Calculation and simulation of optimal e-beam transport through quadrupoles and wiggled of the tandem free electron laser

A. Abramovich, Y. Pinhasi, L Merhsine A. Gover

One of the major difficulties in operating a free electron laser (FEL) is obtaining an optimal e-beam transport through the beam line of a FEL , which includes coils, quadrupoles , wiggled and other electron optics component. Here we present a method of obtaining an optimal beam transport using simulation code ELOP and optimization code QuadOpt.

In order to obtain optimal beam transport through the wiggler and quadruples we developed a procedure for determining the adjustable parameters of the wiggler and quads.

The procedure starts by determining with the aid of "*ELOP*" program what are the optimal position parameters of the entrance and exit correction magnets, so that an electron entering the wiggler on axis ($x=0$, $y=0$, $\alpha_x=0$, $\alpha_y=0$) propagates along the wiggler without betatron oscillation (only pure wiggling motion) and exits on axis.

The next step in the procedure is to simulate the optimal beam transport of an electron beam of finite emittance ε. To do this we first determine the phase space coordinates of the central electron (the on axis entering electron) at plane $z=0$ (center of the wiggler). To simulate a beam, we add at this plane 8 more electrons positioned in phase space (x, α_x) and (y, α_y) on the perimeters of exact ellipses of area ε , radiuses r_{b0} and $\alpha_0=\varepsilon/(\pi r_{b0})$ centered around the phase space coordinates of the central electron in this plane. These 8 electron are now propagated with "ELOP" in the negative direction producing in effect a "time reversed " picture of the beam propagation (see figure 1).

According to theory, if the beam radius r_{b0} is chosen according to (1) (in both x and y dimensions), then scalloping-free beam propagation should be exhibited. This is confirmed very well in Fig. 1 which demonstrates reversed beam propagation from z = 0 to z = -750 mm without scalloping in either the x or y dimension.

$$r_{b0} = \sqrt{\varepsilon / \pi k_\beta} \qquad (1)$$

Note that even though in our experiment the wiggling amplitude is larger than the beam radius (because of the large B_w and small γ), still the beam width stays uniform also in the x dimension, ideally kept in focus by the two longitudinal focusing magnets.

Relying on "ray reversibility" of electron-optics we may say that Fig. 1 describes correctly also the normal forward propagation of an electron beam of emittance ε, which injected into the wiggler with optimal parameters to avoid scalloping. This is an important result, because it allows us to determine the optimal waist parameters of the converging injected beam including the waist radiuses and waist positions. The waist radiuses are approximately known beforehand (about r_{b0} given by (1)), however their exact values and the exact virtual waist positions cannot be easily found without this simulations procedure, because the wiggler does not have a sharp start of the sinusoidal field as in the simple model. However with the present procedure the parameters of the virtual waists of the beam can be found by propagating again in the forward direction the 9 electrons lying on the oblique phase space ellipses of the z = -750 mm plane, this time with a vanishing magnetic field of the wiggler. The results are given in fig 2. These parameters are now the target waist parameters that should be achieved with the aid of the four quads at the entrance of the wiggler. Using the procedure we obtained four parameters of the beam radii X_{bo}, Y_{bo} and the waists positions relative to the physical end (first magnet place) of the wiggler Δ_x ,Δ_y. The simulation results are summarized in Table 1 for $\varepsilon=22\pi$ mm*mrad.

The trajectory parameters obtained previously are used as input for the "QuadOpt" optimization code in order to find the required excitation currents for quadrupoles Q1 - Q4 . The required exitation currents are also given in Table 1.

Table 1. Electron beam parameters and calculated required quadrupole currents

	Waist Parameters (mm)				Quadrupole Currents (A)			
Emittance (mm*mrad)	X_{bo}	Δ_X	Y_{bo}	Δ_Y	I_1	I_2	I_3	I_4
22*π	1.02	15	1.61	25	1.36	1.14	1.35	0.81

Finally we used the *"ELOP"* program to obtain results of 9-electrons beam transport through the whole system of first 4 quads (Q1-Q4), wiggler and the second set of quads (Q5-Q8); currents for quadrupoles Q5 - Q8 were determined in a similar manner with some manual changes due to imperfection beam transport through the wiggle. The parameters of the wiggler exit and excitation currents of the quadrupols Q5-Q8 are given in table 2.

	Waist Parameters (mm)				Quadrupole Currents (A)			
Emittance (mm*mrad)	X_{bo}	Δ_X	Y_{bo}	Δ_Y	I_5	I_6	I_7	I_8
22*π	1.02	15	1.61	25	0.65	1.30	1.23	1.90

Figure 3 show the beam transport from screen S1 located at accelerator exit to the entrance to the deceleration region. Also fig 3 show the positions of the screens S1, S2 and S3 . the diameter at those location are give in table 3.

Table 3: beam diameter on the screens

Diameter [mm]	Screen S1	Screen S2	Screen S3
X direction	**7.5**	**5**	**7.5**
Y direction	**7.5**	**6**	**7.5**

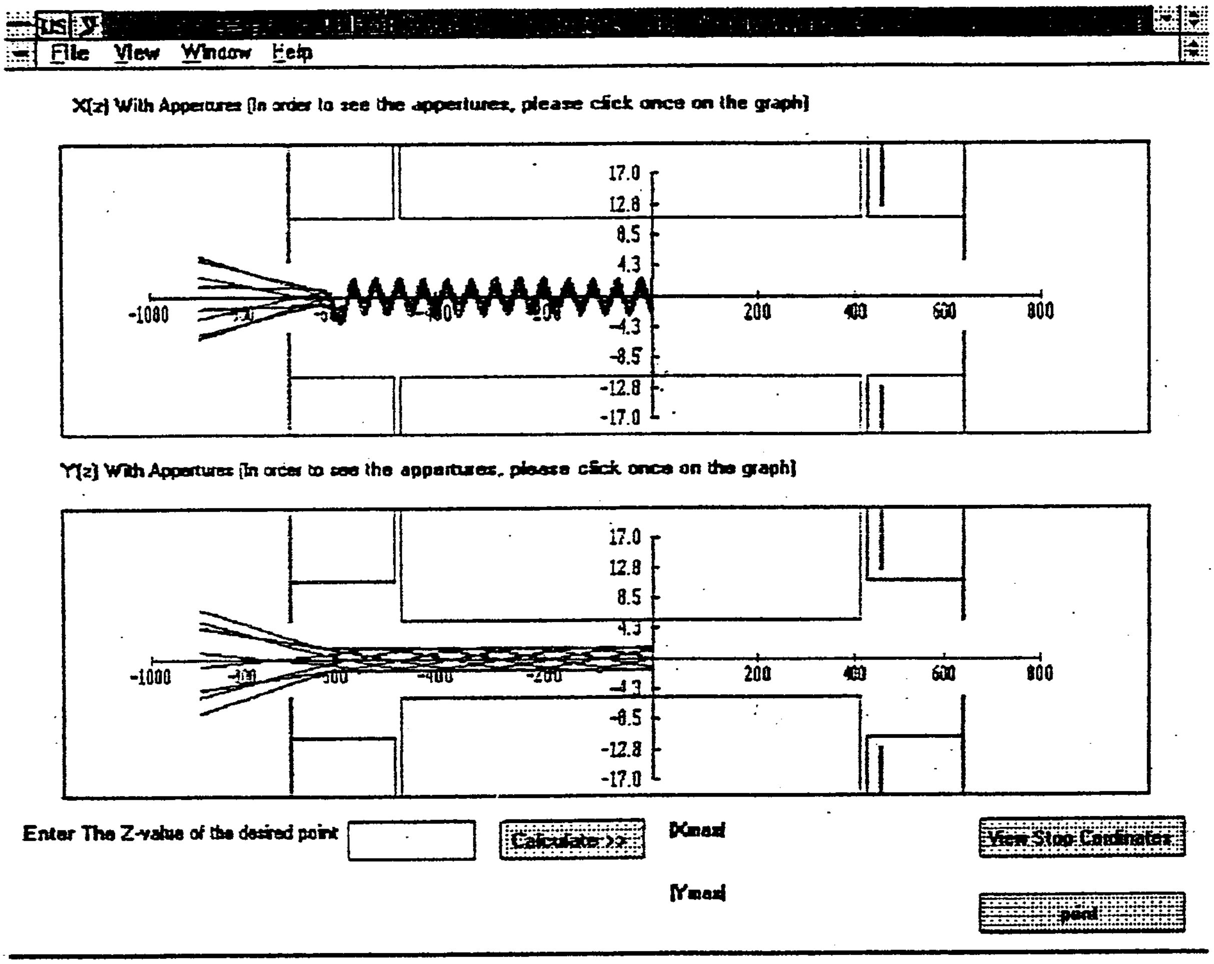
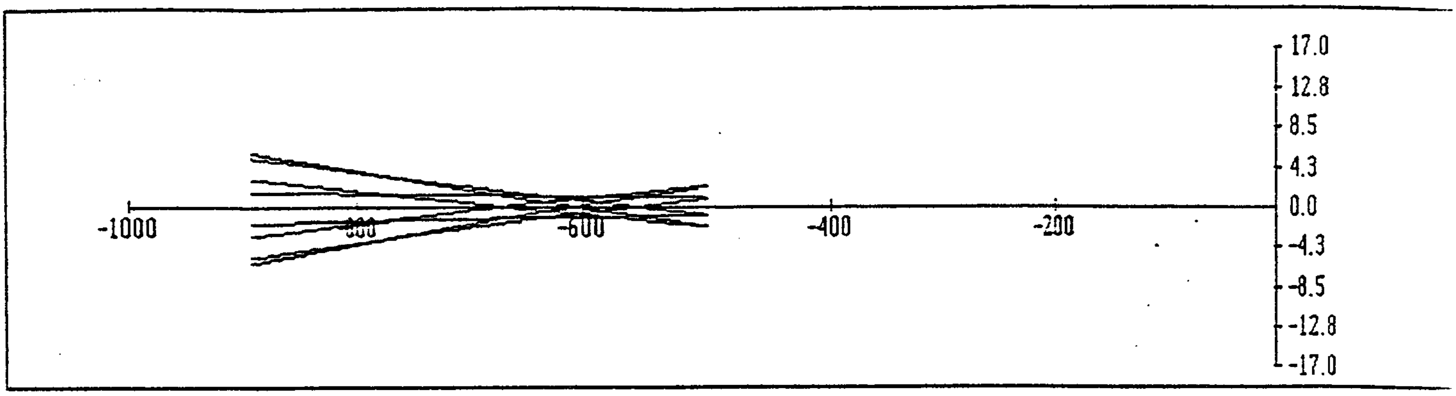
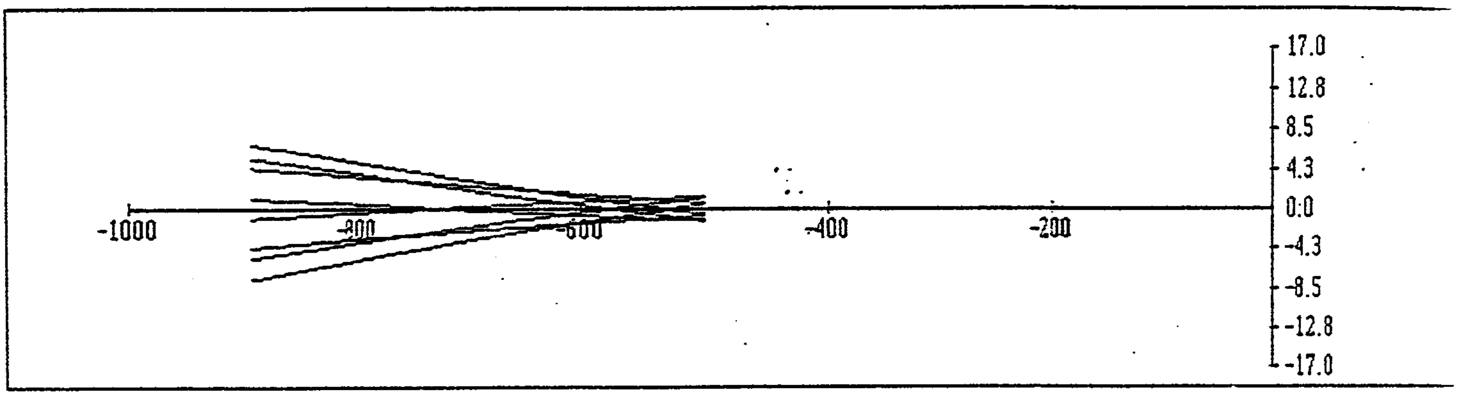

File View Window Help
X(z) With Appertures (In order to see the appertures, please click once on the graph)
17.0
12.8
8.5
4.3
-4.3
-8.5
-12.8
-17.0
-1000
200
400
600
800
Y(z) With Appertures (In order to see the appertures, please click once on the graph)
17.0
12.8
8.5
-8.5
-12.8
-17.0
-1000
200
400
600
800
Enter The Z-value of the desired point
Calculate >>
[Xmax]
[Ymax]
View Stop Coordinates

Fig 1

X(z) With Appertures (In order to see the appertures, please click once on the graph)



Y(z) With Appertures (In order to see the appertures, please click once on the graph)



Enter The Z-value of the desired point | Calculate >> | |Xmax| | View Step Cordina

|Ymax| | point

Fig 2

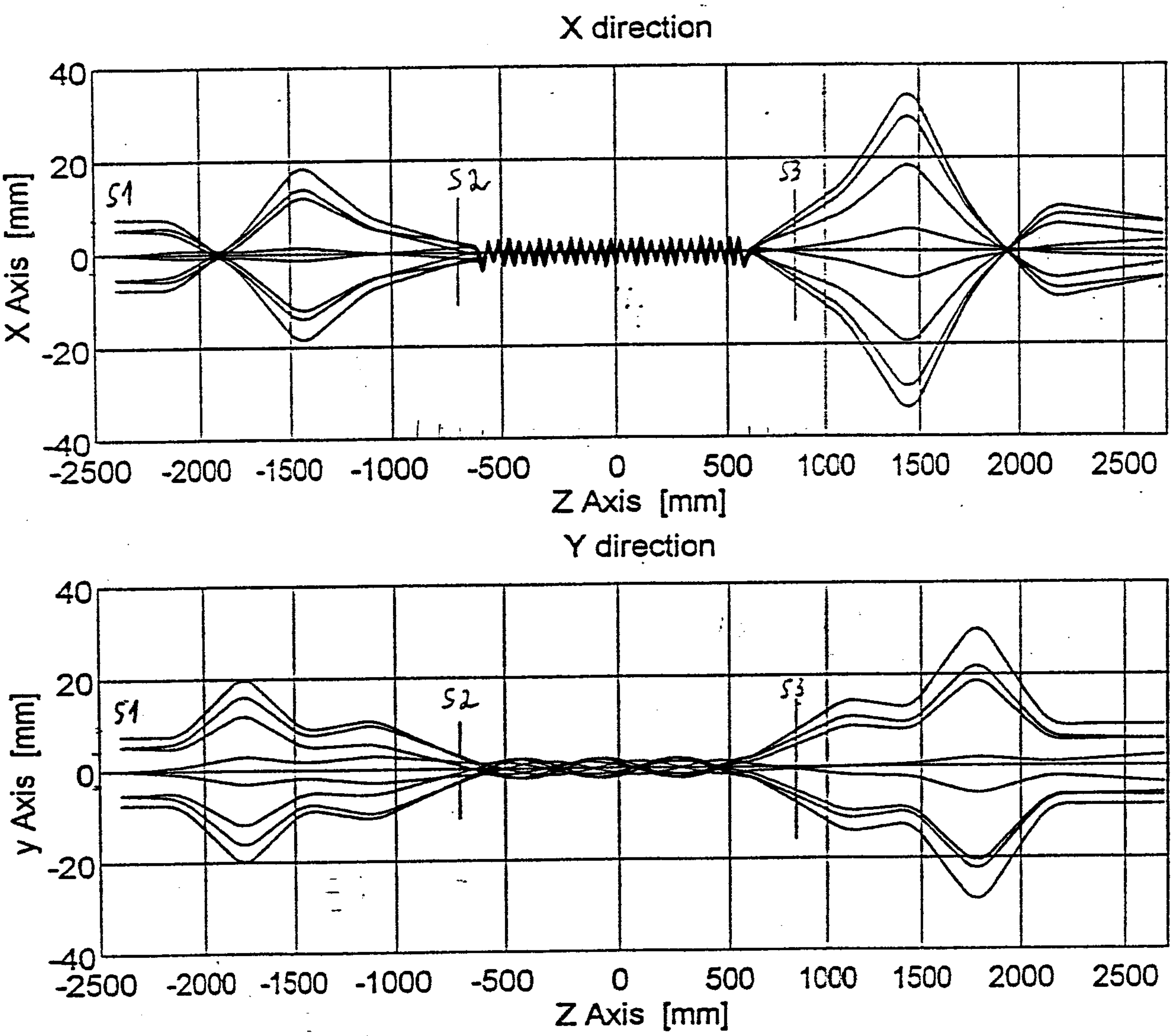

X direction
40
20
0
-20
-40
X Axis [mm]
S1
S2
S3
-2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000
2500
Z Axis [mm]
Y direction
40
20
0
-20
-40
y Axis [mm]
S1
S2
S3
-2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000
2500
Z Axis [mm]

Fig 3.