THE BROOKHAVEN ACCELERATOR TEST FACILITY

LASER LINAC BEAM LINE

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ABSTRACT

We report here the low emittance beam transport line for laser acceleration experiments at the Brookhaven Accelerator Test Facility(ATF). In order to preserve the low emittance($\sim 10^{-10}$ m-rad) 50 MeV electron beam, great care has to be paid to the higher-order effects. The low-emittance transport line consists of two parts; the first part performs an emittance selection, and the other part provides the possibility of energy selection and beam transport to the experimental area.

1. INTRODUCTION

The Brookhaven Accelerator Test Facility is a facility dedicated to accelerator physics [1,2] and FEL R & D[3]. The short(6-picosecond) low-emittance electron beam is produced by photocathode RF-gun[4]. The beam will be accelerated to 50 MeV by two sections of SLAC type S-band linac(later this will be upgraded to 100 MeV).

The two major initial experiments at ATF are visible FEL and laser acceleration experiments. The FEL experimental beam line has been designed by

A. Steenbergen. Table 1 lists the beam parameters at the middle of the last matching quadrupoles before entering the first dipole. Fig.1 is the beam envelopes and dispersion along the FEL beam line while table 2 gives the element parameters of FEL beam line. Due to the budgetary and space constraints, we have decided that the laser acceleration experimental beam line will share as much as possible with the FEL line without compromising each experiment.

2. EMITTANCE SELECTION LINE

The laser acceleration beam line is required to perform emittance and energy selections besides transporting a low emittance($\sim 10^{-10}$ m-rad) 50 MeV electron beam to the experiment station. The best location of the emittance selection line will be after the exit of the linac, so it not only functions as emittance selector, but also as a matching section for the FEL line. The transport line will share the first dipole and the first three quadrupoles with FEL line, an extra dipole is needed to bend the beam to the experimental area and recombine the momentum.

We assume that the last triplet of the injection line[6] into the linac will produce a double parallel beam waist about 25 cm from the exit of the linac, where the first collimator will be located. Table 3 gives the beam parameters at that location. In order to effectively select the emittance of both transverse planes, the phase ellipse has to be rotated 90°. In TRANSPORT notation[5], the phase ellipse parameters at second collimator are:

$$\sigma_{11}(1) = R_{11}^2 \sigma_{11}(0) + R_{12}^2 \sigma_{22}(0)$$

$$\sigma_{22}(1) = R_{21}^2 \sigma_{11}(0) + R_{22}^2 \sigma_{22}(0)$$

$$\sigma_{12}(1) = R_{11}R_{21}\sigma_{11}(0) + R_{12}R_{22}\sigma_{22}(0)$$

since $\sigma_{12}(0) = 0$ at the first collimator. A similar formula can be written for $y - y'$ phase space. The emittance selection demands $R_{11} = R_{22} = 0$ and make R_{12} large. The emittance selected by the beam line is:

$$\epsilon = \frac{r_0^2}{R_{12}}$$

where r_0 is the one- σ beam size at the first collimator.

An antisymmetric beam line consisting of 6 quadrupoles can satisfy the above conditions simultaneously in both the x and y phase spaces, Table 4 lists the elements' parameters for the emittance selection line. We also consider the emittance increment caused by the chromatic effect. The emittance growth due to chromatic effect for a quadrupole can be estimated[6]:

$$\Delta\epsilon = \frac{\langle x^2 \rangle}{f} \frac{\Delta P}{P_0}$$

where f is the focal length of the quadrupole. Other parameters which play a large rule in deciding R_{12} are the drift distances before and after the third quadrupole, generally, the longer those drift distance are, the larger R_{12} . Our parameters were chosen so that the total length of the emittance selection line is about 5 m. Fig.2 is the beam envelopes of the emittance selection line.

3. ACHROMATIC TRANSPORT LINE

The next section of the laser linac beam line transports the collimated electron beam from the second collimator to the experiment area with $n\pi$ phase advance in both transverse directions, which providing energy selection. In the transport line, there are not only chromatic effects, but also geometric effects from the dipoles, it is very importance to keep the beam line symmetric and the beam sizes small so that emittance growth caused by all these effects are small. Due to the attractive properties of a telescopic system[7], we have studied two versions of telescopic system. Since the beam after the emittance selection is almost parallel, we first consider a quasi-telescopic system, which produce a parallel to parallel image only. Table 5 give the beam line parameters while fig.3 is plots of beam envelopes and dispersion for this line.

Since our quasi-telescopic system can image only perfect parallel beam into the parallel beam, for $R_{11} = R_{22} = -1$, the phase ellipse will be tilted from the upright position by:

$$\theta = \frac{\sigma_{22}}{\sigma_{11}} R_{12}$$

where σ_{22} and σ_{11} are phase ellipse's parameter at the second collimator. They are 1.5625×10^{-6} and 1.5625×10^{-2} , respectively. In our beam line, R_{12} is about 10, so the angle between the upright phase ellipse and our imaging ellipse is about 5.7×10^{-2} degree.

We then looked into a telescopic system, which can produce both a parallel-to-parallel and a point-to-point image simultaneously. Table 6 lists the parameters for such a system, and the beam envelopes and dispersion are plotted in fig. 4.

Comparing the two designs, the telescopic system is better from an optics point of view, but it has larger horizontal beam size which limits the energy selection, and therefore a larger emittance increase. The quasi-telescopic system is able of providing better energy selection, and is compatible with telescopic system. In summary, our achromatic beam line can operate in both modes, the mode of operation depending on the energy selection requirement and the emittance of the beam being transported to the experimental area.

Finally, we give the emittance selection line parameters as FEL matching section in table 7, and the beam envelopes from linac exit to the entrance of the first dipole are plotted in Fig. 5.

4. CONCLUSION

We have presented a complete beam line for the laser acceleration experiments of ATF. The beam line will perform the emittance and energy selection without significant increment of the transverse emittance. The effectiveness of emittance selection is restricted by the quadrupole strength and the drift space length.

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5. REFERENCES

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Table 1 Beam parameters at the matching point for FEL experiment

ϵ_z^a	7×10^{-2}	ϵ_y^a	7×10^{-2}
$x_{rms}(\text{mm})$	0.757	$x'_{rms}(\text{mrad})$	0.0925
$y_{rms}(\text{mm})$	0.193	$y'_{rms}(\text{mrad})$	0.3629
$(\frac{\delta P}{P_0})_{rms}(\%)$	0.3	$P_0(\text{Mev/c})$	100

^a 1 - σ geometric emittance in mm-mrad.

Table 2 FEL beam line elements parameters

	Length cm	Gradient Kg/cm	Field Kg
Quad	5.1	0.283112	
Drift	60		
Dipole	30		2.42528
Drift	110		
Quad	10	-0.236510	
Drift	200		
Quad	10	0.33678	
Drift	200		
Quad	10	-0.175984	
Drift	200		
Quad	10	0.261839	
Drift	200		
Quad	10	-0.494153	
Drift	110		
Drift	30(Space for IFEL sector dipole)		
Drift	80		
Quad	10	-0.559984	
Drift	45		
Quad	10	0.494130	
Drift	100		
Dipole	30		2.42528
Drift	40		
Drift	60(for wiggler)		
Drift	40		
Dipole	30		2.42528
Drift	100		
Quad	10	0.400229	
Drift	45		
Quad	10	-0.333525	
Drift	395		

Table 3 Beam parameters at the collimators for laser acceleration line

ϵ_z^a	1.56×10^{-4}	ϵ_y^a	1.56×10^{-4}
$x_{rms}(\text{mm})$	0.125	$x'_{rms}(\text{mrad})$	0.00125
$y_{rms}(\text{mm})$	0.125	$y'_{rms}(\text{mrad})$	0.00125
$(\frac{\delta P}{P_0})_{rms}(\%)$	0.2	$P_0(\text{Mev/c})$	50

^a 1 - σ geometric emittance in mm-mrad.

Table 4 Emittance selection beam line elements parameters

	Length	Gradient	Field
	cm	Kg/cm	Kg
Drift	25(from linac exit to the beam waists)		
Drift	15		
Quad	10.2	0.35877	
Drift	8		
Quad	10.2	-0.39558	
Drift	115		
Quad	20.4	0.53712	
Drift	120		
Quad	20.4	-0.53712	
Drift	115		
Quad	10.2	0.39558	
Drift	8		
Quad	10.2	-0.35877	
Drift	15		

Table 5 Parallel to parallel achromatic beam line elements parameters

	Length cm	Gradient Kg/cm	Field Kg
Drift	100		
Quad	10.2	0.28526	
Drift	15		
Quad	10.2	-0.27118	
Drift	60		
Dipole	30		1.21264
Drift	110		
Quad	10	0.21206	
Drift	200		
Quad	10	-0.13576	
Drift	200		
Quad	10	0.21206	
Drift	110		
Dipole	30		1.21264
Drift	60		
Quad	10.2	-0.27118	
Drift	15		
Quad	10.2	0.28526	
Drift	100		

Table 6 Telescopic achromatic beam line elements parameters

	Length cm	Gradient Kg/cm	Field Kg
Drift	99.867		
Quad	10.2	-0.29475	
Drift	15		
Quad	10.2	0.42944	
Drift	60		
Dipole	30		1.21264
Drift	110		
Quad	10	0.21206	
Drift	200		
Quad	10	-0.12522	
Drift	200		
Quad	10	0.21206	
Drift	110		
Dipole	30		1.21264
Drift	60		
Quad	10.2	0.42944	
Drift	15		
Quad	10.2	-0.29475	
Drift	99.867		

Table 7 FEL matching line parameters

	Length cm	Gradient Kg/cm	Field Kg
Drift	25		
Drift	15		
Quad	10.2	0.37661	
Drift	8		
Quad	10.2	-0.36124	
Drift	115		
Quad	20.4	0.0	
Drift	120		
Quad	20.4	0.0	
Drift	115		
Quad	10.2	0.12355	
Drift	8		
Quad	10.2	-0.27409	
Drift	115		
Quad	10.2	0.0	
Drift	15		
Quad	5.1	0.283112	

FEL BEAM LINE TRANSVERSE BEAM ENVELOPES
FOR $DP/P=0.3\%$

Fig. 1

EMITTANCE SELECTION LINE TRANSVERSE BEAM ENVELOPES
FOR $DP/P=0.2\%$

ACHROMATIC BEAM LINE TRANSVERSE BEAM ENVELOPES
FOR $DP/P=0.2\%$

Fig. 3

ACHROMATIC BEAM LINE TRANSVERSE BEAM ENVELOPES
FOR $DP/P=0.2\%$

Fig. 4

FEL MATCHING LINE TRANSVERSE BEAM ENVELOPES
FOR $DP/P=0.3\%$

Fig. 5

(M)

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