LATTICE DESIGN OF BEAM TRANSPORT SYSTEM OF FELI

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Abstract

A plan of lasing wide range FEL (Free Electron Laser) is in progress at FELI. For this purpose, an S-band linac accelerator system of four output energy levels is under construction. This paper describes the lattice design of its beam transport (BT) system.

Introduction

FELI is planning to generate wide range FEL from infrared(20 μm) to ultraviolet(0.3 μm) for variety of application researches in the future. The authors designed an S-band linac accelerator system[1,2] with four output energy levels of 30, 75, 120, 165 MeV and corresponding four BT and lasing sections.

As linacs have poor capability of beam quality improvement, it is very important not to degrade qualities of the electron beam extracted from accelerating sections.

In order to preserve beam qualities, the authors designed to lay out the accelerator components in a straight line as far as possible to avoid beam quality degrading, which is mainly due to bending. For beam offsetting sections, we adopted a "chicane" of S-type, point symmetrical, double achromatic lattice, expecting that the effect of the counter bending of two bending magnets cancels the degrading of beam qualities including nonlinear effects. Successful lasing of FELIX[3] also suggests the merit of such point symmetrical lattice.

As achromaticity requires fixed and strong quadrupole field corresponding the geometry of the chicane, there is no means of leveling the rapid oscillation of beam size along the beam line.

Therefore, the authors used a strong triplet of quads after the last bending magnet to adjust beam profile and to make a small beam waist in the region of succeeding undulator. Electron beam, which has got through an undulator, is adjusted with its profile by a doublet of quads and is introduced into a water beam dump in a small room located in a side wall of accelerator room. Besides, the BT system can return the used electron beam to the main accelerating line through the succeeding S-type chicane as the same as offsetting chicane. Here, not only a strong triplet prepared but also additional several quads and accelerating tubes (treated as drift spaces) are necessary for the improvement of the profile and qualities of the returned electron beam getting through strong quadrupole field of the achromatic chicane. Total system including its layout is described by T. Tomimasu[1].

Lattice Design of Offsetting Chicane

The lattice of beam offsetting chicanes with 0.9 m offset is an S-type point symmetrical, double achromatic lattice composed of a triplet of quads and a pair of 22.5 deg bending magnets. Their bending radii are 0.5 m for 30 MeV and 75 MeV, 0.75 m for 120 MeV, and 1m for 165 MeV chicanes, respectively.

Bending magnets deform longitudinal structures of electron bunches according to their emittance and energy deviation. In order to maintain longitudinal bunch structures that has been made up at injection system, the offsetting chicane should satisfy isochronicity, to say nothing of achromaticity. Considering that an exactly isochronous lattice needs at least three bending magnets[4], the authors compared two candidate lattices as Fig.1. Lattice A is a point symmetrical, isochronous lattice with four 22.5 deg bending magnets, and lattice B is an ordinary, point symmetrical, double achromatic lattice with two 22.5 deg bending magnets.

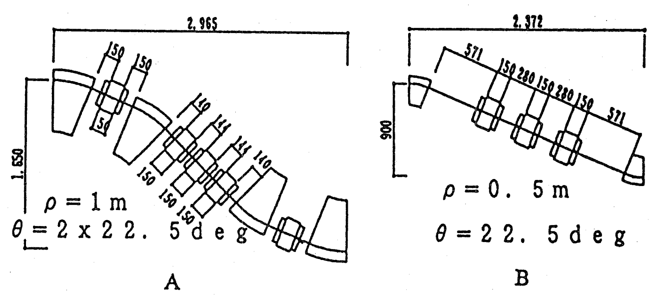

Fig. 1 Isochronous Lattice - A: a point symmetrical, isochronous lattice with four 22.5 deg. bending magnets, and B: normal, point symmetrical, double achromatic lattice with two 22.5 deg bending magnets

Table 1 Comparison of Candidate Lattices

Lattice Type	A	B
Total Bending Angle	45 (22.5x2) deg	22.5 deg
Offset	1.65 m	0.9 m
Field Gradient(Ka/Kb/Kc)	(34.0/-40/42.3)m^{-2}	(32.1/-30/*)m^{-2}
Contribution of ⊿P/P on Flight Time Difference	0	1.0mm(3.3ps) (⊿P/P=1%)
Total Lattice Planning	Difficult	Possible

Following the notations of codes TRANSPORT[5] and DIMAD[6], first-order beam optics can be expressed using transformation matrix as follows.

$$x_i^{out} = \sum_{j=1}^{6} R_{ij} x_j^{in} \qquad (1)$$

where, $x_1=x$, $x_2=x'$, $x_3=y$, $x_4=y'$, $x_5=\ell$ (the path length difference between an arbitrary particle and the central trajectory), $x_6=\Delta P/P$ (fractional momentum deviation of the particle from the assumed central trajectory). Using this expression, a lattice is achromatic or isochronous if its transformation matrix satisfies following relations[6].

Achromaticity ...... $R_{16}=R_{26}=0$ (2)

Isochronicity ...... $R_{51}=R_{52}=0$ (3a), $R_{56}=0$ (3b)

It must be noted that equations (2) and (3a) are equivalent, and therefore, an isochronous system is necessarily achromatic[4,5].

A DIMAD calculation gives Table 1 which suggests that (1) the exactly isochronous lattice A requires too large quadrupole field gradient, which results in too large beam radius, and (2) for the double achromatic lattice B, chromatic contribution of 0.3 % energy deviation is 1.0 ps (0.3 mm). The transformation matrix of lattice B is as follows.

$$R=\begin{pmatrix} 1.20899 & 0.21964 & 0 & 0 & 0 & 0 \\ 2.10187 & 1.20899 & 0 & 0 & 0 & 0 \\ 0 & 0 & 2.65614 & 3.94337 & 0 & 0 \\ 0 & 0 & 1.53551 & 2.65614 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0.10013 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix} \quad (4)$$

Considering that the component R_{56}(=0.10013) is twice as large as that of each 22.5 deg bending magnet(=0.05007), increases of bunch length due to energy deviation is summed up by each bending magnet. In fact, this component is proportional to $\rho\,\theta$ (the product of radius and angle of bending) and smaller radius ρ and angle θ of bending give smaller chromatic contribution of energy deviation.

Besides, Fig.2 obtained by TRANSPORT shows the changes of microbunch length. This figure suggests that this type of lattice practically cancels bunch elongation effects of each bending magnet as mentioned by M. Berz[7]. In addition, it is useful that these characteristics are independent of the distance between two bends or positions of quads. Appreciating these properties and simplicity of lattice structure, the authors adopted lattice B for the offsetting chicane of their BT design.

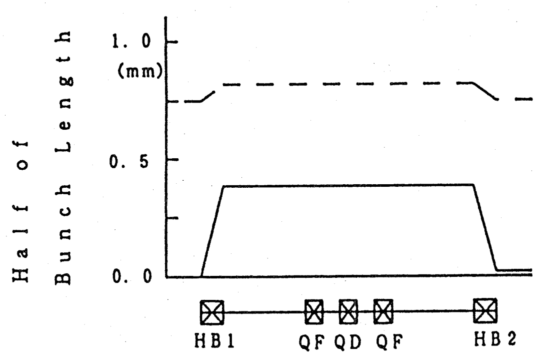

Fig. 2 Change of Bunch Length through Lattice B
Result of TRANSPORT Calculation with Entrance Beam Conditions of x≦1mm, x'≦1mrad, and ℓ (bunch length) =0(solid line), ≦±0.75mm(dashed line).

Magnetic Buncher

The authors are planning to use a magnetic buncher as shown in Fig.3 before the last accelerating section, for additional compression of longitudinal bunch structure of electron beam. Differentiating the length of trajectory written as Eq.(5) through energy dependent variable ρ, and taking the lowest order of (L/ρ), difference of trajectory due to energy deviation can be approximated as Eq.(6).

$$\ell = 4OA+2AB = 4\rho\sin^{-1}(L/\rho)+2\lambda/\sqrt{1-(L/\rho)^2} \quad (5)$$

$$\Delta\ell = -(L/\rho)^3(2\lambda/L+4/3)(\Delta\rho/\rho) \quad (6)$$

Using designed value of θ=30 deg and $L=\lambda$=0.15 m, we obtain Eq.(7), which suggests considerable compression of electron bunches.

$$\Delta\phi = -4.3(\Delta\rho/\rho)\% \quad (\text{for } \theta=30 \text{ deg}) \quad (7)$$

For 0.3% of $\Delta P/P(=-\Delta\rho/\rho)$, one can expect phase bunching of 1.3 deg. This is enough compression to the bunches of 3-5 deg. Besides, this buncher is effective for degraded beam returned from preceding lasing undulator sections. This type of magnetic buncher has additional merit that we can flexibly choose bunch compression rate, because one can continuously change bending angle, and therefore corresponding bending radius.

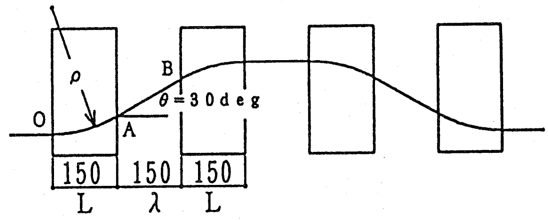

Fig. 3 Geometric Parameters of Magnetic Buncher

Lattice Calculation

In order to check the feasibility of the lattice design, the authors calculated, with code MAGIC, beam radius distribution throughout a total trajectory including offset chicanes, undulator sections, return chicanes. Boundary conditions at the calculation starting point, i.e., the outlet point of buncher, are E=5 MeV, x=y=1 mm, x'=y'=1 mrad corresponding the normalized emittance of 10π mm・mrad, and $\beta_x = \beta_y$=1 m.

Figure 4(a) shows total layout of the BT system of FELI accelerator system and the trajectory adopted for calculation. Fig.4(b) shows a detail of the beam line around the lowest energy, 30 MeV, IR undulator. Figure 4(c) represents the calculated result showing that the BT system can focus electron beams at the center of lasing undulators. Beam profile at undulator section can be adjusted flexibly, and Fig. 4 (c) shows that the minimum beam waist radius will be less than 0.5 mm at the lowest energy IR undulator. Of course, beam waists become narrower for higher energy undulator sections. This figure also shows how the returned electron beam getting through strong quadrupole field of chicanes is controlled by succeeding quads.

Summary and Discussion

This paper presented a lattice design of the BT system of FELI accelerator system. This BT system has double achromatic and almost isochronous, S-type chicanes and a magnetic buncher. The authors had discussed about the isochronicity of the chicane lattice and capability of a magnetic buncher. Lattice calculations showed the feasibility of the total lattice design. The BT system can flexibly choose the location of waist points at the lowest energy undulator region with a minimum beam radius of 0.5 mm.

References

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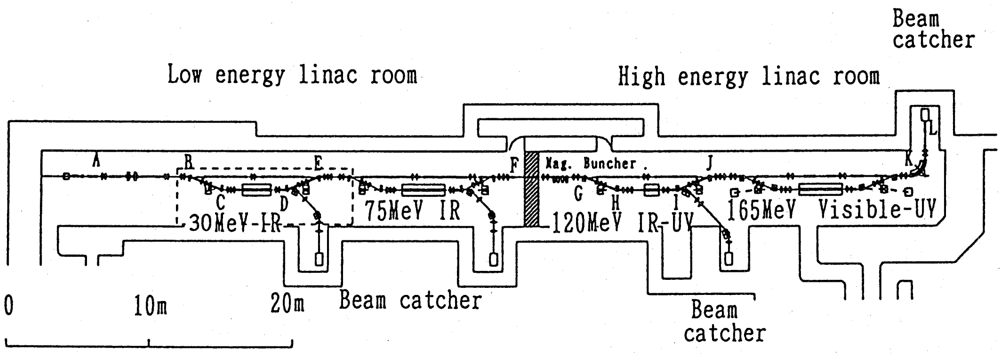
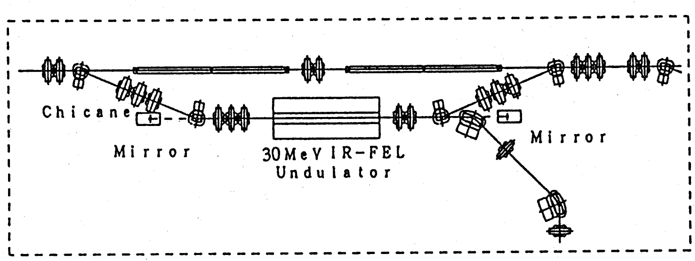
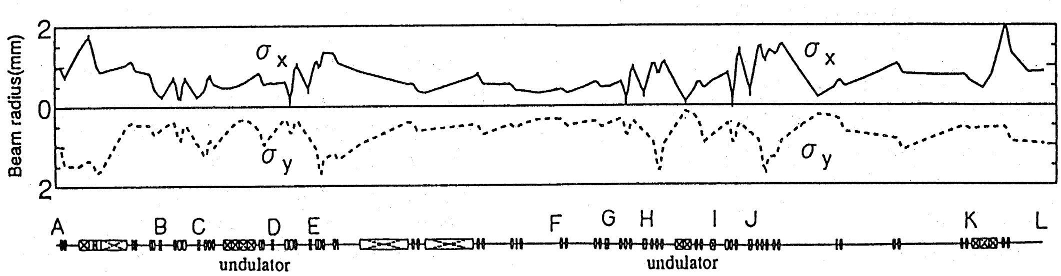


(a) Layout of BT System



(b) Beam Line around 30 MeV, IR-FEL Undulator



(c) Distribution of Beam Radius along Beam Line Noted by A–L on (a)

Fig. 4 Layout of BT System and Distribution of Beam Radius.