CTF3: DESIGN OF DRIVING BEAM COMBINER RING

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Abstract

In CTF3 the beam compression of the driving beam structure between the main linac and the decelerating section is obtained with a delay loop and a combiner ring which increase the pulse current by a factor 10. The design of the combiner ring is presented. Tunable isochronicity condition, corrected up to second order, should assure preservation of the correlation in the longitudinal phase space during the compression. Path-length tuning devices are included in the combiner ring layout to compensate for orbit variations.

1 INTRODUCTION

The first two CLIC Test Facilities, CTF1 and CTF2 have demonstrated the basic principles of rf power production by decelerating a high current electron beam. CTF3 is foreseen to check the feasibility of pulse compression in the driving beam structure [1].

The facility will be installed at CERN, in the existing LIL and EPA buildings, which will be available after LEP shutdown. It will use the existing 3 GHz klystrons and modulators for the production of the beam. The macropulse from the linac is 1.4 μs long and is composed by 140 ns long sequences of *odd* and *even* buckets. Inside each sequence the bunch separation is twice the rf wavelength, 20 cm, with maximum bunch charge of 2.3 nC.

The first compression is done in the delay loop, where each sequence of odd buckets is recombined with the near sequence of even ones. In the resulting beam structure the 140ns bunch trains, in which the bunch separation has become 10 cm, are followed by 140ns long voids.

The second compression phase is done in the combiner ring (CR), 84 m long (twice the delay loop). Each group of successive 5 bunch trains does *n-1/2* turns inside the ring, with *n* from 1 to 4. When they are extracted the bunch separation is reduced down to 2 cm, and the distance between successive bunch trains is four times 140ns.

Preservation of beam emittance and longitudinal correlation during the compression imposes tight requirements on the ring design. The design of the combiner ring is the subject of this paper. A preliminary design, in which the general characteristics were already discussed, is described in [1]. The availability of magnets (dipoles and quadrupoles) of EPA and related transfer lines has suggested the possibility of reuse for the CR project. The following design is based on the use of these magnets.

2 COMBINER RING LATTICE

The ring consists of four isochronous arcs, two short sections housing the path length tuning device and two symmetric opposite long sections for injection and extraction. Quadrupole triplets around the arcs are used for matching. The layout of the ring is shown in Fig. 1 and the main parameters are listed in table I.

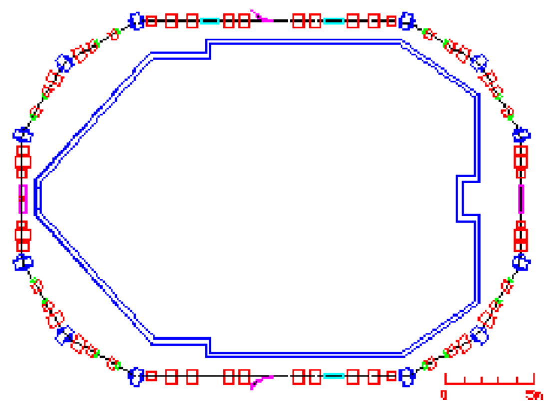

Figure 1: Combiner ring layout.

Table I – CR main parameters

Energy (MeV)	160/350
Circumference (m)	84
Bending Radius (m)	1.075
No. Cells	4
No. Dipoles	12
Dipole Field (T)	0.5/1.1
No. Quadrupoles	52
Max.Int.Gradient (T)	0.9/1.8
No. Sextupoles	24
Max.Int.Gradient (T/m)	6/13
Max. beta (m) (H/V)	11/11
Max. Dispersion (m)	.73
Betatron Tune (H/V)	8.10/3.63
Chromaticity (H/V)	-11/.9

2.1 Isochronous Arc

The arcs are triple bend achromats, with negative dispersion in the central dipole, which makes vanish the term of the first order transport matrix relating path length with energy:

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

(D_x is the dispersion and ρ the bending radius).

Three quadrupoles in each half arc allow tunability of betatron functions and tunes. Tuning the arc central quadrupole by few percent is the simple knob, which varies the momentum compaction α_c around zero. Figure 2 shows the amount of variation of α_c obtained by changing the gradient by ±6%.

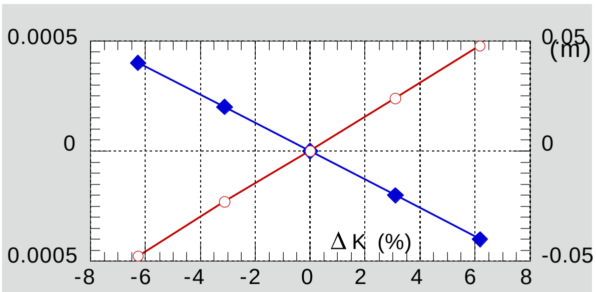

Figure 2: Momentum compaction (full points) and R_{56} (hollow points) tuning.

2.2 Injection and Extraction

Equal structures are designed for the injection and extraction regions, which have similar requirements, thus doubling the ring periodicity. Injection and extraction septa are placed symmetrically (see fig.1) in the middle of a straight section 2.7m long. The septum is placed at the section center, in a free zone, 2.7 m long. The π phase advance in between the two injection kickers is created by four quadrupoles arranged symmetrically around the septum. In the extraction region this assures the necessary $\pi/2$ phase advance between the extraction kicker and the septum. The space corresponding to the second kicker can be used to house a rf cavity in the hypothesis of storing the beam for diagnostic purposes.

A critical issue is the value of the horizontal betatron function, β_{xk}, at the fast rf injection kickers, affecting the amount of beam loading of the successive turns [3]. Values of β_{xk} = 2 m and α_{xk} = 0 correspond to minimum beam loading. The design allows the necessary tunability. The optical functions from the middle of the arc to the injection section are shown in Fig. 3.

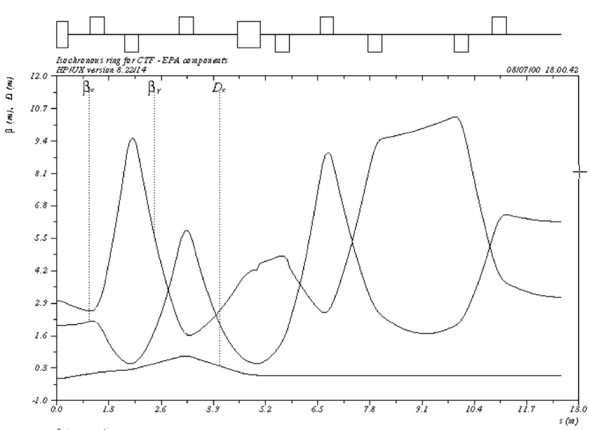

Figure 3: Optical functions from mid arc to injection/extraction.

2.3 Path-length tuning section

The tuning of the relative phase of injected and circulating bunches and the compensation of orbit variations is needed twice in the ring, to adjust independently each bunch train. The path-length tuning devices are variable field, one period, wiggler magnets, housed in the short straight sections. With respect to a magnetic chicane the wiggler offers the advantages to be more compact, with a larger tuning range, and a lower contribution to the R_{56} term. It has two half end poles and a central pole, independently powered, with bending angles –7°, 14°, -7° and total length 1.6m. Changing the field by ±12% the path length variation is ± 1mm, which is twice the original requirement[1]. The dispersion function introduced by the wiggler is selfmatched and the contribution to the momentum compaction, -5 10^{-3} per wiggler, is compensated inside the arcs. Figure 4 shows the path length variation as a function of the wiggler field and the corresponding change of the matching triplet gradients. The optical functions from the arc center to the wiggler center are shown in Fig. 5.

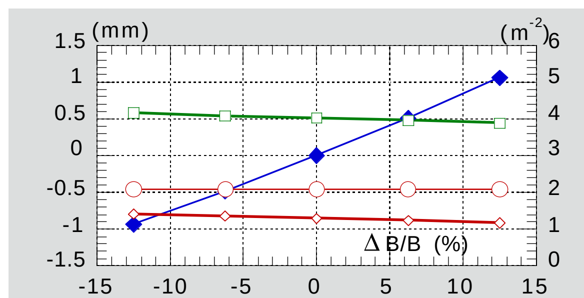

Figure 4: Path length (full points) as a function of wiggler field and matching triplet strength (hollow points)

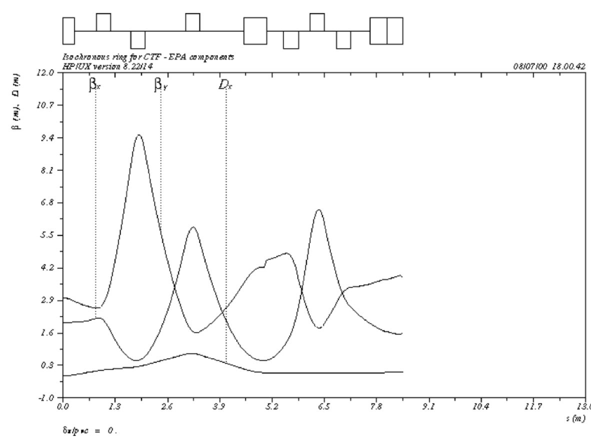

Figure 5: Optical functions from mid arc to wiggler center

3 ISOCHRONICITY

The path length variation with energy is given up to the second order by:

$$c\Delta t = R_{56}\frac{\Delta p}{p} + T_{566}\left(\frac{\Delta p}{p}\right)^2 + \ldots$$

where T_{566} is the element of the second-order transfer matrix.

The isochronicity to the first order is assured by the zero integral of the dispersion function in each arc of the ring. Particles with energy deviations ±2.5% and with zero transverse initial invariant change their path length by up to 2.5 cm, with a clear second order dependence (see Fig. 6); even going to α_c values of few 10^{-2}, the second order term is still dominant. The cancellation of the second order term is done by sextupoles. A focusing sextupole in each arc can do the job but this solution, increasing the negative vertical chromaticity leads to isochronicity loss in the presence of vertical oscillations. The best solution is a compromise between the T_{566} cancellation and the chromaticity correction. A possible solution, which can still be improved, is the use of three sextupoles in each half arc, which give a chromaticity of –1, -.3 in the horizontal and vertical plane respectively and T_{566} = 0.002. Figure 6 shows the path length for different $\Delta p/p$ of initially on axis particles.

6a) 6b)

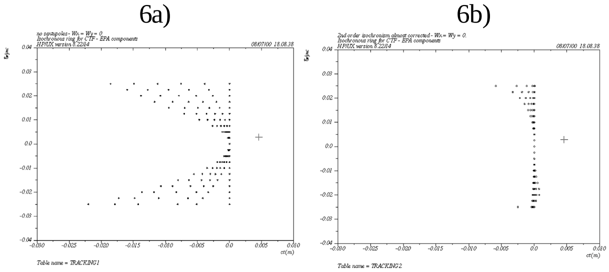

Figure 6: Path length with energy deviation with first (6a) and second (b) order isochronicity correction.

4 COHERENT SYNCHROTRON RADIATION

One of the potentially dangerous effects for the beam emittance preservation is the coherent synchrotron radiation wake. Short, high charge bunches can emit coherent synchrotron radiation (CSR) at wavelengths longer than the bunch length. The main effects on the beam itself are energy loss and energy spread. An analytic evaluation of the effect is possible in the case of constant bunch length and circular orbit, with uniform bending angle. In the case of the CR it has been shown that the effect, while being relevant, is still tolerable. In particular, the distortion to the longitudinal phase space distribution does not prevent the final bunch compression. However in the combiner ring the bunches do not have a constant length, nor follow a circular orbit. Therefore, a check has been made using the code TraFiC^4 [4], recently tested successfully against experimental results in CTF2 [5]. A full isochronous cell has been used in the simulation. The rms bunch length oscillates in the cell from about 1.1 mm to 1.7 mm, in good agreement with MAD calculations. Unfortunately, TraFiC^4 does not yet allow the use of sextupoles, so that the second order momentum compaction cannot be corrected, and the final bunch length after one pass in the cell is slightly longer than the initial one (from 1.35 mm to about 1.4 mm). In spite of that, a first evaluation of the longitudinal wake has been obtained by plotting the difference between initial and final energy of the macroparticles against their initial position in the bunch (see Fig. 7). The average energy loss and the macroparticle energy loss are in reasonable agreement with the analytical evaluation of the wake.

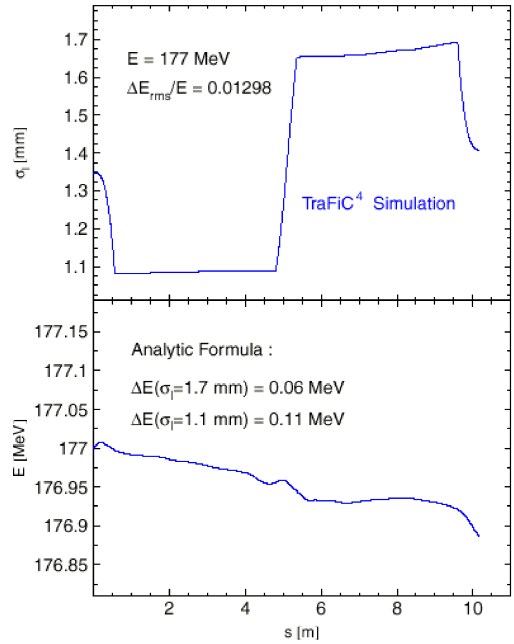

Figure 7: Rms bunch length evolution in one CTF3 arc cell (top) and average energy loss along the cell (bottom), as evaluated by TraFiC^4.

5 EXTRACTION KICKER

A pulsed kicker which extracts the entire bunch train has been designed. The flat top duration is slightly longer than the entire CR bunch train length (143 ns) in order to deflect all the bunches with the same angle. The rise time is shorter than the distance of the kicker from the injection septum (~60 ns) to allow the injection and extraction of the last linac pulse in the same turn. The kicker is based on stripline pair design where each electrode, 50 cm long, forms with the vacuum chamber a transmission line of 50Ω characteristic impedance. The kicker has been designed using HFSS electromagnetic 3D code, and a prototype has been built to measure the efficiency and to study and damp the high order mode trapped in the structure.

REFERENCES

[1] CLIC Study Team, "Proposals for Future CLIC Studies and a New CLIC Test Facility (CTF3)" - CERN/PS 99-047 (LP) and CLIC Note 402 (1999).

[2] H.H.Braun et al.,'The CLIC RF Power Source' – CERN 99-06

[3] S.Gallo et al., "Studies on the RF Deflectors for CTF3", this Conference.

[4] A. Kabel, M. Dohlus, T. Limberg, "Using TraFiC4 to Calculate and Minimize Emittance Growth due to Coherent Synchrotron Radiation", to be published in NIM A.

[5] H.H. Braun, R. Corsini, L. Groening, F. Zhou, A. Kabel, T.O. Raubenheimer, T. Limberg, "Emittance Growth and Energy Loss due to Coherent Synchrotron Radiation in the Bunch Compressor of the CLIC Test Facility (CTF 2), this Conference.