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Layout of bunch compressor for Beijing XFEL test facility

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Abstract

In this paper, we describe the layout of the bunch compressor for the Beijing XFEL test facility (BTF). Our bunch compressor setup is different from the usual one due to the space limit. The compensation X-BAND cavity and the first bunch compressor are separate in distance. The electron bunch is decelerated first and then accelerated to enter the first bunch compressor. The simulation result shows that our setup works well, and the nonlinear term is well compensated. Also, we present the result about the CSR emittance dilution study. Finally, we develop a program to study microbunch instability in the second BTF bunch compressor.

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Keywords: Bunch compressor; Beam dynamics; XFEL

1. Introduction

The Beijing X-ray free electron laser test facility (BTF) [1] is proposed to reside in the BEPCII linac which is the best electron linear accelerator in China. BTF will not use the existing DC gun preinjector, but will use photoinjector to obliquely inject electron bunch to the main linear accelerator of BEPCII through low energy transport line DL1. At the same time, three accelerator sections will be removed in order to install two magnetic bunch compressors (BC1, BC2) to compress the electron bunch. After the accelerator section A46, the beam is extracted and injected to the undulator through high-energy transport line DL2. BTF will provide the electron beam with the energy of 1.2 GeV, the energy spread of 0.15%, the normalized emittance less than 2.5 mm mrad, and the peak current of 600A. Fig. 1 is the schematic layout of BTF, the two bunch compressors divide the main linac into three sections: L_1, L_2 and L_3. In particular, the compensation X-BAND cavity is placed immediately after the photoinjector and before DL1, since there is no available space in the main linac.

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2. Bunch compressor and beam dynamics

In order to obtain the BTF accelerator output parameter, we need to choose the parameters of each section of the linac to get the correct accelerating and compressing. The parameters which we can change include the strength of the bunch compressor, the energy of the bunch compressor, and the accelerating phases of each linac section. The optimized parameters of BTF accelerator are shown in Table 1.

The two bunch compressors of BTF adopt the C type four-dipole chicanes, and the main parameters are presented in Tables 2 and 3.

With the above parameters, we have done start-to-end simulation. The photoinjector is composed of 1.6 cells BNL-type RF gun and two S-BAND accelerating structure sections. The beam parameters from the photoinjector are the energy: 153 MeV, the relative energy spread: 0.14%, normalized horizontal emittance: 1.23 mm mrad. The beam parameters after the high-energy transport line DL2 are the energy: 1.2 GeV, the relative energy spread: 0.12%, and the normalized horizontal emittance 1.42 mm mrad. BTF FEL is proposed to adopt two-stage cascading HGHG method. With the beam parameters from our start-to-end simulation of BTF accelerator, the FEL output power is 1 GW at

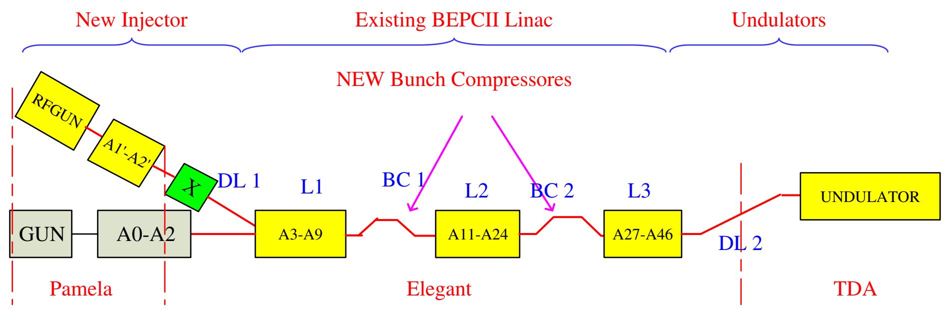

Fig. 1. Schematic layout of BTF.

Table 1
The optimized parameter of each section

	E_{in} (GeV)	E_{out} (GeV)	$\sigma_{z\text{-in}}$ (mm)	$\sigma_{z\text{-out}}$ (mm)	$\sigma_{\delta\text{-in}}$ (%)	$\sigma_{\delta\text{-out}}$ (%)	ϕ_{rf} (°)	R_{56} (mm)
L_1	0.136	0.344	0.87	0.87	0.2	1.53	−29	—
BC1	0.344	0.344	0.87	0.34	1.53	1.53	—	−31.5
L_2	0.344	0.700	0.34	0.34	1.53	1.11	−29.8	—
BC2	0.700	0.700	0.34	0.14	1.11	1.11	—	−15
L_3	0.700	1.18	0.14	0.14	1.11	0.12	40	—

Table 2
BC1 parameters

Parameter	Value	Unit
Energy	0.344	GeV
Energy spread (rms)	1.53	%
Compressing ratio (rms)	2	
R_{56}	~31.5	mm
Total length	3.05	m
Project distance between the first and second bend magnet	0.85	m
Project distance between the second and third bend magnet	0.55	m
Bend length	0.2	m
Deflection angle	7.28	degree
Emittance dilution	7	%

Table 3
BC2 parameter

Parameter	Value	Unit
Energy	0.70	GeV
Energy spread (rms)	1.11	%
Compressing ratio (rms)	3.5	
R_{56}	~15	mm
Total length	7.77	m
Project distance between the first and second bend magnet	3.2	m
Project distance between the second and third bend magnet	0.17	m
Bend length	0.2	m
Deflection angle	3.6	degree
Emittance dilution	20	%

the wavelength of 45 nm and 0.41 GW at the wavelength of 9 nm.

3. X-BAND compensation cavity

In the electron longitudinal phase space, the relation of energy and time is not completely linear, the high order nonlinear terms are incorporated due to the different accelerating phases, and the main contribution is from the second-order term. When the bunch is compressed, these nonlinear terms can lead to a serious nonuniform of longitudinal phase space, and the locally high peak current will occur to strengthen the CSR effect. Therefore, the emittance dilutes and the local energy spread deteriorates. Using a X-BAND harmonic cavity, the second-order term effect can be compensated. In BTF, there is no available space to place the X-BAND cavity in the main linac, so we place the cavity immediately after the photoinjector and before the low-energy transport line. The X-BAND cavity and the first bunch compressor are placed separately. Our setup is different from the usual compensation method. The electron bunch is decelerated first and then accelerated. The simulation shows that this layout also works well, and the second-order term is compensated effectively. In our setup, the compensation cavity decelerating voltage is also given as [2]:

$$eV_x = \frac{E_0\left[1-(1/2\pi^2)(\lambda_s^2 T_{566}/R_{56}^3)(1-\sigma_z/\sigma_{z0})^2\right]-E_i}{(\lambda_s/\lambda_x)^2-1}.$$

In BTF design, $\lambda_s/\lambda_x = 4$, $R_{56} = -31.5\,\text{mm}$, $T_{566} \approx 47.25\,\text{mm}$, $E_i = 324\,\text{MeV}$, $E_0 = 7\,\text{MeV}$, $\sigma_{z0} = 870\,\mu\text{m}$ and