TL-2 is installed

4.1 Linear Optics

The optics design of this line is broken in three modules [7]. Module-1 is a small horizontal achromat made by one dipole magnet and two extraction septa of CR. From CR, the beam comes towards wall AB and the dipole magnet bends the beam in opposite to septa, and making the direction of beam propagation, parallel to this wall. Because of opposite nature of bending in the achromat, the betatron phase advance is π. For meeting the achromatic condition, this module consists of three quadrupole magnets.

Module-2 serves mainly three purposes. The first is to send the beam from Module-1 to Module-3 with matching the optical parameters at the entrance of Module-3. Second is to accommodate a vertical achromat to send the beam downside as the floor levels of LEP pre-injector building and CLEX area are different (see Table-1) and third is to provide a sufficient clear element free space for placing a tail clipper to clip the transverse tails of the electron beam. To control the Twiss parameters at the location of tail clippers, a quadrupole triplet is used. Twiss parameters are decided by the arrangement and strengths of magnets in the optics and give the beam size, divergence and their correlation of the beam as it propagates downstream to optics i.e. these parameters define the optics and using a beam parameter, these give the information about the beam at each location in the optics. The additional beam parameter, which is required to define the beam size and divergence, for a given Twiss parameter, is known as the beam emittance. The beam emittance can be understood as the area occupied by the beam in phase space, which is an invariant of motion (at least in linear dynamics). There are three beam emittances, one in each direction i.e. horizontal, vertical and longitudinal. There are three Twiss parameter in horizontal as well as in vertical plane. First Twiss parameter is denoted by β, and it provides the information about the beam size, second parameter is denoted by γ, and it provides the beam divergence, and last parameter is α, which gives a correlation between β and γ. Twiss parameters with inclusion of dispersion and its derivative with *s* define the linear beam optics.

For matching optical parameters at the entrance of the vertical achromat in Module-2, a quadrupole doublet is placed before this achromat. This vertical achromat is a dog-leg optics, and has three quadrupole magnets to control the dispersion as well as Twiss parameters. After this achromat, one quadrupole triplet is placed to match the optics for Module-3. In this way, this module consists of two dipole magnets (for vertical achromat) and eleven quadrupole magnets.

Third module contains an S-arc for tuning the R_{56} and also a quadrupole doublet to match the optics for CLEX area. Therefore, this module is the most complex and important module. The complete line placed in the building is shown in Fig. T.3.7. In this figure, green blocks are dipole magnets, red and blue blocks are quadrupole magnets and yellow blocks are sextupole magnets.

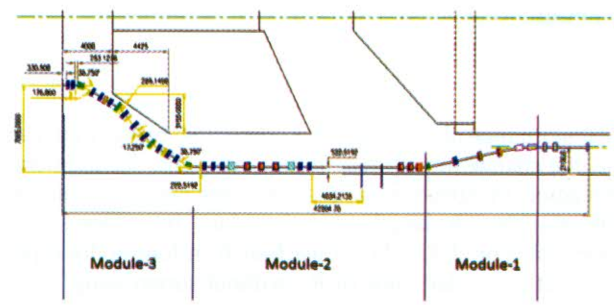

Fig. T.3.7 Complete layout of TL-2 inside the building

For making the achromatic arc, there are four dipole magnets. The dispersion profile cannot be changed in first and last dipole magnet due to achromatic condition (achromat can be made only for unique values of dispersion and its derivative at the entrance of last magnet). Hence, the contribution in R_{56} for these two dipole magnets is fixed. In the remaining two dipole magnets, by changing the profile of dispersion function, R_{56} can be tuned to the desired values. To generate the desired profile of dispersion inside the second magnet, there are three quadrupole magnets between the first and second dipole magnet. Magnets are placed symmetrically in the arc and therefore, similar quadrupole triplet is placed between the third and fourth dipole magnets. Another quadrupole triplet is accommodated in the path from second to third dipole magnets. The purpose of having three quadrupole magnets is not only to generate a desired dispersion for R_{56}, but also to generate a higher value of dispersion, so that the second order aberration can be corrected using sextupole magnets. This second order correction is discussed in next sub-section.

In entire range of tuning of R_{56}, optics is optimized in a way, such that the maximum beta function in both the planes remain below 40 m. With maximum of 2.5 m dispersion and 1% momentum spread in the beam, the beam sizes up to 3 is ~25 mm, which is well below the aperture of vacuum pipe. Aperture of vacuum pipe is 90 mm in horizontal plane and 40 mm in vertical plane in Module-1 and 3. In Module-2, vacuum pipe is round with 40 mm diameter, however in Module-2, there is no dispersion and therefore beam sizes are also smaller.

4.2 Correction of Second Order Aberration

Matrix element R_{56} relates the path length on momentum deviation linearly. When bunch length becomes very short, the second order effect also becomes significant and the second order effect must be suppressed. In second order map, the most important coefficient for a bunch compressor relates the path length on the square of the momentum deviation. This coefficient is defines as

$$\Delta L = T_{566}\delta^2 \qquad [10]$$

In longitudinal phase space, this coefficient brings a curvature i.e. the change in path length becomes same for momentum deviation irrespective of its sign. This curvature increases effective bunch length and therefore its suppression is essential. Fig. T.3.8 shows the bunch in longitudinal phase plane at particular value of R_{56} without suppressing $T_{566,}$ and with its suppression.

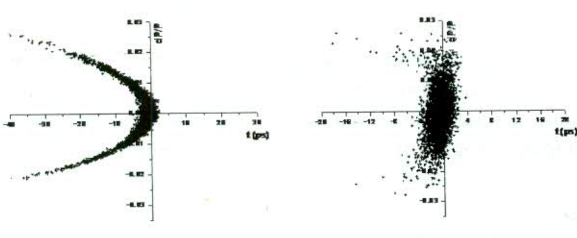

Fig. T.3.8 Bunch (in longitudinal phase plane) after the line without correction of T566 and with its correction

Other coefficients of second order map are not so significant in the case of a small beam emittance. To suppress this coefficient (T_{566}), four sextupole magnets are installed in S-arc (Module-3). Inclusion of sextupole magnets poses a detrimental effect on the transverse beam optics. Sextupole magnets make the dynamics highly nonlinear, and due to this nonlinear nature, these magnets increase the beam emittance and thus deteriorate the beam quality. In TL-2, sextupole scheme is optimized in a way such that the beam emittance should not increase beyond 10% in correction of T_{566}. Although, there are standard ways to incorporate the sextupole magnets in the optics to have minimum effect on emittance, in the case of TL-2, due to very wide range of tuning, optics parameters also vary in wide range and these standard ways do not work in the entire range of tuning. Therefore a new way is devised to optimize the sextupole scheme in TL-2 [8].

The kick imparted by a sextupole magnet on an electron depends on the beta function and betatron phase at the location of the magnet. Therefore, choosing the proper values of beta function at the four sextupole magnets and proper phase advances, kick can be minimized simultaneously in both the planes. Total kick (θ) on an electron in a transfer line, containing *N* sextupole is given by

$$\theta_x = \frac{1}{4}\varepsilon \sum_{i=1}^{N} (ml)_i \{(\beta_{xi} - \beta_{yi}) + (\beta_{xi} cos[2(\phi_{xi} - \phi_{x0})] - \beta_{yi} cos[2(\phi_{yi} - \phi_{y0})])\} \qquad [11]$$

$$\theta_y = \varepsilon \sum_{i=1}^{N} (ml)_i \left\{\sqrt{\beta_{xi}\beta_{yi}} cos(\phi_{xi} - \phi_{x0}) cos(\phi_{yi} - \phi_{y0})\right\} \qquad [12]$$

Here, subscripts *x* and *y* show the horizontal and vertical plane, respectively. In these expressions, *m* and *l* show the sextupole strength and effective length, respectively, θ shows the betatron phase and ε is the emittance. Subscript *0* on phase shows the initial betatron phase. In S-arc, all the quadrupole magnets are utilized in obtaining the desired dispersion profile for R_{56}, keeping higher values of dispersion at sextupole magnets to minimize the required strength of these magnets to suppress T_{566}. Therefore, it is not possible to shape beta function in Module-3 using the arc quadrupole magnets. Therefore, quadrupole triplet before the entrance of Module-3 is used to tune the initial beta function in a way, so that the sextupole kick becomes lesser and also beta function does not reach beyond 40 m in the arc. The variation in sextupole kick with initial beta function for two settings of R_{56} (-0.30 m and +0.30 m) is shown in Fig. T.3.9. The chosen operating point (zero on horizontal axis) is very close to minimum values of kicks. Slight deviation in operating points from minimum is based on the value of maximum beta function in arc and on some practical considerations. Using this scheme, in the entire range of tuning, T_{566} is suppressed without diluting beam emittance beyond 10%.

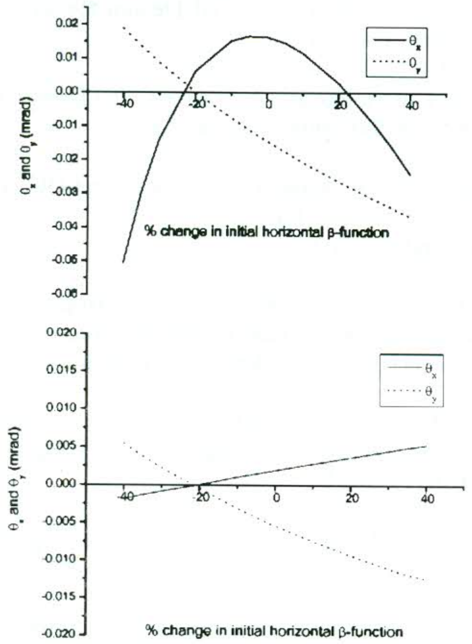

Fig. T.3.9 Sextupole kick with variation in the initial beta function

The phase space plots, which indicate the dilution in emittance, are shown in Fig. T.3.10 with and without sextupole magnets for R_{56}=+0.30 and -0.30 m.

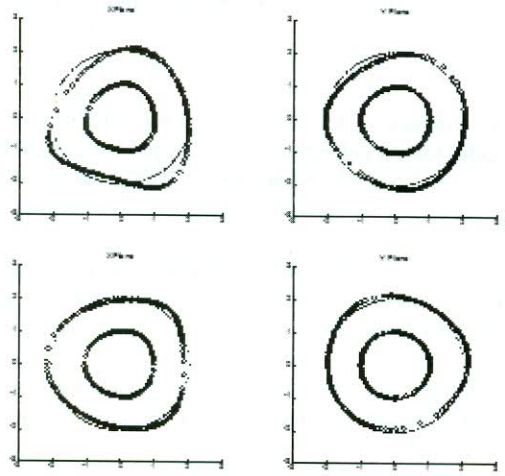

Fig. T.3.10 Phase space distortion in transverse plane due to sextupole magnets (thin lines are without sextupole magnets and lines with small circles show the presence of sextupole magnets. Inner plots are for 1σ and outer plots are for 2σ beam sizes)

5. CSR Simulation Studies

On a curved path inside the dipole magnet, electron emits synchrotron radiation. When bunch length becomes very short, on traversing from a dipole magnet, different electrons of the bunch emit synchrotron radiation coherently and this coherent synchrotron radiation (CSR) can also have detrimental effect on the beam qualities. Emitted photon travels on a straight path while electron bunch travels on a curved path and thus electron which emits radiation lags behind the emitted photon. This is shown in Fig. T.3.11. In this way, tail of the bunch interacts with the head of the bunch.

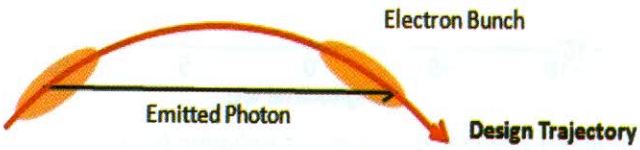

Fig. T.3.11 Tail-head interaction of a bunch through emitted radiation

This also tells that different slices of the bunch experience different strengths of the field, and this field variation along the bunch length for a Gaussian bunch is represented in Fig. T.3.12.

Due to the field variation along the bunch length, the head of the bunch gets more energy while tail looses the energy. Energy in CSR is proportional to N^2, where N is number of electrons in the bunch. Thus CSR carries a significant amount of energy from the bunch at the place where dispersion is non zero (inside the dipole magnet). Due to this CSR emission and interaction of tail-head, different slices of the bunch have different energies. Therefore the travel time of different slices of the bunch changes and bunch length deteriorates. Similarly, different slices have different energy means these slices oscillate around the different dispersive orbit and effective projected transverse emittance of the bunch increases. Therefore, it is required to quantify the effects of CSR on bunch of TL-2. CSR simulation studies, which are carried out using code ELEGANT [10] reveal that although CSR have a small effect on particle distribution on the bunch in TL-2, but does not change bunch length and transverse emittance significantly in the operating range of parameters [11]. If bunch length is shortened to a value less than 1 ps, the effect of CSR increases and becomes significant.

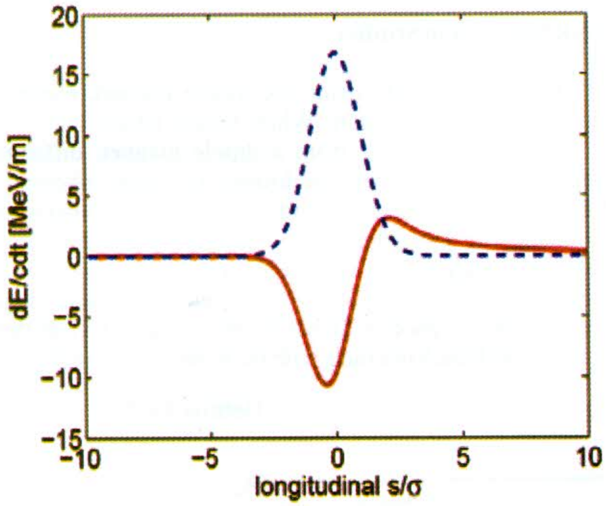

Fig. T.3.12 Field due to emitted radiation for a Gaussian bunch [taken from ref. 9]

6. Conclusions

An optics design and optimization of a transfer line for bunch compression has been carried out for CTF3 at CERN under the DAE-CERN collaboration. The transfer line is able to tune the R_{56} in a very wide range, as required. A new sextupole scheme has been evolved to suppress the second order longitudinal aberration T_{566} in the entire rage of tuning, while keeping the transverse emittance dilution below 10%. CSR studies show that in the operating range of this transfer line, there is no significant detrimental effect on the beam quality. On the basis of this design, TL-2 has been installed at CERN, and is in successful operation [12].

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