A SIMPLE S-CHICANE FOR THE FINAL BUNCH COMPRESSOR OF TTF-FEL

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Abstract

For FEL operation of the TTF linac at the final energy of about 1 GeV, the bunches have to be compressed longitudinally to reach peak currents of 2.5 kA [1]. With a bunch charge of 1 nC, the compression is carried out in 2 stages for reaching the final rms bunchlength of 50 microns. Within this second compressor, where the bunch is very short, coherent synchrotron radiation (CSR) becomes significant and can induce unacceptable emittance growth. In this paper, we investigate a 4-bend S-chicane with a varying compression factor R_{56}. In addition to its simplicity, this compressor is also dispersion free at all orders.

1 INTRODUCTION

For FEL operation of the TTF linac in Phase II, the bunches have to be compressed longitudinally to reach peak currents of 2.5 kA at the final energy of about 1 GeV [1]. With a bunch charge of 1 nC, the compression is carried out in 2 stages for reaching the final rms bunchlength of 50 µm (Fig.1). After a first compressor (BCII) which shortens the 1 mm long bunch, expected from the gun, to about 200 µm, a second compressor (BCIII) has to further reduce to the final required bunchlength. However, the SASE process will take place only if transverse emittance as well as energy spread is kept small enough while the beam is compressed and accelerated to high energy.

Specifically, the normalized transverse emittance and energy spread at the undulator entrance must be of the order of $\gamma\varepsilon \approx 2$ π.mm.mrad and $\sigma_\varepsilon \approx 1$ MeV at the final energy of 1 GeV. The first compressor (BCII) has been commissioned [2] and is the only compressor to be used for the proof-of-principle experiment. It consists of a symmetric 4-bend chicane which is dispersion free to all orders in the absence of space charge. This type of chicane provides negative values of the compression factor R_{56}. Within the second compressor (BCIII), where the bunch is even shorter, coherent synchrotron radiation (CSR) becomes significant and can induce unacceptable emittance growth. In order to alleviate the CSR effects, several compensation schemes have been proposed, as the double chicane compressor, separated by a -I transfer matrix [3], the FODO-lattice compressor [4] or a simple 4-bend chicane with a moderate R_{56} [5]. In this paper, we investigate a 4-bend S-chicane with a variable compression factor. In addition to its simplicity, this compressor is also dispersion free at all orders, and provides a R_{56} coefficient of the same sign as the upstream compressor. With the opposite R_{56} sign of the FODO-lattice, the RF phase of the accelerating sections just before BCIII has to be moved far away from the crest of the accelerating wave in order to reverse the δ-z correlation, resulting in a final energy loss. Furthermore, operating in the under-compression mode, a negative R_{56} coefficient of the last compressor contribute to reduce the final energy spread thanks to the longitudinal wakes which will decrease the energy of the trailing particles.

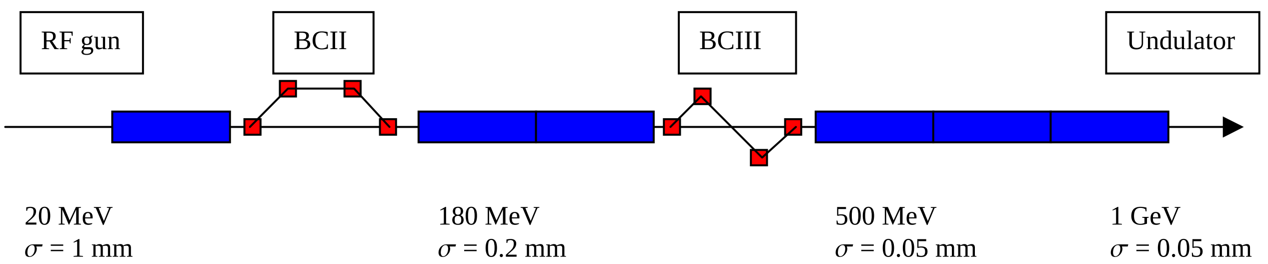

Figure 1 : Sketch of the 2-stage bunch compression of TTF-FEL

2 EMITTANCE GROWTH MECHANISMS

When a bunch follows a curved trajectory, the individual particles experience collective radiatives forces. Longitudinal effects induce energy spread and then dilute the transverse emittance through the chromatic transfer function of the bending system [6]. Transverse forces, which kick directly the particles from their reference orbit, have also, at a less extent, an emittance contribution. An electron loosing an energy at a given location in the bending system will be map to the end with an off position and angle depending on the local dispersion function D. One expect therefore an induced emittance proportional to the square of the dispersion function and then to the square of the compression factor $R_{56.}$ In order to study more precisely the effects of relevant parameters, like the compression magnitude, the length and deviation angle of the dipole magnets, or the beam energy, we used the 3-D tracking code Trafic4, developed at DESY. This code computes the "slice" emittance, the quantity of interest for lasing (the emittance and energy spread requirements have to be maintained over the co-operation length, typically much smaller than the bunch length) as well as the projected (correlated) emittance. This latter quantity must nevertheless be kept small enough to prevent the laser from chirping and the brightness from decreasing.

3 BUNCH COMPRESSOR ISSUE

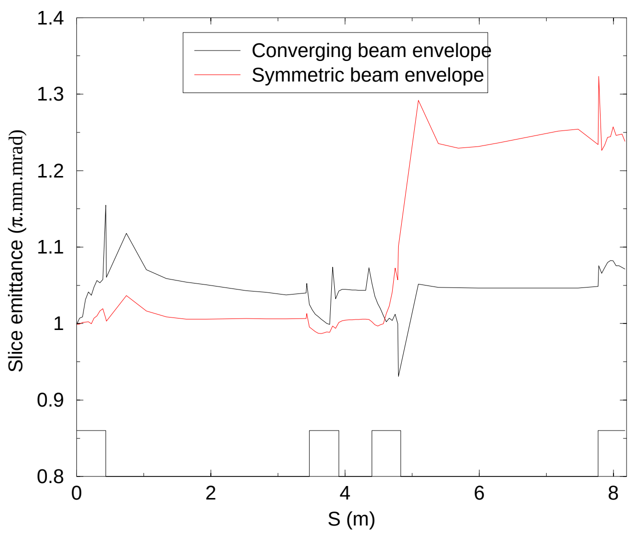

Figure 1 : Slice emittance along a chicane (R_{56} = 0.05 m) for a converging beam and for a symmetric (a waist in the middle) beam envelope.

First, a bending system embedded in a FODO-lattice as been investigated [4]. The compressor of 16 m long consist of 10 FODO-cells, six of them filled with bending magnets. The beam matching is fixed by the FODO-cells and the compression rate can be tuned between 0.1 and 0.05 m. While the correlated emittance is kept relatively small, the slice emittance growth is important, both giving a large total emittance (table 1), even when resorting to shielding effects. All calculation and subsequent are for the BCIII design value ie : 1 nC with an initial emittance of 1 π.mm.mrad, compression from 200 to 50 μm @ 500 MeV. A simple 4-bend chicane was investigated in [5]. In addition to its simplicity, this compressor is dispersion free at all orders. The compression rate R_{56} could be tuned by varying the dipole field with a sufficiently large beam pipe. The slice emittance increase is highly dependent on the incoming beam matching and a minimum is achieved with a converging beam (figure 1). While the slice emittance is very attractive, the correlated emittance increase is important, leading to a large total transverse emittance, even when resorting to shielding effects. In both cases, the only way to reduce the total emittance down to 2 10^{-6} is to reduce the R_{56} down to 0.05 m yielding to an increase of the correlated energy spread. It is possible to reduce the energy spread by reducing, in the same ratio than the R_{56}, the incoming bunch length, but in return, it will increase again the transverse emittance growth by a shorter bunch in BCII.

		γε (π.mm.mrad)		
Type	Shielding	Slice	Correlated	Total
FODO-	none	2.3	0.6	3.6
cells	12 mm	1.5	1.4	3.
Chicane	none	1.4	7	10
	10 mm	1.1	2.7	4.3

Table 1 : Transverse emittance versus compressor type with R_{56}=0.1 m

Based on the double chicane compressor scheme separated by a -I transfer matrix, or simply on a double chicane of opposite deviation side, we investigated a simple S-chicane, sketched in figure 2, that can be considered as a chicane variation. It is also a dispersion free compressor at all orders and the slice emittance increase is also highly dependent on the beam matching. As for the chicane, a minimum is obtained with a converging beam.

		γε (π.mm.mrad)		
ΔL (m)	Shielding	Slice	correlated	Total
0.	None	1.9	0.7	3.1
0.6 m	None	1.9	0.4	3
1.5 m	None	1.9	1.2	3.3

Table 2 : Transverse emittance versus ΔL with R_{56}=0.1 m

The two inner magnets of opposite deviation present the advantage to compensate each other their effect on the correlated emittance.This compensation scheme can be optimized by moving the two inner magnets in bloc axially toward the end by a length ΔL (figure 2) of the compressor : in that way the R_{56} component of the second dipole (weak CSR) increases while the one of the third dipole (strong CSR) decreases, but keeping the total R_{56} and length of the S-chicane constant. We give in table 2 the different emittances obtained versus the displacement ΔL of the two inner magnets. While the slice emittance is unchanged, the correlated as well as the total emittance reach a minimum for ΔL = 0.6 m.

The compression factor can be also changed by varying the dipole angle. Although the transport is no longer fully achromatic, the induced increased emittance is negligible. The residual dispersion δD, when varying the deviation angle θ by δθ, with the same geometry and l the length of the outer dipoles, is given by:

$$\delta\vec{D} \approx (3/2\,\theta^2\delta\theta, 0)$$

With l = 0.3 m, $\Theta = 5°$ and $\delta\Theta = 1.5°$, the residual dispersion is only of 10^{-4} m and can be neglected.

S-Chicane		γε (π.mm.mrad)		
R_{56} (m)	shielding	Slice	Correlated	Total
0.10	None	1.9	0.3	3.1
0.10	12 mm	1.4	0.5	2
0.075	None	1.3	0.3	2
0.05	none	1.1	0.2	1.5

Table 3 : Transverse emittance versus R_{56}

In table 3 we give the different emittances obtained when reducing the R_{56} from 0.1 to 0.05 m with the two inner magnets moved toward the end by ΔL = 0.6 m. The geometry of BCIII and its main characteristics are sketched in figure 2 and resumed in table 4. Without resorting to the shielding, it is then possible to reduce the total emittance in the 2 π.mm.mrad region with R_{56} equal or lower than 0.075 m, while a 12 mm beam pipe height shielding is needed to obtain such emittance with R_{56} = 0.1 m.

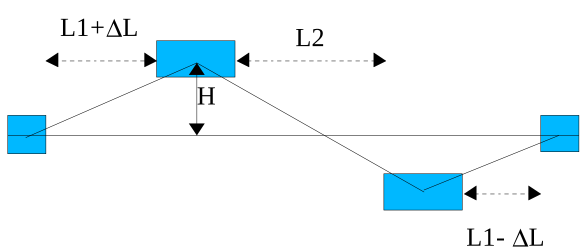

Figure 2 : Sketch of S-chicane compressor

R_{56}	0.1 m	0.05 m
L1+ΔL	3.64 m	3.64 m
L1-ΔL	2.44 m	2.44 m
L2	6.38 m	6.38 m
H	0.34 m	0.24 m
Dipole length (inner/outer)	0.6 / 0.3 m	0.6 / 0.3 m
Dipole field	0.5 T	0.35 T
Dipole deviation (inner/outer)	10 / 5°	7/3.5°

Table 4 : Characteristics of the S-chicane.

4 CONCLUSION

In this paper, we proposed a 4-bend S-chicane with a variable compression factor R_{56} as a possible solution for the final bunch compressor of TTF-FEL. Beside its simplicity, this compressor allows to maintain a transverse emittance lower or equal to 2 π.mm.mrad as well as an energy dispersion lower than 1 MeV, when compressing a 1 nC bunch from 200 to 50 µm at 500 MeV.

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