Nuclear Instruments and Methods in Physics Research A 764 (2014) 48–52

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Generation of energy bands in the electron beam with an asymmetric chicane-type emittance exchange beamline

Bo-Cheng Jiang*, Zhen-tang Zhao, Chao Feng

Shanghai Institute of Applied Physics, Chinese Academy of Sciences, Shanghai 201204, China

ARTICLE INFO

Article history:
Received 18 April 2014
Received in revised form
17 June 2014
Accepted 27 June 2014
Available online 10 July 2014

Keywords:
Emittance exchange
Energy bands
EEX-HHG
FEL

ABSTRACT

An asymmetric chicane-type transverse to longitudinal emittance exchange beam line is investigated and presented in this paper. This design is more feasible for existing machines due to its coaxial arrangement of the components and dispense of symmetric requirement of two doglegs compared to two-dogleg type one. By inserting quadrupoles between the dogleg and deflecting cavity, the dispersion can be amplified and hence the bending angle of the chicane is reduced with the same deflecting cavity parameters which will reduce the coherent synchrotron radiation effect.

1. Introduction

Transverse to longitudinal emittance exchange (EEX) has been proposed and widely investigated theoretically [1–4] and experimentally [5,6]. The EEX scheme is now beyond its original application of exchanging emittances between the transverse and the longitudinal planes to get smaller transverse emittance for free electron laser (FEL) purpose. The 4-D beam phase space manipulation is possible nowadays to meet the demands of various applications [7–10]. One of them is the generating high harmonic of the seed laser for producing short wave length FEL(EEX-HHG) [8,9]. In this scheme, an EEX beam line with a multi-slit mask at the entrance segments the beam into a series of beamlets separated in horizontal plane, which will produce energy bands at the exit of the beam line. After energy bands were created, the beam energy was modulated by a seed laser in a short undulator. The following chicane will convert energy modulation to longitudinal density modulation which will contain high harmonics of the seed laser. The scheme is similar to the echo-enabled harmonic generation scheme [11] for which the energy bands is created by an over suppressing chicane of an energy modulated bunch. The key technique of EEX-HHG is the energy bands generation using EEX beam line. This paper is following EEX-HHG scheme to investigate EEX capability of a new type beam line named as asymmetric chicane-type EEX beam line.

The EEX beam line proposed in [1] and experimentally demonstrated in [6] is a two-dogleg type EEX. In this case the beam line preceding and following the deflecting cavity is non-coaxial which places some obstacles for its adoption to the existing linac. Recently a chicane-type EEX beam line has been proposed [12] that an exact emittance exchange and even phase space exchange can be achieved by adding two quadrupoles before the deflecting cavity to change the sign of the dispersion function, thus one of the doglegs' bending angle can be reversed which makes the whole beam line coaxially. A forward step has been made to amplify the dispersion function which allows a reduction of RF deflecting voltage or a reduction of bending angles of the chicane magnets so as to match the EEX requirement $\eta^* k = -1$($\eta^* = -N\eta$, where η is the dispersion function of a half chicane, η^* is the amplified dispersion function see by the cavity, N is the amplification factor, k is the deflecting cavity strength parameter). This type of beam line is called a telescope EEX beam line.

In this paper, a novel idea is proposed, i.e. the doglegs preceding and following the deflecting cavity can be asymmetric. As long as $\eta^* k = -1$ is satisfied, an exact emittance exchange will be achieved for thin lens approximation. For such an asymmetric chicane-type emittance exchange beamline, the design will be more flexible. In this paper, we will show that only the first dogleg needs to match with input beam parameters. The second one can be flexible. The bending magnet can be weaker as long as there is enough drift space. The transfer matrix analysis is performed for the asymmetric chicane-type EEX beam line and an emittance dilution formula is derived analytically. The simulations were performed to benchmark against the theoretical prediction. The coherent synchrotron radiation (CSR) effect to the emittance dilution is also checked out.

* Corresponding author.
E-mail address: jiangbocheng@sinap.ac.cn (B.-C. Jiang).

http://dx.doi.org/10.1016/j.nima.2014.06.079

2. Transfer matrix of asymmetric EEX beam line

2.1. Beam transfer matrix

The asymmetry chicane-type EEX beam line is similar to telescope EEX beam line [12] as shown in Fig. 1. Two focusing quadrupoles Q1, Q2 with focal lengths $f1$ and $f2$ are placed in front of the deflecting cavity. The space between them is $f1+f2$. And a pair of focus–defocus quadrupoles Q3, Q4 with focal lengths $f3$ and $-f4$ are placed behind the cavity. The space between them is $f3-f4$. We define

$$N_1=\frac{f_2}{f_1}. \tag{1}$$

$$N_2=\frac{f_3}{f_4} \tag{2}$$

If f_3=f_4, N_2 will equal to 1 and Q3, Q4 will be vanished.

Two bending magnets with opposite magnet field with a drift space in between (half of the chicane) is called a dogleg [1]. The transfer matrix (only horizontal and longitudinal planes are considered) of the dogleg is shown in Eq. (3) and the transfer matrix of deflecting cavity for thin lens approximation can be written in Eq. (4).

$$R_{L1,2}=\begin{bmatrix} 1 & L_{1,2} & 0 & \eta_{1,2} \\ 0 & 1 & 0 & 0 \\ 0 & \eta_{1,2} & 1 & \xi_{1,2} \\ 0 & 0 & 0 & 1 \end{bmatrix}, \tag{3}$$

$$R_{Cthin}=\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & k & 0 \\ 0 & 0 & 1 & 0 \\ k & 0 & 0 & 1 \end{bmatrix}, \tag{4}$$

where subscript 1, 2 denotes the first and the second dogleg, respectively. $L_{1,2}=(2L_{b1,2}cos\theta_{1,2}+D_{1,2})/\cos^2(\theta_{1,2})$ [13], $L_{b1,2}$ are the bending magnets' lengths, $\theta_{1,2}$ is the bending angle, $D_{1,2}$ is the drift space between the bending magnets, $\eta_{1,2}$ and $\xi_{1,2}$ are the dispersion and momentum compaction function of doglegs.

The transfer matrix of quadrupole doublets prior to and after the deflecting cavity can be respectively written under here,

$$R_B=\begin{bmatrix} -N_1 & a & 0 & 0 \\ 0 & -1/N_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \tag{5}$$

$$R_D=\begin{bmatrix} 1/N_2 & b & 0 & 0 \\ 0 & N_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \tag{6}$$

where

$$a=f_1+f_2-N_1L_1-L_2/N_1, \tag{7}$$

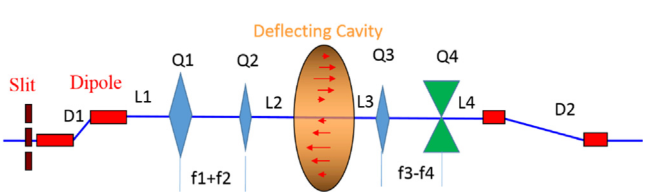

Fig. 1. The slit is imposed at the entrance of the EEX beam line.

$$b=f_3-f_4+N_2L_4+L_3/N_2. \tag{8}$$

To match an exact EEX, we needs:

$$\eta_1k=\frac{1}{N_1}, \tag{9-1}$$

$$\eta_2k=-1/N_2. \tag{9-2}$$

Multipling matrixes of the different sectors and substituting Eqs. (9-1, 9-2), the transfer matrix of the whole beam line can be written as

$$R=\begin{bmatrix} 0 & 0 & k(b+L_2N_2) & -\frac{1}{kN_2}+k(b+L_2N_2)\xi_1 \\ 0 & 0 & kN_2 & kN_2\xi_1 \\ -kN_1\xi_2 & \frac{1}{kN_1}+k(a-L_1N_1)\xi_2 & 0 & 0 \\ -kN_1 & k(a-L_1N_1) & 0 & 0 \end{bmatrix}. \tag{10}$$

The 4×4 matrix R in Eq. (10) is constructed from four 2×2 blocks [2], A, B, C, and D as follows

$$R=\begin{bmatrix} A & B \\ C & D \end{bmatrix}, \tag{11}$$

where

$$A=\begin{pmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{pmatrix}, B=\begin{pmatrix} R_{13} & R_{13} \\ R_{23} & R_{24} \end{pmatrix}, \text{etc.}$$

The emittance exchange can be therefore written as [2],

$$\varepsilon_x^2=|A|^2\varepsilon_{x0}^2+|B|^2\varepsilon_{z0}^2+tr\{(A\sigma_xA^T)^aB\sigma_zB^T\}, \tag{12}$$

$$\varepsilon_z^2=|C|^2\varepsilon_{x0}^2+|D|^2\varepsilon_{z0}^2+tr\{(C\sigma_xC^T)^aD\sigma_zD^T\}, \tag{13}$$

where ε_x, ε_z are the transverse and longitudinal emittances respectively, A^a is the adjoint (or symplectic conjugate) of A. $|A|$ is determinant of A and $tr\{\}$ is the trace of the matrix.

With $\sigma_x=\begin{bmatrix} \varepsilon_{x0}\beta_{x0} & -\varepsilon_{x0}\alpha_{x0} \\ -\varepsilon_{x0}\alpha_{x0} & \varepsilon_{x0}\gamma_{x0} \end{bmatrix}, \sigma_z=\begin{bmatrix} \varepsilon_{z0}\beta_{z0} & -\varepsilon_{z0}\alpha_{z0} \\ -\varepsilon_{z0}\alpha_{z0} & \varepsilon_{z0}\gamma_{z0} \end{bmatrix}$.

It can be found out that (where subscript 0 means input bunch parameters):

$$|A|^2=|D|^2=0, \tag{14}$$

$$|B|^2=|C|^2=1, \tag{15}$$

$$tr\{(A\sigma_xA^T)^aB\sigma_zB^T\}=tr\{(C\sigma_xC^T)^aD\sigma_zD^T\}=0. \tag{16}$$

Eqs. (14)–(16) means that an exact emittance exchange between transverse and longitudinal planes has been achieved.

For a thick lens approximation, the beam transfer matrix of the cavity can be written into [2]:

$$R_C=\begin{bmatrix} 1 & Lc & kLc/2 & 0 \\ 0 & 1 & k & 0 \\ 0 & 0 & 1 & 0 \\ k & kLc/2 & k^2Lc/4 & 1 \end{bmatrix}, \tag{17}$$

where Lc is the length of the cavity. The transfer matrix for the whole beam line is given by

$$R=\begin{bmatrix} 0 & \frac{-Lc}{4N_1N_2} & \frac{kLc}{4N_2}+k(b+L_2N_2) & \frac{-4+k^2(Lc+4N_2b+4{N_2}^2L_2)\xi_1}{4kN_2} \\ 0 & 0 & kN_2 & kN_2\xi_1 \\ -kN_1\xi_2 & \frac{4-k^2(Lc+4N_1^2L_1-4N_1a)\xi_2}{4kN_1} & \frac{k^2Lc\xi_2}{4} & \frac{k^2Lc\xi_1\xi_2}{4} \\ -kN_1 & -\frac{k(Lc+4N_1^2L_1-4N_1a)}{4N_1} & \frac{k^2Lc}{4} & \frac{k^2Lc\xi_1}{4} \end{bmatrix}. \tag{18}$$