CTFF3 TECHNICAL NOTE

INFN - LNF, Accelerator Division

Frascati, June 10, 2001

Note: **CTFF3-005**

CTF3 Transfer Line Design

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Abstract

The CLIC project (CERN $e^+ e^-$ Linear Collider) is based on the two beams accelerating concept. A main beam is accelerated by a high frequency, 30 GHz, power source provided by a high current driving beam. This scheme allows a very efficient energy gain per unit length.

The basic idea of energy transfer from the drive beam to the main one has just been tested using the CTF1 and CTF2 facilities.

The CTF3 experiment is aimed at verifying the drive beam compression scheme, which should reduce the bunch spacing from an initial value of 20 cm down to 2 cm.

1. Introduction

In CTF3 the electron beam is produced by a 3 GHz Linac. It consists in 4.5 μs long pulses, having only even and odd buckets filled in the first and second half respectively. The separation between bunches is 20 cm. The even bunch trains are injected by an RF deflector [1] in the Delay Loop [2] which allows their recombination with the incoming odd ones, resulting in a compression of the bunch spacing by a factor 2. After that the beam goes through the Combiner Ring [3] where a further compression by a factor 5 takes place and a final interbunch separation of 2 cm is obtained.

The different CTF3 structures are joined by 60 m long Transfer Lines which are the subject of this paper.

Many considerations related to wake field effects and transverse emittance growth [4] [5] impose preservation of the beam time structure. In this framework all the CTF3 components must be isochronous.

An accelerating structure is isochronous when the following condition is satisfied:

$$R_{56} = \int \frac{\eta_x}{\rho} ds = 0$$

where R_{56} is the linear transfer matrix dispersive term, η_x is the horizontal dispersion, ρ is the curvature radius, and the integration range is over the section taken into account. Contributions to the R_{56} integral come mainly from deflecting magnets and off centre quadrupoles.

2. Transfer Line General Description

The CTF3 transfer lines are made up by several well defined sections, matching the spatial requirements imposed by housing all the complex in the existing buildings. They have been designed assuming an energy for the beam from the Linac in the range 180÷350 MeV.

The beam from the Linac passes through a four-bend achromat where the bunch length can be modified over a wide range, then a section provides the necessary matching with the Delay Loop betatron function allowing beam injection and extraction. A s-shape line drives the beam around the Combiner Ring where a dispersion free section provides the proper betatron functions for injection.

The general Transfer Line layout [6] is shown in Figure 1; Figure 2 presents the betatron functions over all the line.

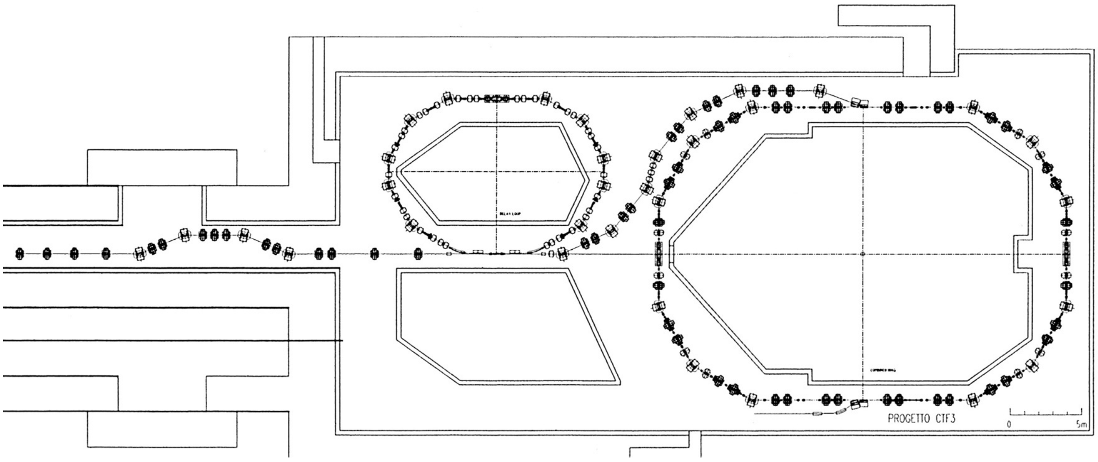

Figure 1: CTF3 Layout

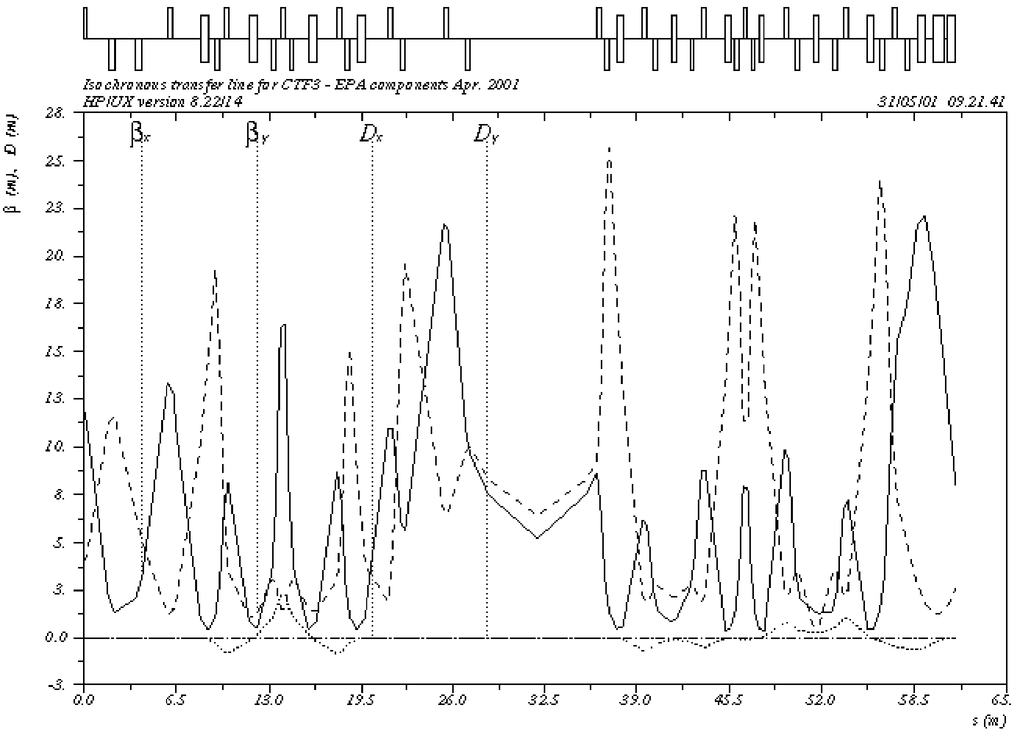

Figure 2: Transfer Lines Optical Functions

A special attention has been put in reusing when possible the magnets available after the EPA ring decommissioning. It has been possible for all the bending magnets and for few quadrupoles, the ones preceding the four-bends achromat insertion. In fact space limitation in the zone between the Delay Loop and Combiner Ring required smaller quadrupoles. For this reason the .3 m long quadrupoles [7], designed for the DAΦNE complex, have been used. The maximum strenght of the DAΦNE type quadrupoles, in linear regime, is:

$$K_{MAX} = 4.8\ (2.5)\ [m^{-1}] \quad @ \quad .18\ (.35)\ [GeV]$$

The .505 m long EPA quadrupoles have a smaller focusing strength since their maximum K value is:

$$K = .823\ [m^{-1}] \quad @ \quad .35\ [GeV].$$

A complete list of all the magnetic elements in the CTF3 Transfer Line is presented in Table 1 with respect to bending and septa, and in Table 2 concerning the quadrupoles.

Table 1: Bending Magnets in the CTF3 Transfer Line

	Angle [rad]	Zone
DS1	-.3927	Four-Bends Achromat
DS2	.3927	
DS3	.3927	
DS4	-.3927	
ID1	-.4363	1st Isochronous Arc
ID2	-.4363	
ID3	-.4363	
ID4	.4363	2nd Isochronous Arc
ID5	.4363	
ID6	.4363	
SPT1	-.0349	Combiner Ring Injection
SPT2	-.3428	
DSP	.3777	

Table 2: Quadrupoles in the CTF3 Transfer Line

	KL [m^{-1}]	Zone
Q1	0.7125	From Linac
Q2	-0.2204	
Q3	-0.4537	
Q4	0.6742	
KQS1	-1.2954	Four-Bends Achromat
KQS2	1.6156	
KQS3	1.6668	
KQS4	-1.5121	
KQS5	1.9784	
KQS6	-1.2761	
KQS7	-1.1623	
KQDL1	0.8441	Delay Loop Insertion
KQDL2	-0.9114	
KQDL3	0.4114	
KQDL4	-0.2313	
KQDL5	1.1314	
KQDL6	-1.0866	
KQF(1)	1.2659	1st Isochronous Arc
KQD(1)	-0.4595	
KDDQ1	-1.1436	
KDDQ2	2.3439	
KDDQ3	-1.1289	
KQF(2)	1.3934	2nd Isochronous Arc
KQD(2)	-1.2047	
KSPQ1	-0.8362	Combiner Ring Injection
KSPQ2	0.6561	
KSPQ3	-0.0802	

2.1 Four Bend Magnets achromat

The four bends achromat is an insertion designed to modify the bunch length in order to provide a wide set of different experimental condition during the operation. In the first order approximation the bunch length variation is proportional to the R_{56} matrix element according to the formula:

$$\Delta l = -R_{56}\frac{\Delta p}{p} = 0$$

Varying the horizontal dispersion and, as a consequence, the R_{56} the bunch length can be tuned.

In Figure 3 a schematic layout of this zone is presented. The quadrupole doublets just after the first dipole and before the last one allow a full control over the horizontal dispersion derivative at the insertion side dipoles, while the quadrupole triplet is used to make the betatron function symmetric over the section and to vary the positive peak value of the horizontal dispersion in order to tune the R_{56} factor.

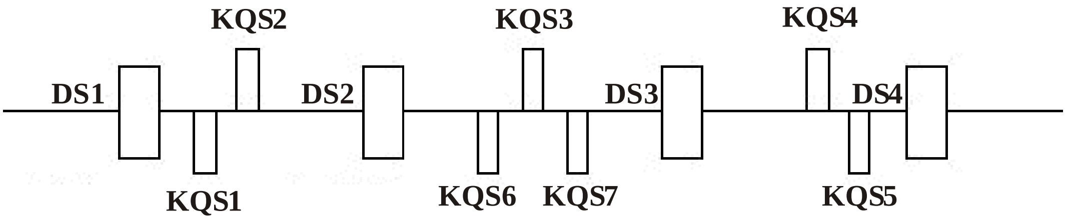

Figure 3: Four-bends achromat schematic layout

The betatron function relative to the four bends achromat are shown in Figure 4. The horizontal dispersion and its derivative are obviously equal zero at both ends of this section.

Table 3 gives the available excursion range for the R_{56} coefficient; it can be varied over a wide range including zero, when the bunch length is completely unaffected, keeping the quadrupole strengths reasonably low.

Assuming an energy deviation $\Delta p/p$ = .833% the R_{56} values in Table 3 allow a bunch length excursion $\Delta l_b = \pm 2.5$ mm.

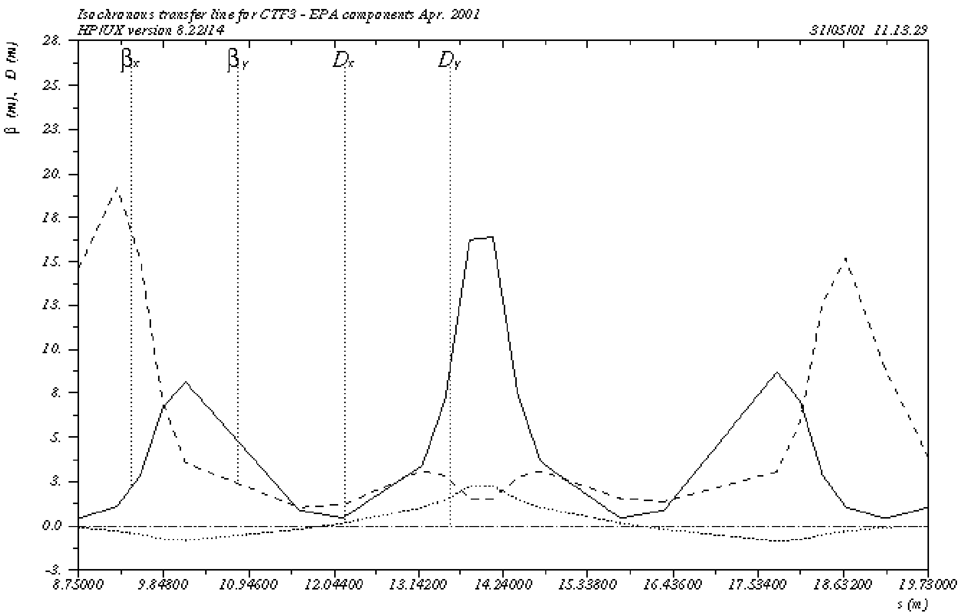

Figure 4: Four Bends Achromat Optical Functions

Table 3: Quadrupole strenghts for different R_{56} in the four-bends achromat

	R56 = -.3 [m]	R56 = 0 [m]	R56 = .3 [m]
KQS1 K2 [m-1]	-1.5366	-1.5204	-1.3902
KQS2	1.9737	1.6451	1.3294
KQS3	1.7941	1.7990	2.0690
KQS4	1.9137	1.6373	1.3662
KQS5	-1.6246	-1.2820	-1.2530
KQS6	-0.9722	-0.9625	-1.2699
KQS7	-1.1477	-0.86532	-0.70083

2.2 Delay Loop Insertion

The Delay Loop insertion includes 6 quadrupoles. They are used to match the betatron functions in the 6.5 m long straight section shared with the ring, see Figure 5.

The betatron values at both ends (point A and C) and in the centre (point B) of the shared line are reported in Table 4. They are symmetric with respect to the point B where match the Delay Loop design requirements [2].

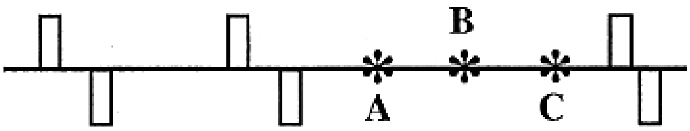

Figure 5: Delay Loop insertion schematic layout, A C and B are the symmetry points of the shared line.

Table 4: Betatron functions at the A, B and C symmetry points

	A	B	C
β_x [m]	7.47	5.23	7.49
β_y [m]	8.254	6.418	8.248
α_x	.654	0.00	-.657
α_y	.535	0.00	-.534

2.3 S-Shape Section

The s-shape section is intended to move the beam trajectory 11 m apart in the parallel direction drive the beam at the same level of the Combiner Ring injection septa. Due to the narrow passage between the Delay Loop and the Combiner Ring the s-shape is mandatory. It has been designed using two three bends isochronous modules of the same kind of those proposed at CERN [8]. The betatron functions between the two modules are matched by a quadrupole triplet.

2.2.1 Combiner Ring Insertion

The line for injecting in the Combiner ring includes a dipole drive the beam at the entrance of the first septum where the beam trajectory is bent by 19.64°, a further deflection by 2° is provided by the final one. The matching of the betatron functions required for injection is obtained by a quadrupole triplet and the obtained values are listed in (3).

$$\begin{gathered} \beta_x = 8. \quad [m] \\ \beta_x = 8. \quad [m] \\ \eta_x \sim 0. \; [m] \\ \eta'_x \sim 0. \end{gathered} \tag{3}$$

The contributions to the R_{56} coming from dipole and septa are cancelled by tuning properly the R_{56} in the isochronous modules of the s-shape section.

The septa used are the ones designed for the accumulator of the DAΦNE complex [9] having a thickness of 1.5 mm and a very low stray field.

3 Beam Envelope

The beam envelopes have been computed assuming for emittance and momentum deviation the nominal values:

$$\varepsilon_x = \varepsilon_y = 10^{-6} \text{ [m rad]}$$

$$\sigma_e = .8\%$$

The rms beam envelopes, as defined in 4, are shown in Figure 6.

$$\sigma_x = \sqrt{\varepsilon_x \beta_x + \sigma_e \eta_x^2}$$
$$\sigma_y = \sqrt{\varepsilon_y \beta_y} \qquad (4)$$

The horizontal beam size has a relevant contribution coming from the energy spread related term in the four-bends achromat section.

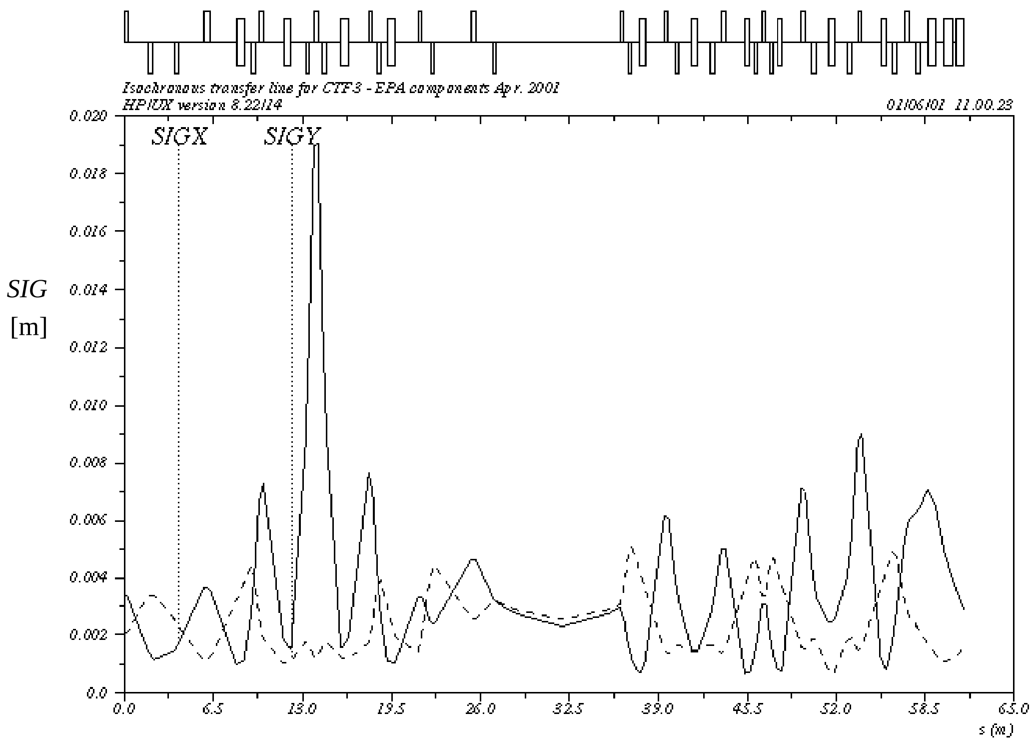

Figure 6 Transfer Lines Beam Envelopes (rms values)

4 Combiner Ring Extraction Line

About the Combiner Ring extraction line, it has not jet defined in detail, since its shape depends on the positioning of the RF Power Extractor. However some general consideration about its design can be done.

Due to the symmetry in the Combiner Ring the extraction line can be obtained from the injection one just by reflection. The necessary bunch compression can be provided exploiting the flexibility of the four bends achromat in tuning bunch length. So the only parts which will have to be designed are the straight sections, matching the Combiner Ring extraction line, the four bends achromat and the RF Power Extractor.

5 Summary

The Transfer Line described satisfies the spatial requirements imposed by the CTF3 facility general layout. It matches the Delay Loop and the Combiner Ring insertions.

A tunable four bends achromat allows fine bunch length tunability over a wide range.

The first order isochronicity is satisfied and the low value of the dispersion guarantees a low contribution to the second order isochronicity.

References

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