ELECTRON BEAM OPTICS DESIGN OF VARIABLE ENERGY BEAM TRANSPORT LINE FOR A TUNABLE INFRA-RED FREE ELECTRON LASER AT RRCAT

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Abstract

A variable energy electron beam transport line has been designed to transport a 15-25 MeV electron beam from the injector linac to the undulator of a tuneable infra-red free electron laser (IR-FEL) being built at the Raja Ramanna Centre for Advanced Technology(RRCAT). Beam optics of this transport line, which uses a dog-leg type bend, has been designed to match the twiss parameters of the beam to that of the undulator as per FEL design requirements and keep the beam envelop within acceptable limits through out the transport line. In this paper, we discuss the evolution of design of electron beam optics from the linac to the undulator.

INTRODUCTION

A beam transport line, transports the charged particle beam from one accelerator/point to another accelerator/point. It is designed in such a way that minimum loss of particles takes place during the transport process and an adequate space is provided for the beam diagnostic devices and the vacuum components. Beam losses are minimised with the help of proper combination of quadrupole lenses. Phase space parameters of the beam are matched at the exit point of the line as per the requirements. Dispersion function and its derivative at the injection point are also matched. A tuneable beam transport line has been designed to transport a 15-25 MeV electron beam from an injector Linac to the injection point of an undulator which is used to produce a tuneable infra-red free electron laser (50µm-12 µm wavelength) [1]. A dogleg bend which is an achromatic as well as isochronous is required because of ~ ps bunch structure in FEL system. There were two main constraints on the design of the line. First, this line has to be housed in a 5 m wide tunnel so the lateral distance is not be more than ~ 3 m and second, the minimum bending angle, 22.5^0 of the bending magnets of the achromat.

DESIGN STRATEGY

Keeping in mind the requirements of the beam transport line, a 6.5 m long beam transfer line was designed from an injector linac to the injection point of the undulator. As shown in Fig.1 it has 2 bending magnets (with same bending angle 22.5^0 , BM1 bends to the left and BM2 bends to the right) in the dogleg bend structure, 6 focusing and 3 defocusing quadrupoles magnets for proper beam focusing and optical parameters (β_x, β_y, α_x, α_y, η_x, $\acute{\eta}_x$) matching at the injection point of the undulator.

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An achromat consists of two bending magnets and a quadrupole triplet. To achieve the achromatic condition a symmetric quadrupole triplet FDF was chosen. The strength of the quadrupoles was chosen in such a way that the dispersion function and its derivative becomes zero after the second bending magnet [3]. The change in the path length of the off momentum particle is given as:

$$\Delta L = \delta \int_0^L \frac{D(s)}{\rho(s)} ds \qquad (1)$$

Where D(s) is dispersion function, ρ(s) is bending radius and δ = fractional momentum change (ΔP/P). To achieve the isochronous condition, the change in the path length of the off momentum particle should be zero. Dispersion function was made oscillatory (phase advance 2 π) by making the magnetic structure mirror symmetric with respect to the centre of the defocusing quadrupole of the achromat so that the integral part in the equation becomes zero. Optical parameters (β_x, β_y, α_x, α_y,) at the injection point of the undulator were matched by optimizing the drift spaces and the strengths of the quadrupoles Q1, Q2, Q3, Q4, Q8 and Q9 as shown in the Fig. 1. The beam parameters for FEL are presented in the table1.We present next the detailed results of the 50 µm FEL beam optics design.

Table 1: The beam parameters for FEL

S.No.	**Parameters**	**At Linac Exit.**	**At Undulator Injection for FEL wavelength (µm)**		
			50	**30**	**12.0**
1	β_x	4.9 m	2.50 m	2.55 m	2.6 m
2	β_y	4.9 m	0.234 m	0.303 m	0.806 m
3	α_x	0.0	1.06	0.822	1.32
4	α_y	0.0	0.0	0.0	0.0
5	η_x	0.0	0.0	0.0	0.0
6	$\acute{\eta}_x$	0.0	0.0	0.0	0.0
7	ε_x mm-mrad	---	0.849	0.66	0.593
8	ε_y mm-mrad	---	0.849	0.66	0.593
9	ΔP/P (max.)	0.5 %	0.5 %	0.5 %	0.5 %

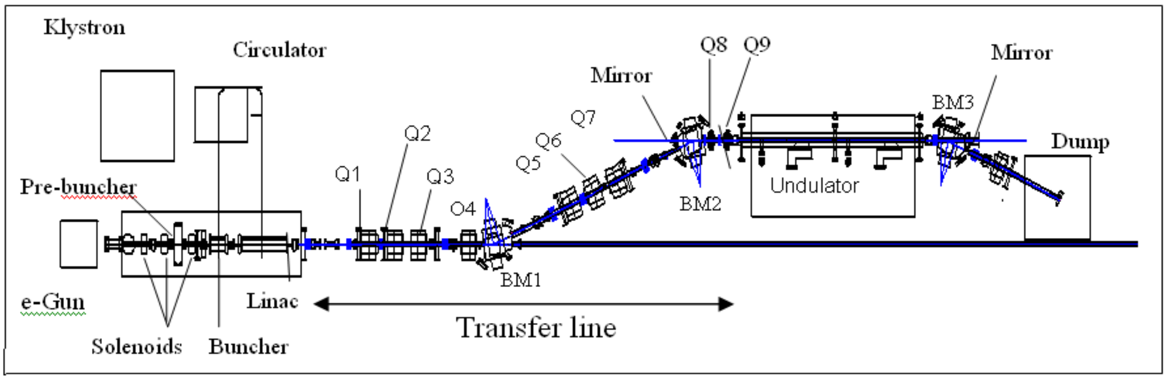

Figure 1: Layout of the IRFEL System

THE BEAM OPTICS DESIGN FOR 50 MICRON FEL

Both the bending magnets (rectangular) of the achromat have same bending angle 22.5° and same effective length 0.2 m. All 7 Quadrupole magnets from injector linac exit point to the end of the achromat structure have same effective length 0.2m. Last 2 Quadrupole magnets in the line have effective length of 0.082m. These two quadrupoles are slim as per the requirement of the compact 4.1m cavity FEL design. The Table-2 gives the quadrupole strengths for the 50 µm FEL design for 17.6 MeV beam.

Table-2: Strengths of the Quadrupole Magnets

S.No.	Quadrupole Magnet	Normalized Strength of the magnets (m^{-2})
1	Q1	4.29
2	Q2	-11.464
3	Q3	9.67
4	Q4	1.336
5,6	Q5, Q7	22.41
7	Q6	-23.77
8	Q8	- 40.887
9	Q9	39.258

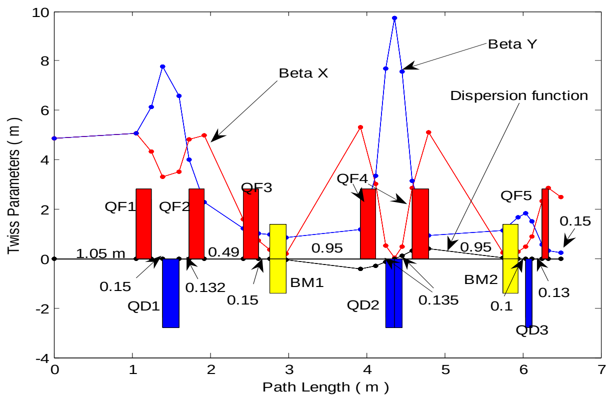

Figure 2: Lattice parameters in transport line

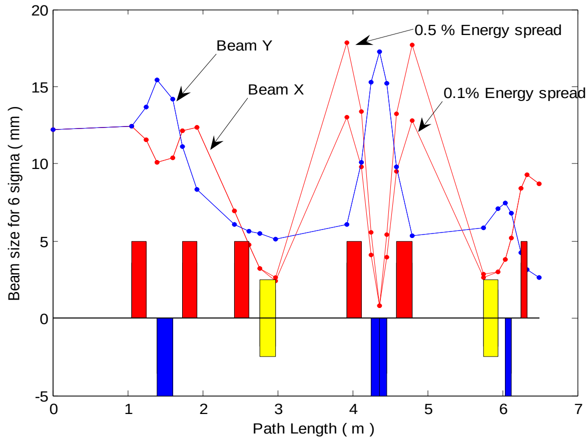

Figure 3: Beam envelope in the transport line

In figures-2 and 3 the twiss parameters and beam envelope are shown for the same case. Maximum beam size (± 3σ) is well within the good field region (±15 mm) of the quadrupoles within the beam line.

CONCLUSION

A beam transfer line with dogleg bend for 15-25 MeV electron beam was designed as per the requirement of the FEL design. Beam energy spread of 0.5 % was considered to see the maximum beam size in the dogleg bend due to dispersion. Beam sizes in the horizontal and the vertical planes were within acceptable limit through out the line.

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