DAΦNE TECHNICAL NOTE

INFN - LNF, Accelerator Division

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Note: **I-7**

DAΦNE TRANSPORT-LINES

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Abstract

The latest design (as of 25/01/92) of DAΦNE transport lines with the design parameters and some preliminary results of orbit-error corrections for the lines are described in this note.

Introduction

As was briefly stated in the previous technical note for the transport lines, the main design concept of this set of transport lines is to reduce the redundant lines as much as possible so as to reduce the number of components. Consequently many restrictions have been imposed on the design. The major difficulties are due to a section shared by both the beam from the LINAC to the accumulator ('IN' beam) and the one from the accumulator to the main rings ('OUT' beam). The quadrupole strengths & polarities during injection and extraction of the beam are fixed since there is only a few tens of milliseconds between them. Therefore a polarity of the same quadrupole changes for injection and for extraction within this section. Another severe restriction is the inclusion of some quadrupole-free sections imposed by either architectural constraints or operational arrangement such as transportation of a detector to the observation point.

Design Details

The latest design of the DAΦNE Transport lines (Figs. 1-a, b) incorporate the section (bet. TR1 and HB2) which is shared by four different beams (positron 'IN' & 'OUT' and electron 'IN' & 'OUT', also has a part of line (bet. HB2 and HS1) which is shared by two 'OUT' beams. The computer-code LEDA [1] was used to calculate the optical functions and to determine the configuration of the focusing magnets. The beamline-paths and the locations of the bending magnets have practically been predetermined by architectural requirements, even though alterations are still possible if it becomes absolutely necessary.

The magnet HB1 has to have alternate polarities at the rate of approximately 50 Hz and HB2 is switched on (for 'OUT') and off (for 'IN') at about 1 Hz which is the rate of extraction. The rise time of magnetic field change for these magnets must be less than 20 msec which is the transition time between injection and extraction. The magnet HS1 is activated only for a positron beam and is kept unused for an electron beam. The route for a positron beam has been chosen in such a way that (i) the short branch for injection to a DAΦNE main ring is used, (ii) the direction of the rotation of the particles in the accumulator and the main ring coincide. There are two quadruple-free sections in the lines. One is between the magnets HB1 and HB2 where there is a thick wall (~ 10 m) which has a small space in the middle where one quadrupole (QA2) is located. The other one is between EB8 and EB9, the part of which should be disassembled in order for a detector to go through. Fig. 1-b shows the lay-outs of vertical bends from the side. The height difference between the LINAC and the accumulator ring is 60 cm and between the LINAC and the main rings tentatively 70 cm which will be increased to 120 cm in the next phase of design. The parameters of the magnetic elements are listed in Table 1. All the bending magnets except long septa are rectangular ones and HB1 and HB2 are laminated magnets to be pulse-activated. The path lengths at each element and the polarities of the quadrupoles are given in Table 2. Note that the same polarity for the two different beams represents opposite field directions.

Optical Functions & Beam Widths

The half-width of beam envelope (i.e. a beam radius) is calculated by the following formula.

$$\Sigma_i = C\sqrt{\varepsilon_i \beta_i + \left\{\eta_i \left(\frac{\Delta p}{p}\right)\right\}^2} \qquad (1)$$

where i = x or z. ε_i is the emittance for a Gaussian beam or the equivalent acceptance for a square beam. β_i is the betatron function and η_i is the dispersion function. $\Delta p/p$ represents the momentum spread of the beam, and C is multiplication factor (1.1 for the 'IN' beams and 3.0 for the 'OUT' beams [2]).

Fig. 2-a shows the optical functions for the positron 'IN' beam. At the bottom of the graph, horizontal bending magnets are depicted empty squares extending both above and below the line, and vertical ones have crosses within. A square above the line represents a focusing quadrupole and one below defocusing one. The distance is measured from an injection point in the accumulator ring. The half-widths of the beam-envelopes are shown in Fig. 2-b where the vertical width is shown with a reversed sign. The probable value of the acceptance and the momentum spread of the positron beam from LINAC have been chosen to be 1.0×10^{-5} m. rad. and 1.0×10^{-2} , respectively.

Figs. 3-a, b show the optical functions for the electron 'IN' beam and its envelopes. Even though the maximum horizontal beam size is smaller in this case than the one for positron beam, the average strengths of quadrupoles in the shared section are higher so that the line is more susceptible to alignment and component errors.

Figs. 4-a, b show the optical functions and beam envelopes for the positron 'OUT' beam from the accumulator to the DAΦNE main ring through the short branch, and Figs. 5-a, b also show the ones for the electron 'OUT' beam which goes all the way to the far side of the main ring (the long branch). The emittance of the beam from the accumulator is to be around 3.0×10^{-7} m. rad. and the momentum spread is assumed to be 1.0×10^{-3}. The vertical half-widths of an envelope are favorably maintained less than 10.75 mm, and the horizontal ones are not so strict but less than 20 mm in order to avoid large pole size for the magnets. There are few locations which slightly exceed these reference values. Whether it is correctable by reasonable means is yet to be investigated. The values of optical parameters to be matched at the accumulator-ends and the DAΦNE-ends are given in Table 3. These are still tentative values and are subject to minor changes during the course of finalization of the main-ring design and the accumulator-ring design.

Orbit Corrections

For the orbit correction, a computer-code "MAD" [3] is used. However certain adjustments are needed to utilize MAD for transport lines since MAD is mainly designed for storage rings. The adjustments taken are as follows. By setting the derivatives of the betatron functions (α_i) at the both ends zero, one can create a pseudo reflective symmetry without making major changes in quadrupole strengths. It turns out it was also necessary to make dispersions and their derivative (η_i, η'_i) vanish at the ends. Then create a fictitious storage ring to apply MAD to find the optimum locations and strengths of correctors with given errors assigned to each element of the line. Figs. 6-a÷d show the optical functions of the fictitious rings. In order to avoid large changes in terms of quadrupole strengths to create these rings one drift space has been slightly shortened in each 'IN' solution. Table. 4 shows the tentative locations of correctors and monitors.

The results of error estimates and the orbit corrections for 'IN' solutions are shown in Table 5. Among different types of errors field errors appear to be most damaging and angular misplacements least. From the second analysis of varying the field errors, the field error should be mo more than 1.0×10^{-3}). For 'IN' solutions all the numbers seem acceptable after correction. In order to make sure that this pseudo-ring-scheme works, the same correctors have been assigned to the open lines and it turns out that the maximum deviations form reference orbits are close to the cases for the closed lines.

The fairly preliminary results for 'OUT' solutions are given in Table 6. Note that the data for positron 'OUT' solution have been obtained by the means of scaling based on the assumption that an orbital deviation is linearly dependent on errors as long as it is reasonably small. This assumption has been confirmed by a scaling-test, the result of which is shown in Table 7. This test is conducted by employing one statistical model and changing the amount of errors linearly to see how the orbital deviations behave. For the vertical deviation the dependence is fairly linear since the angular deviation due to the small bending angle. However as are shown for the horizontal deviation it is no longer linear since some angles are too big to assumed to be infinitesimal. Fortunately it appears that the dependence is less than linear so that the result of scaling would be conservative estimates. Further investigations will take place after the modifications involving extra vertical bends in linear optics are completed. These preliminary results indicate that either increase of the number of correctors or reduction of tolerances in terms field errors might be needed to ensure the stable injections to the main rings.

REFERENCES

[1] G. Vignola and J. Murphy (unpublished)

[2] T. Tanabe, "Electron/positron transport-lines from and to the accumulator ring for DAΦNE", DAΦNE Technical Note **I-3**, September 1991.

[3] Methodical Accelerator Design, Version 8.1 by Hans Grote and F. Christoph Iselin, CERN/SL/90-13 (AP).

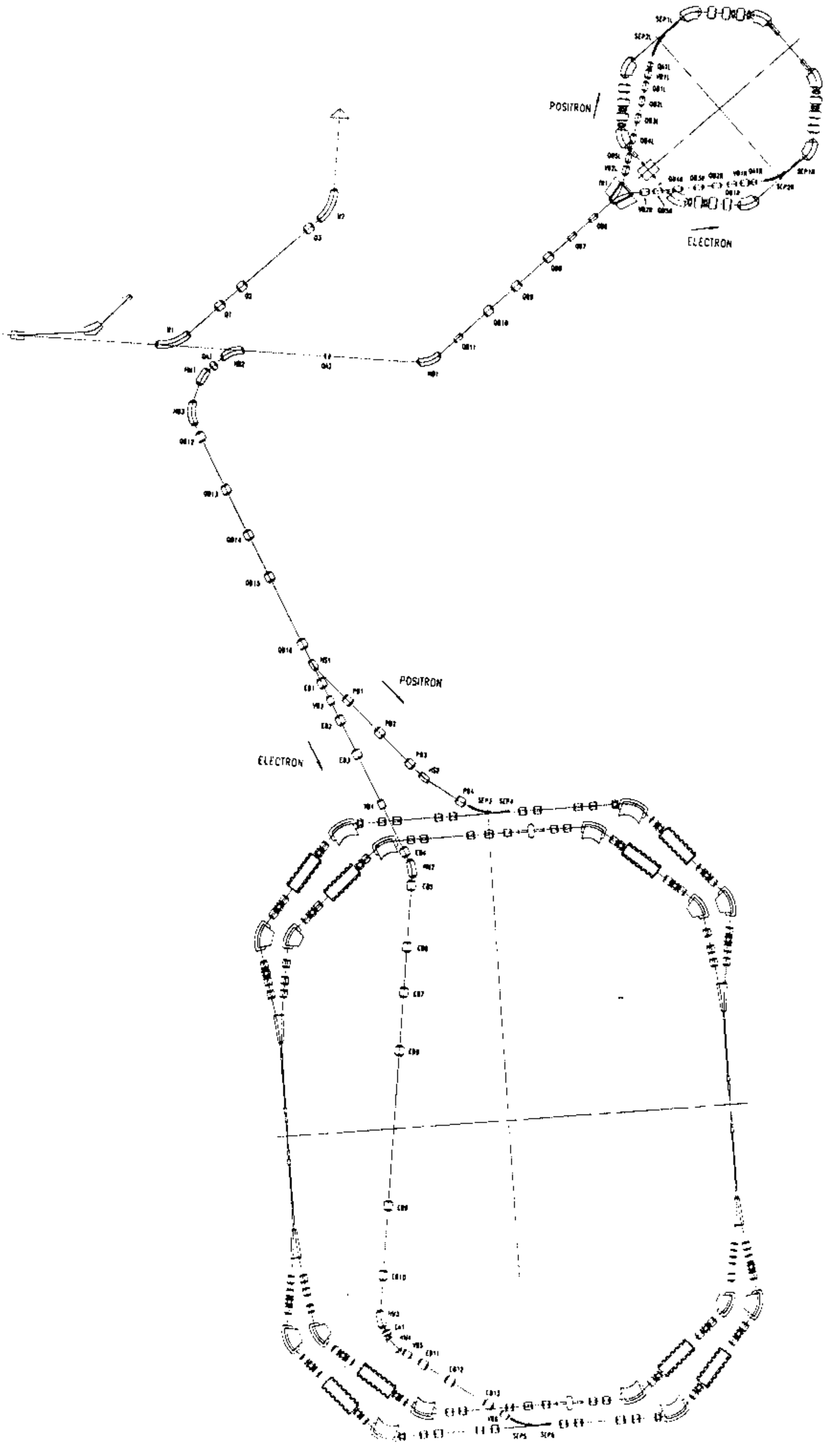
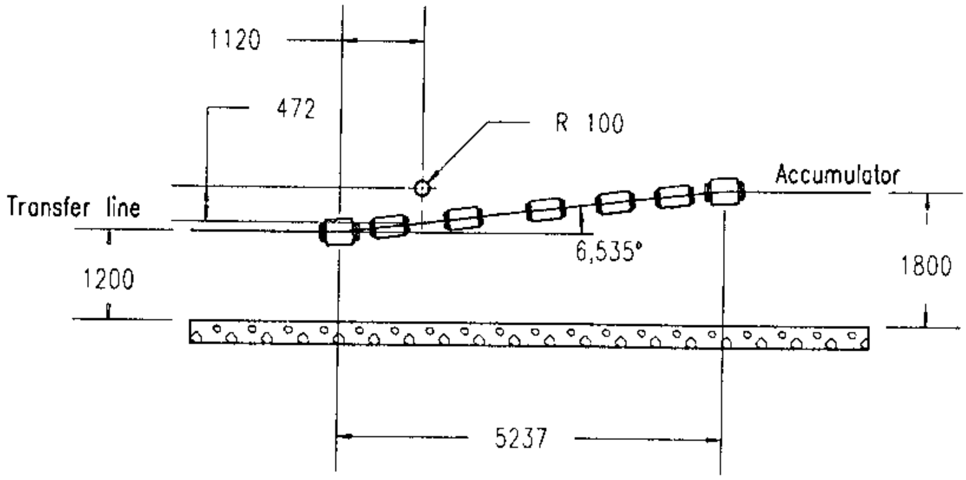
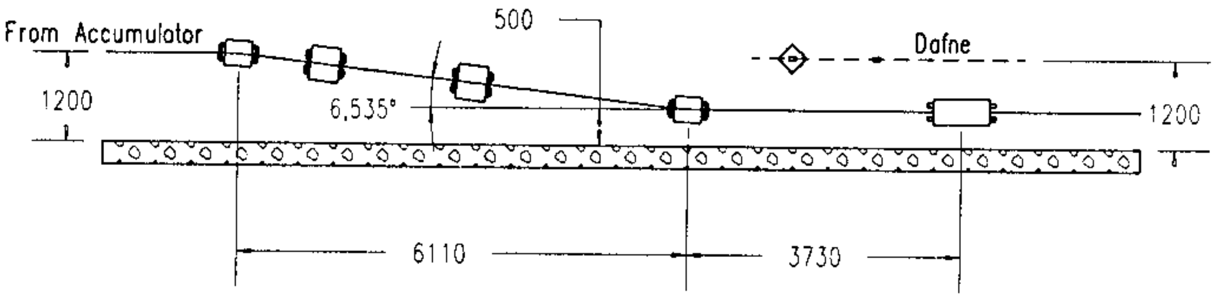


Fig. 1-a: The lay-out of the DAΦNE transport lines with the accumulator ring and the main rings.

VB1 L/R - VB2 L/R



VB3 - VB4



VB5 - VB6

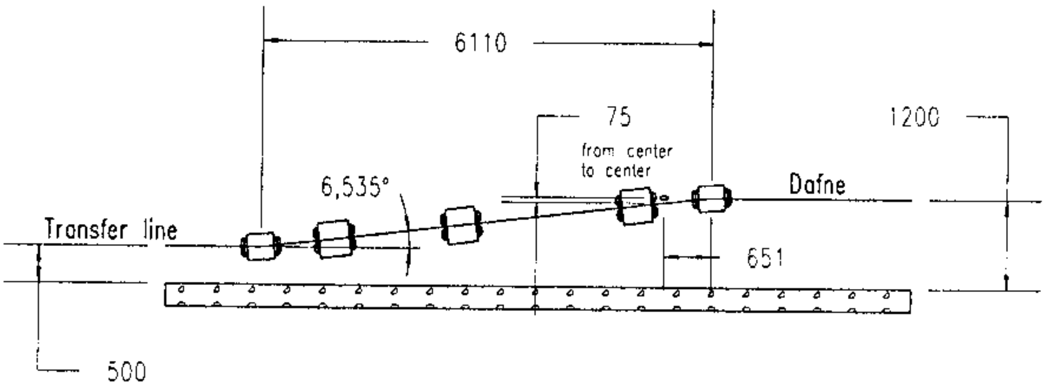


Fig. 1-b: The side views of vertical bends in the parts of lines.

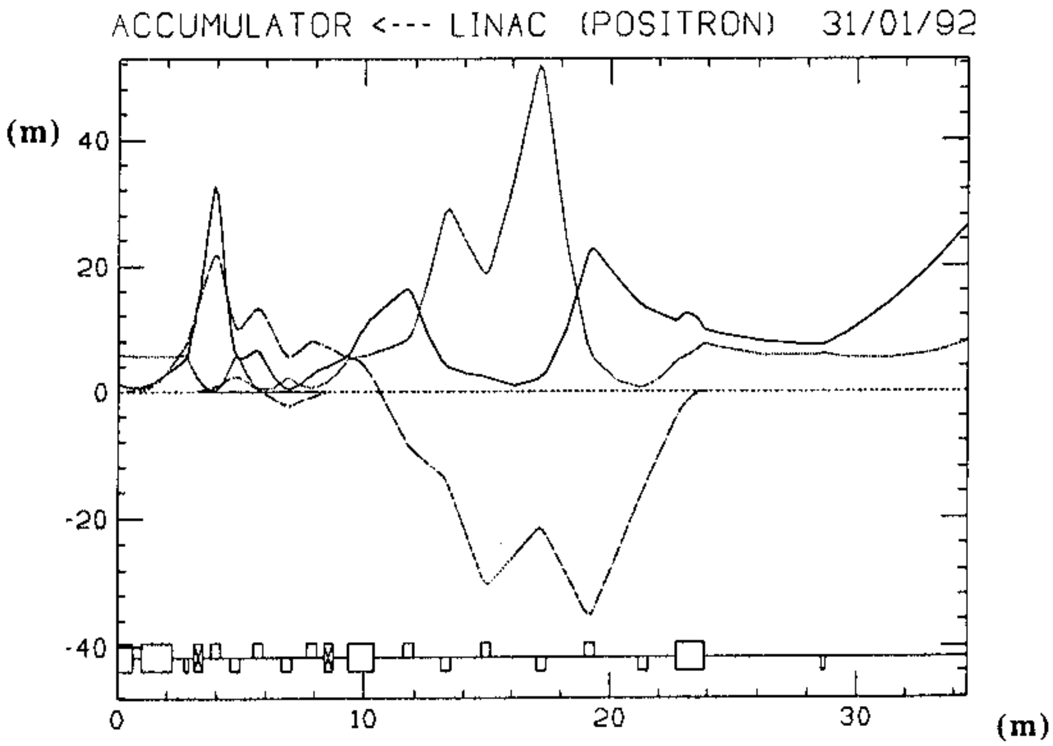


*Fig. 2-a: The optical functions of **positron** 'IN' beam to the accumulator (the left side).*
The solid line corresponds to β_x and the dotted line to $\beta_{z.}$.
The dot-dashed line represents ten times the horizontal dispersion (10 η_x)
and dashed line is ten times vertical dispersion (10 η_z).

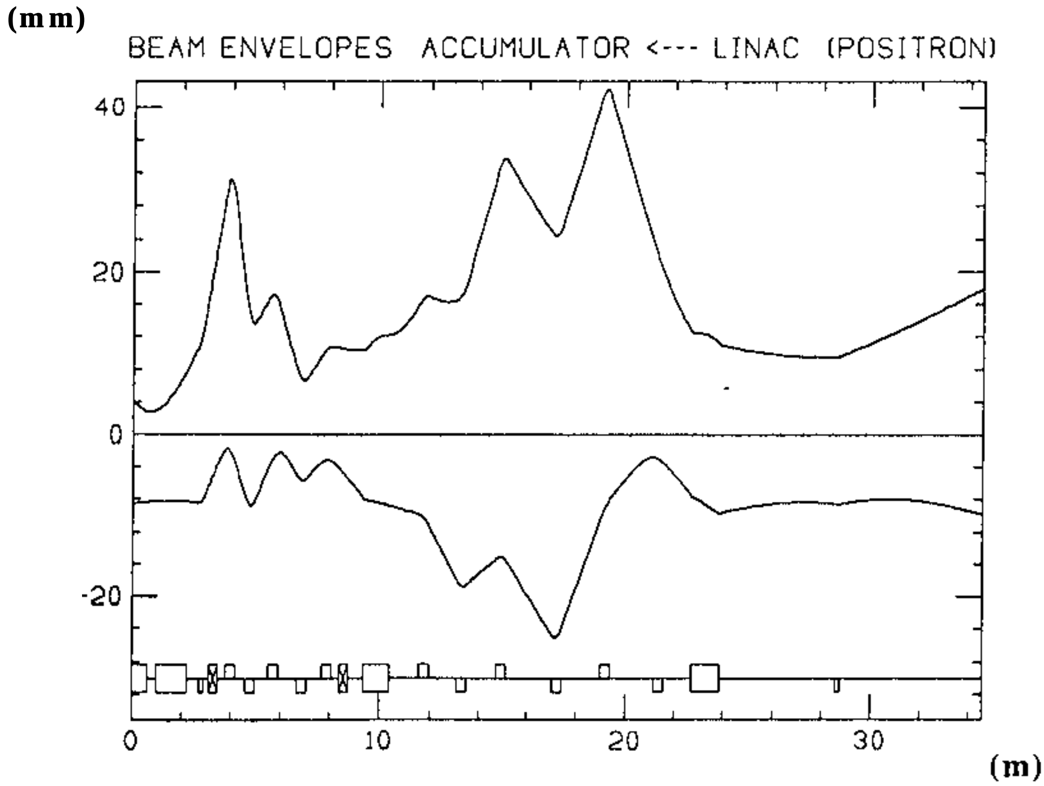


*Fig. 2-b: The horizontal and vertical beam-envelope as a function of distance for the **positron** 'IN' beam. The beam-emittance for each plane is 1.0 $\times 10^{-5}$ m.rad..*
The line in the upper half corresponds to $\Sigma_{z.}$
and that in the lower half to Σ_z, both with $\left(\frac{\Delta p}{p}\right)$ = 1.0 $\times 10^{-2}$.

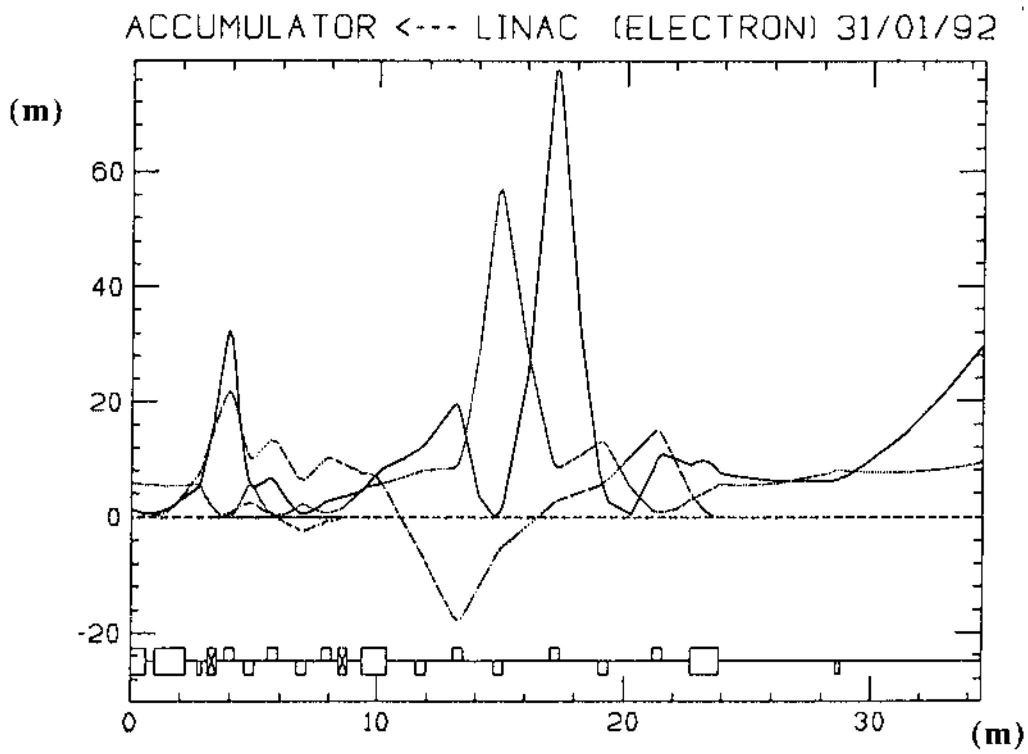


*Fig. 3-a: The optical functions of **electron** 'IN' beam to the accumulator (the left side). The solid line corresponds to β_x and the dotted line to β_z. . The dot-dashed line represents ten times the horizontal dispersion (10 η_x) and dashed line is ten times vertical dispersion (10 η_z) .*

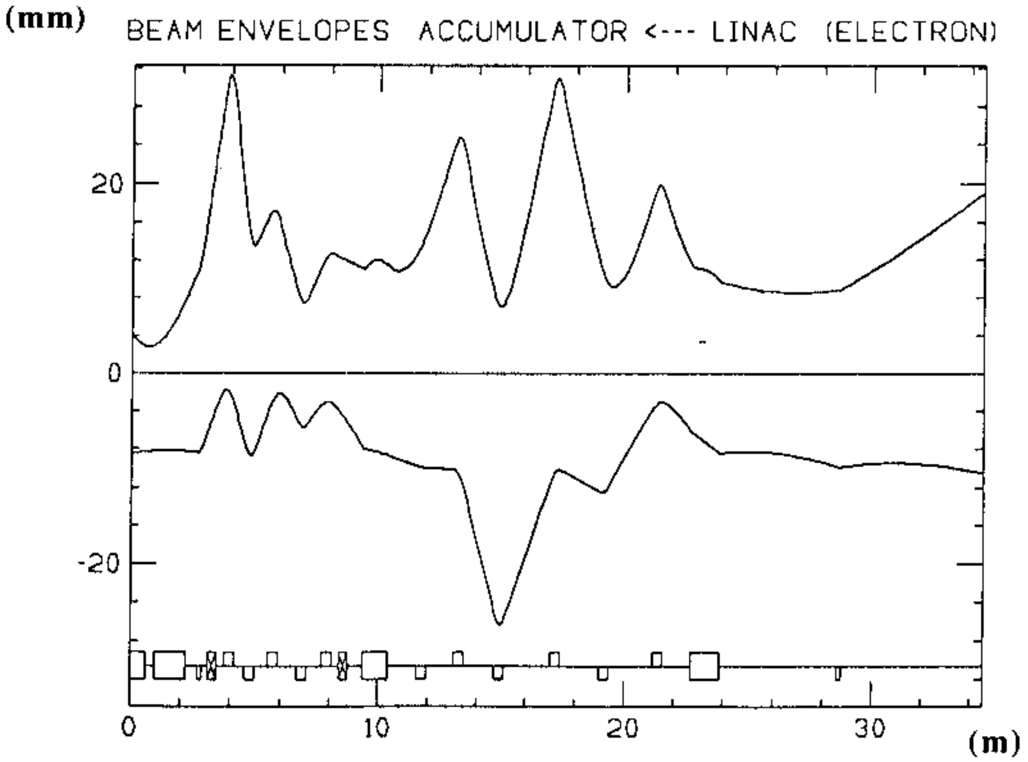


*Fig. 3-b: The horizontal and vertical beam-envelope as a function of distance for the **electron** 'IN' beam. The beam-emittance for each plane is 3×10^{-7} m.rad.. The line in the upper half corresponds to Σ_z. and that in the lower half to Σ_z , both with $\left(\frac{\Delta p}{p}\right) = 1.0 \times 10^{-3}$.*

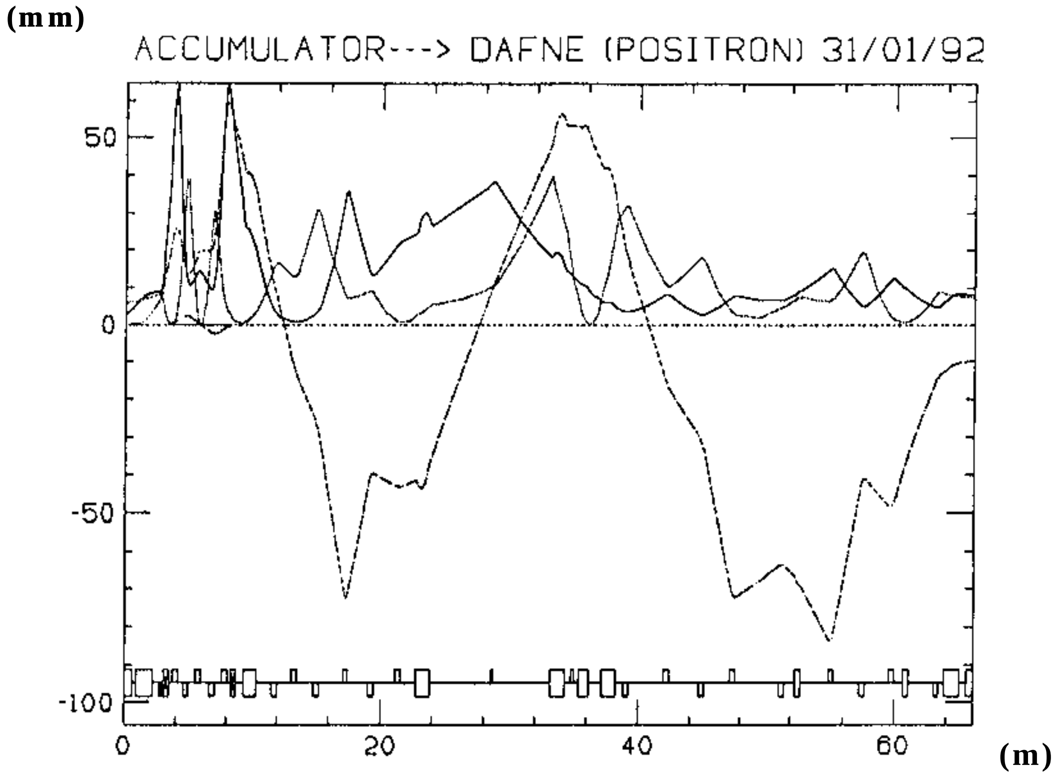


*Fig. 4-a: The optical functions of **positron** 'OUT' beam from the accumulator (the left side) to one of the main rings (to the right) through the short branch. The solid line corresponds to β_x and the dotted line to β_z. The dot-dashed line represents ten times the horizontal dispersion (10 η_x) and dashed line is ten times vertical dispersion (10 η_z).*

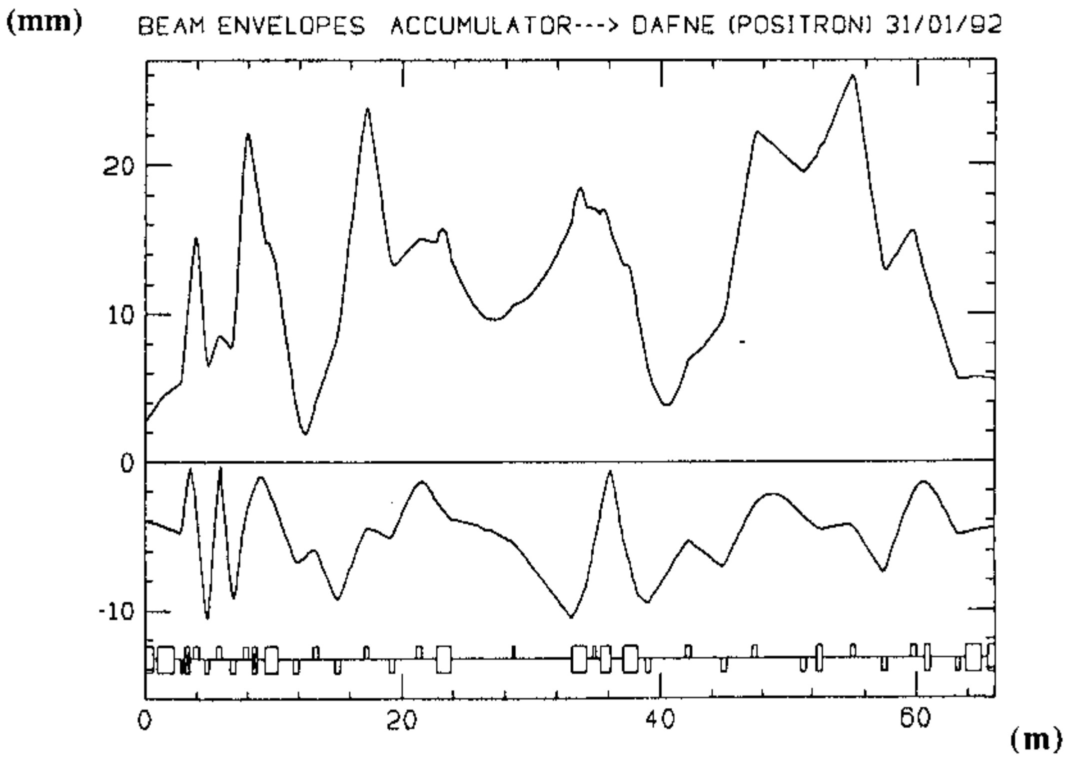


*Fig. 4-b: The horizontal and vertical beam-envelope as a function of distance fo the **positron** 'OUT' beam. The beam-emittance for each plane is 3 $\times 10^{-7}$ m.rad.. The line in the upper half corresponds to Σ_z. and that in the lower half to Σ_z, both with $\left(\frac{\Delta p}{p}\right) = 1.0 \times 10^{-3}$.*

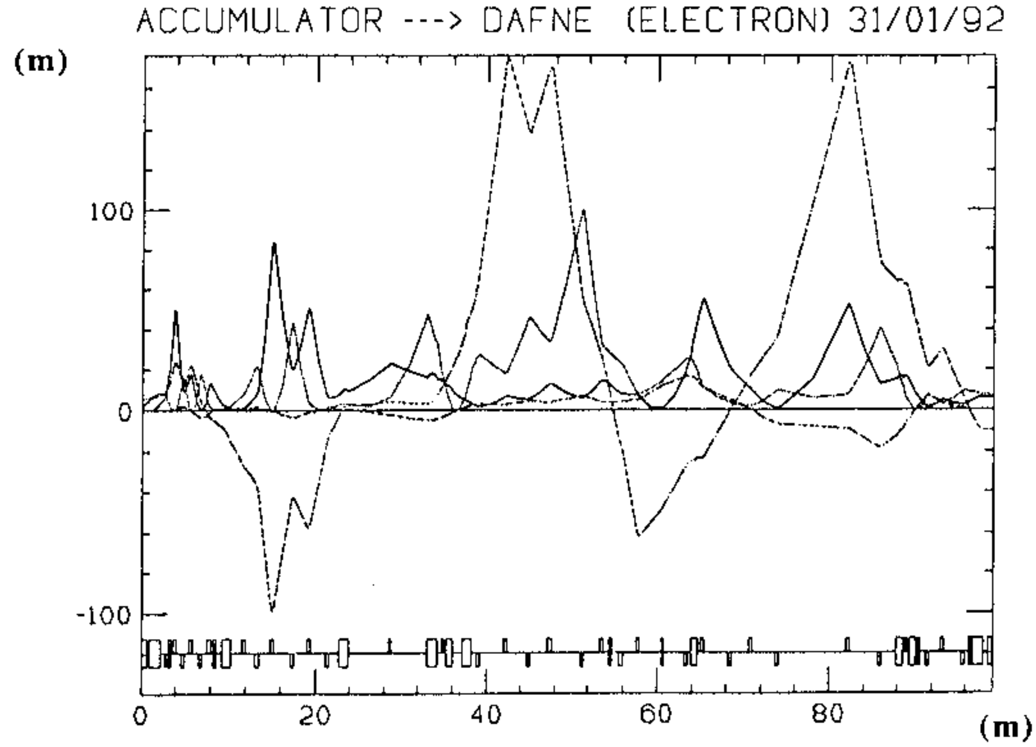


*Fig. 5-a: The optical functions of **electron** 'OUT' beam from the accumulator (the left side) to one of the main rings (to the right) through the short branch. The solid line corresponds to β_x and the dotted line to β_z. The dot-dashed line represents ten times the horizontal dispersion (10 η_x) and dashed line is ten times vertical dispersion (10 η_z).*

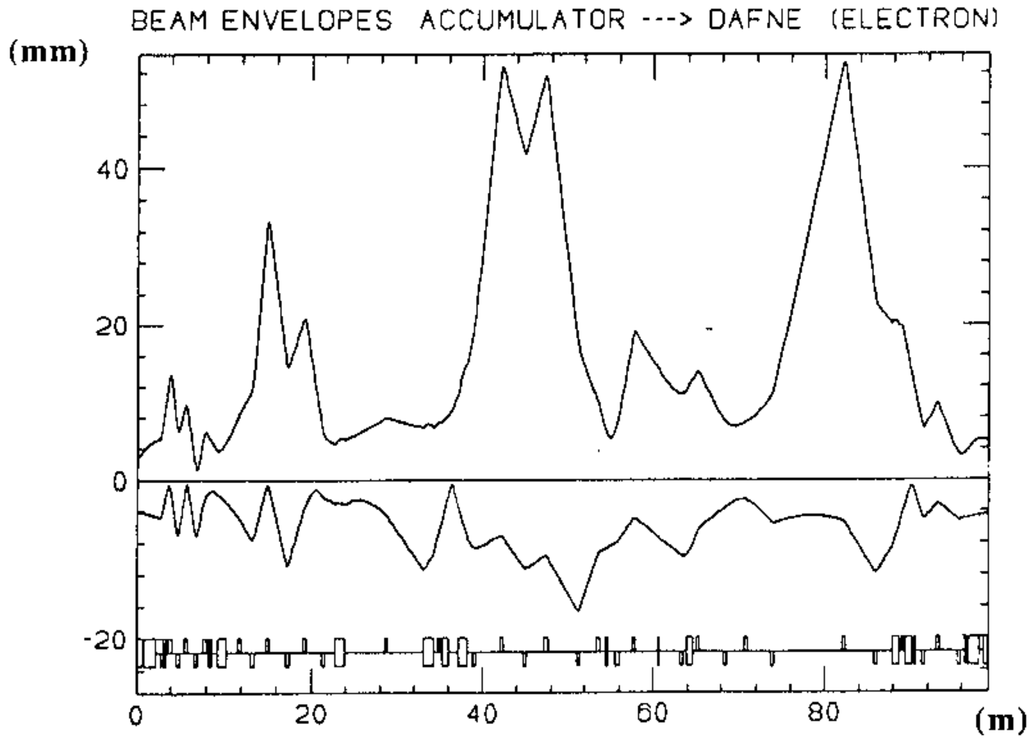
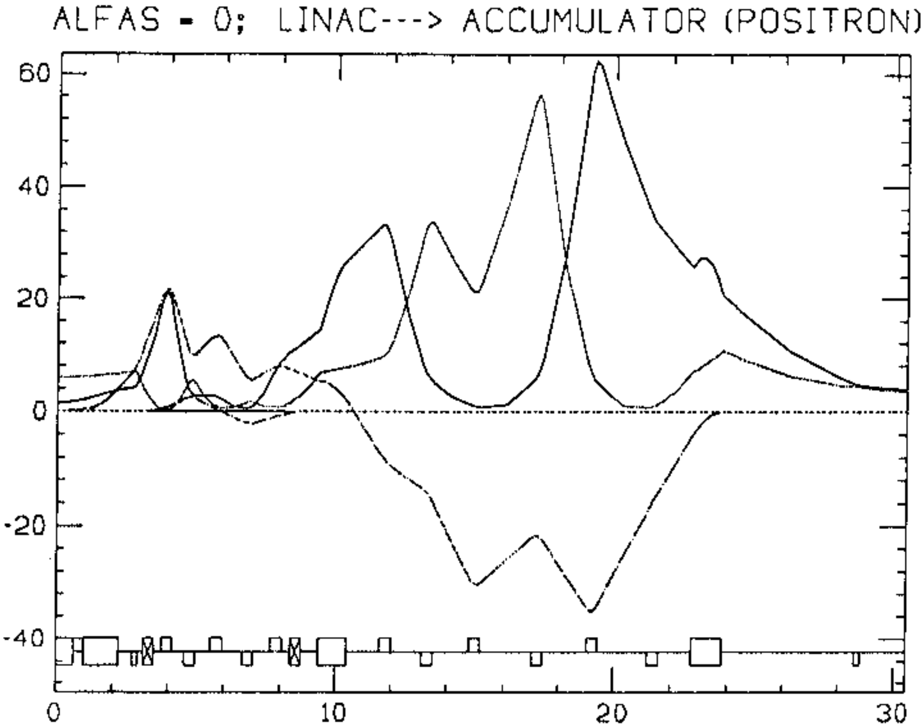


*Fig. 5-b: The horizontal and vertical beam-envelope as a function of distance for the **electron** 'OUT' beam. The beam-emittance for each plane is 3 $\times 10^{-7}$m.rad.. The line in the upper half corresponds to Σ_z. and that in the lower half to Σ_z, both with $\left(\frac{\Delta p}{p}\right) = 1.0 \times 10^{-3}$.*

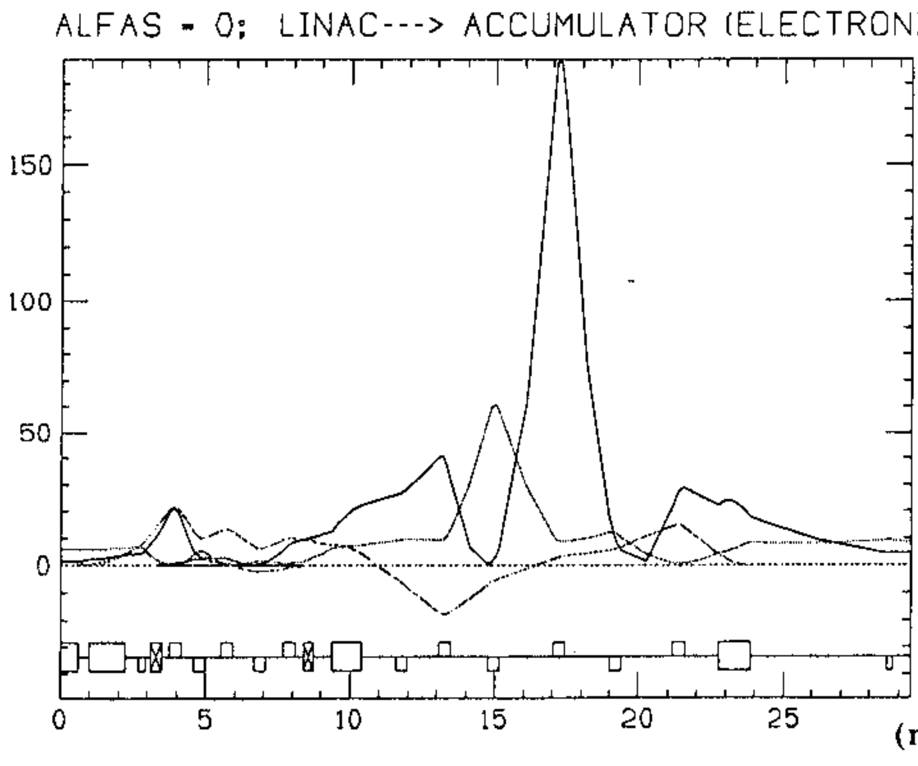
(m)



(m)

Fig. 6-a: The optical functions of a fictitious ring for ***positron*** *'IN' solution with $\alpha_i = 0$, η_i, $\eta'_i = 0$. The drift spase at the right most end has been slightly shortened to obtain the reflective symmetry.*

(m)



(m)

Fig. 6-b: The optical functions of a fictitious ring for ***electron*** *'IN' solution with $\alpha_i = 0$, η_i, $\eta'_i = 0$. The drift spase at the right most end has been slightly shortened to obtain the reflective symmetry.*

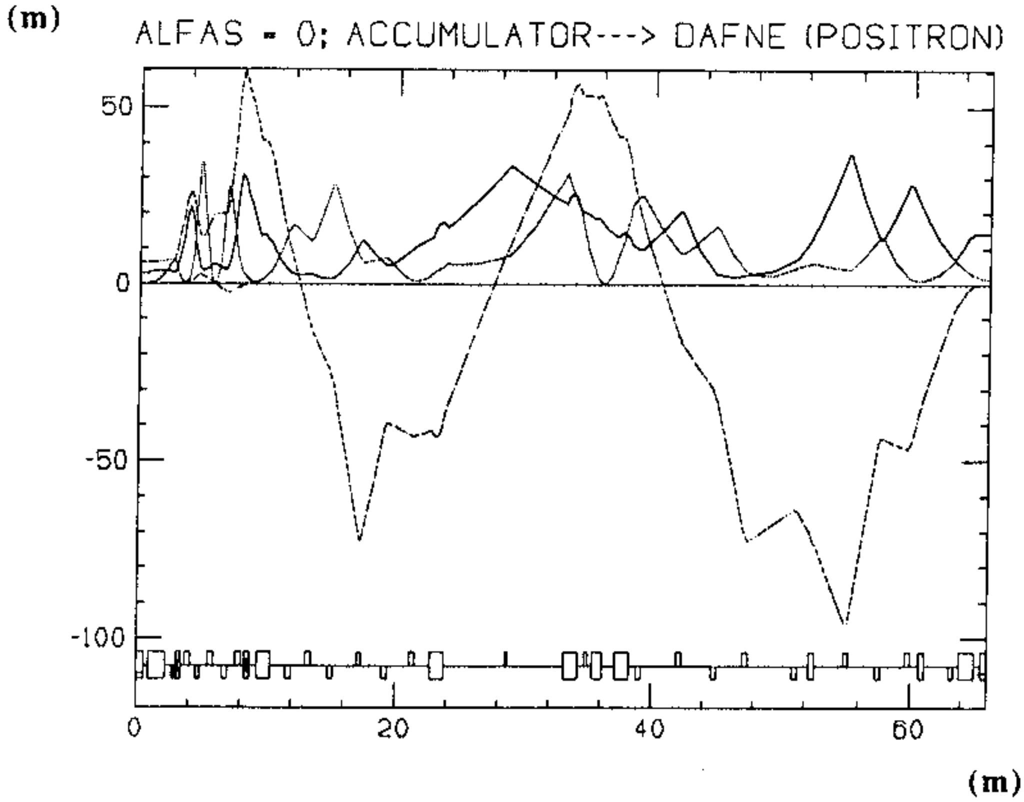


*Fig. 6-c: The optical functions of a fictitious ring for **positron** 'OUT' solution with $\alpha_i = 0$, η_i , $\eta'_i = 0$ at the both ends.*

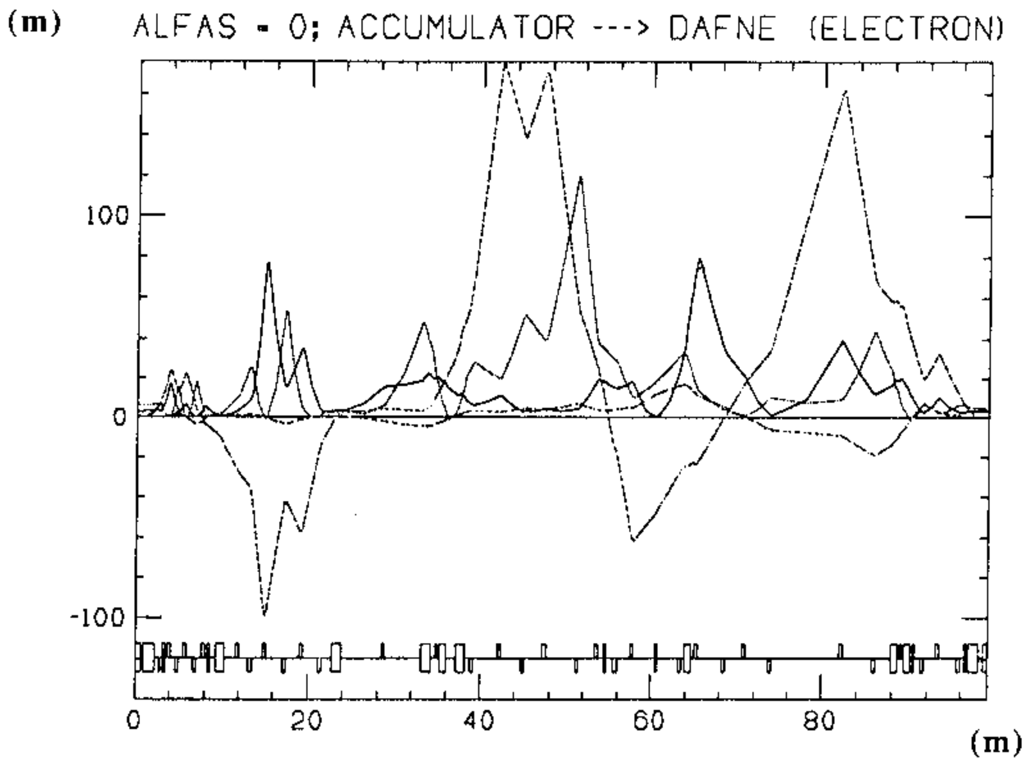


*Fig. 6-d: The optical functions of a fictitious ring for **electron** 'OUT ' solution with $\alpha_i = 0$, η_i , $\eta'_i = 0$ at both ends.*

TABLE 1 - MAGNETIC ELEMENTS

Note: In the columns for σ_x , σ_z + sign represents positron and - electron.
The signs without following word are all for 'OUT' solutions.

SEPTA

Designation	Length (m)	θ (˚)	Dipole field (T)	σ_x (mm)	σ_z (mm)
SEP1L	0.62334	2.5	0.119	4.17 (+in) 3.51(-out)	8.47 (+in) 4.13 (-out)
SEP2L	1.233	34.0	0.824	8.04 (+in) 5.03 (-out)	8.25 (+in) 4.62 (-out)
SEP1R	0.62334	2.5	0.119	4.17 (-in) 3.51 (+out)	8.47 (-in) 4.13 (+out)
SEP2R	1.233	34.0	0.824	8.04 (-in) 5.04 (+out)	8.25 (-in) 4.61 (+out)
SEP3	1.233	34.0	0.824	5.73 (+)	4.87 (+)
SEP4	0.5	2.0	0.119	5.63 (+)	4.55 (+)
SEP5	1.233	34.0	0.824	5.06 (-)	4.85 (-)
SEP6	0.5	2.0	0.119	5.03 (-)	4.55 (-)

DIPOLES

Designation	Length (m)	θ (˚)	Dipole field (T)	σ_x (mm)	σ_z (mm)
VB1L	0.3628	6.535	0.535	24.19 (+in) 10.65 (-out)	5.79 (+in) 3.04 (-out)
VB2L	Same as above			10.48 (+in) 5.39 (-out)	5.38 (+in) 1.47 (-out)
VB1R	0.3628	6.535	0.535	24.19 (-in) 11.67 (+out)	5.79(-in) 26.49 (+out)
VB2R	Same as above			12.20(-in) 20.19 (+out)	5.37(-in) 20.83 (+out)
VB3	Same as above			6.31(-out)	8.72 (-out)
VB4	Same as above			14.48 (-out)	7.44 (-out)
VB5	Same as above			12.24 (-out)	22.89 (-out)
VB6	Same as above			3.68 (-out)	5.00 (-out)
TR1	1.0	36.0	1.075	12.27 (+in) 12.01(-in) 14.79 (+out) 5.01 (-out)	8.68 (+in) 8.64 (-in) 3.41(+out) 2.90 (-out)
HB1	1.112	45.0	1.208	12.50 (+in) 11.22 (-in) 15.74 (+out) 5.39 (-out)	9.73 (+in) 8.64 (-in) 3.90 (+out) 2.98 (-out)
HB2	1.112	45.0	1.208	15.79 (+in) 18.91 (-in) 18.42 (+out) 7.19 (-out)	10.34(+in) 9.77 (-in) 10.35 (+out) 11.38 (-out)
HB3	1.112	45.0	1.208	13.31 (+) 15.31 (-)	8.94 (+) 7.62 (-)
HM1	0.76655	30.0	1.164	16.96 (+) 8.27 (-)	3.47 (+) 4.71 (-)
HM2	0.76657	31.0	1.172	12.96 (-)	9.39 (-)
HM3	0.76657	31.0	1.172	20.56 (-)	8.35 (-)
HM4	0.76657	31.0	1.172	17.48 (-)	2.87 (-)
HS1	0.454	18.27	1.203	21.30 (+)	4.58 (+)
HS2	0.452	13.55	0.892	12.55 (+)	16.93 (+)

QUADRUPOLES

('IN' POSITRONS)

Designation	Length (m)	K (~grad./1.7)	σ_x (mm)	σ_z (mm)
QA1L	0.2	5.00	13.61	8.36
QA2	0.2	0.55	9.48	8.42
QB1L	0.4	3.624	31.20	3.59
QB2L	0.4	5.303	16.57	8.69
QB3L	0.4	2.450	17.13	3.55
QB4L	0.4	4.615	7.65	5.61
QB5L	0.4	1.50	10.68	3.24
QB6	0.4	1.201	17.08	11.22
QB7	0.4	1.185	18.75	18.81
QB8	0.4	1.211	33.77	15.69
QB9	0.4	1.361	25.61	25.01
QB10	0.4	1.225	41.96	10.00
QB11	0.4	1.953	22.83	3.44

('OUT' POSITRONS)

Designation	Length (m)	K (~grad./1.7)	σ_x (mm)	σ_z (mm)
QA1R	0.2	7.50	6.36	4.80
QA2	0.2	0.55	10.69	5.57
QA3	0.2	1.829	17.07	5.95
QB1R	0.4	3.688	15.20	4.84
QB2R	0.4	5.359	8.03	10.48
QB3R	0.4	1.137	8.53	3.12
QB4R	0.4	4.644	10.45	9.14
QB5R	0.4	2.341	22.15	4.49
QB6	0.4	1.201	45.89	6.71
QB7	0.4	1.185	45.86	6.20
QB8	0.4	1.211	9.79	9.19
QB9	0.4	1.361	23.78	4.73
QB10	0.4	1.225	14.01	5.07
QB11	0.4	1.953	15.06	15.72
QB12	0.4	0.572	6.92	9.44
QB13	0.4	0.908	7.08	5.50
QB14	0.4	0.901	10.65	7.03
QB15	0.4	0.670	22.19	3.08
QB16	0.4	0.361	19.68	3.86
PB1	0.4	0.855	25.93	4.56
PB2	0.4	1.349	13.56	7.41
PB3	0.4	0.8	15.62	2.45
PB4	0.4	1.581	5.96	4.98

('IN' ELECTRONS)

Designation	Length (m)	K (~grad./1.7)	σ_x (mm)	σ_z (mm)
QA1R	0.2	5.00	13.61	8.36
QA2	0.2	0.6	9.31	10.27
QB1R	0.4	3.624	31.2	3.59
QB2R	0.4	5.311	16.57	8.69
QB3R	0.4	2.354	17.19	3.53
QB4R	0.4	4.617	8.28	5.69
QB5R	0.4	1.6	12.68	3.22
QB6	0.4	2.576	15.32	9.98
QB7	0.4	2.281	24.97	12.17
QB8	0.4	1.714	7.64	26.33
QB9	0.4	2.102	31.04	11.12
QB10	0.4	1.332	11.17	12.45
QB11	0.4	2.185	19.69	3.27

('OUT' ELECTRONS)

Designation	Length (m)	K (~grad./1.7)	σ_x (mm)	σ_z (mm)
QA1L	0.2	6.2	6.21	4.81
QA2	0.2	0.6	7.96	4.59
QA3	0.2	0.75	7.37	6.90
QB1L	0.4	3.519	13.59	2.93
QB2L	0.4	5.812	7.37	6.83
QB3L	0.4	3.5	9.59	15.72
QB4L	0.4	4.6	2.41	7.06
QB5L	0.4	3.708	6.14	3.02
QB6	0.4	2.576	8.96	5.26
QB7	0.4	2.281	16.07	7.59
QB8	0.4	1.714	33.30	12.25
QB9	0.4	2.102	15.50	10.69
QB10	0.4	1.332	20.78	38.58
QB11	0.4	2.185	6.91	23.48
QB12	0.4	0.6	22.04	8.72
QB13	0.4	0.728	52.69	7.35
QB14	0.4	0.513	42.25	11.18
QB15	0.4	0.65	51.41	9.90
QB16	0.4	0.780	18.33	16.49
EA1	0.2	1.699	19.85	4.54
EB1	0.4	0.7	10.35	9.76
EB2	0.4	0.357	8.22	8.07
EB3	0.4	1.15	19.13	5.03
EB4	0.4	2.460	11.11	9.58
EB5	0.4	0.9	13.98	6.95
EB6	0.4	1.889	7.70	3.68
EB7	0.4	1.897	7.58	2.59
EB8	0.4	0.736	12.04	5.47
EB9	0.4	0.643	53.28	5.66
EB10	0.4	0.747	24.03	11.74
EB11	0.4	2.693	7.20	5.01
EB12	0.4	1.387	9.76	3.20
EB13	0.4	0.681	3.62	5.18

TABLE 2 - THE PATH LENGTH AT EACH ELEMENT

In this table a drift space is designated as O. Defocusing magnet is D and focusing magnet is F in polarity.

Designation	Arc Length (m)	Polarity (pos. in / out)	Polarity (ele. out / in)
SEP1L/R	0.6233	-------	-------
O	0.375		
SEP2L/R	1.2331	-------	-------
O	0.4744		
QA1L/R	0.2	D/D	D/D
O	0.2		
VB1L/R	0.3633	-------	-------
O	0.3		
QB1L/R	0.4	F/F	F/F
O	0.4123		
QB2L/R	0.4	D/D	D/D
O	0.5473		
QB3L/R	0.4	F/F	F/F
O	0.7261		
QB4L/R	0.4	D/D	D/D
O	0.6212		
QB5L/R	0.4	F/F	F/F
O	0.3		
VB2L/R	0.3633	-------	-------
O	0.6408		
TR1	1.0	-------	-------
O	1.206		
QB6	0.4	D/F	F/D
O	1.1		
QB7	0.4	F/D	D/F
O	1.274		
QB8	0.4	D/F	F/D
O	1.874		
QB9	0.4	F/D	D/F
O	1.571		
QB10	0.4	D/F	F/D
O	1.75		
QB11	0.4	F/D	D/F
O	1.168		
HB1	1.1129	- / +	- / + (must be changed)
O	4.75		
QA2	0.2	F/D	F/D
O	4.349		
HB2	1.1129	0 / -	+ / 0

[From here 'OUT' only]

O	0.55		
QA3	0.2	F	F
O	0.3266		
HM1	0.7666	-------	-------
O	1.0756		
HB3	1.1129	-------	-------
O	0.6		
QB12	0.4	D	D
O	2.7		
QB13	0.4	F	F
O	2.3		
QB14	0.4	D	D
O	2.1		
QB15	0.4	F	F
O	3.5		
QB16	0.4	D	D

[POSITRON]

O	0.8020	
HS1	0.4517	-------
O	2.171	
PB1	0.4	F
O	2.0	
PB2	0.4	D
O	1.888	
PB3	0.4	F
O	0.6918	
HS2	0.4517	-------
O	1.9	
PB4	0.4	D
O	0.3701	
SEP3	1.2331	-------
O	0.5	
SEP4	0.5	-------

[ELECTRON]

O	1.9	
EB1	0.4	F
O	0.6349	
VB3	0.3633	-------
O	0.8	
EB2	0.4	D
O	1.598	
EB3	0.4	F
O	2.45	
VB4	0.3633	-------
O	2.4	
EB4	0.4	D
O	0.3592	
HM2	0.7664	-------
O	0.3	
EB5	0.4	F
O	2.8	
EB6	0.4	D
O	2.0	
EB7	0.4	F
O	2.7	
EB8	0.4	D
O	7.884	
EB9	0.4	F
O	3.302	
EB10	0.4	D
O	1.7	
HM3	0.7667	-------
O	0.3	
EA1	0.2	F
O	0.2360	
HM4	0.7667	-------
O	0.2513	
VB5	0.3633	-------
O	0.6197	
EB11	0.4	D
O	1.3183	
EB12	0.4	F
O	2.004	
EB13	0.4	D
O	0.506	
VB6	0.3633	-------
O	0.1434	
SEP5	1.2331	-------
O	0.5	
SEP6	0.4986	-------

TABLE 3 - THE OPTICAL PARAMETERS TO BE MATCHED

(As of 25/01/92)

(i) ACCUMULATOR SIDE

$\beta_x = 1.440$ (m) (in); $\beta_z = 5.929$ (m)

$\beta_x = 2.863$ (m) (out);

$\alpha_x = 1.1191$ (in); $\alpha_z = 0.2555$ (in)

$\alpha_x = -1.1191$ (out); $\alpha_z = -0.2555$ (out)

$\eta_x = \eta_z = \eta'_x = \eta'_z = 0$

(ii) DAFNE SIDE

$\beta_x = 8.31$ (m) (short branch); $\beta_z = 7.4973$ (m)

$\beta_x = 6.0$ (m) (long branch);

$\alpha_x = 0.0877$; $\alpha_z = 0.1583$

$\eta_x = -0.994636$; $\eta_z = \eta'_x = \eta'_z = 0$

TABLE 4 - LOCATIONS OF CORRECTORS & MONITORS

Note: Due to the characteristics of "MAD" program the lengths of correctors and monitors are zero. A drift space is designated as O, and a vertical corrector and a horizontal corrector are show as CV and CH, respectively. MHV means a monitor for both a horizontal and a vertical plane.

[From the accumulator ring]

(i) SHORT BRANCH

SEP 1---O---SEP2---**CV**---**MHV**---O---QA1---O---VB1---**MHV**---O---QB1---**CH**---O---**CV**---QB2---O---QB3---O---QB4---QB5---O---VB2---**MHV**---O---**CV**---TR1---O---QB6---**CH**---O---QB7---**MHV**---O---**CV**---QB8---**MHV**---QB9---**CH**---O---QB10---**CHV**---QB11---O---**MHV**---HB1---O---QA2---**MHV**---**CHV**---O---**CHV**---HB2---O---QA3---O---HM1---**CH**---O---HB3---**MHV**---O---QB12---O---QB13---**CH**---O---**CV**---QB14---O---QB15---O---QB16---O---HS1---**MHV**---**CHV**---PB1---O---PB2---O---PB3---O---HS2---**MHV**---O---**CHV**---PB4---O---SEP3---O---SEP4

(ii) LONG BRANCH

SEP 1---O---SEP2---**CV**---**MHV**---O---QA1---O---VB1---**MHV**---O---QB1---**CH**---O---**CV**---QB2---O---QB3---O---QB4---QB5---O---VB2---**MHV**---O---**CV**---TR1---O---QB6---**CH**---O---QB7---**MHV**---O---**CV**---QB8---**MHV**---QB9---**CH**---O---QB10---**CHV**---QB11---O---**MHV**---HB1---O---QA2---**MHV**---**CHV**---O---**CHV**---HB2---O---QA3---O---HM1---**CH**---O---HB3---**MHV**---O---QB12---O---QB13---**CH**---O---**CV**---QB14---O---QB15---O---QB16---O---**CV**---**MHV**---EB1---O---VB3---O---**CH**---EB2---O---EB3---O---VB4---**MHV**---O---**CV**---EB4---O---HM2---O---EB5---**CH**---O---EB6---O---EB7---O---EB8---O---**CH**---EB9---O---EB10---**CV**---O---**MHV**---HM3---O---EA4---O---HM4---O---VB5---O---EB11---O---EB12---**CH**---O---EB13---O---**CHV**---VB6---**MHV**---O---SEP5---SEP6

TABLE 5 - ERROR ESTIMATES AND ORBIT CORRECTIONS ('IN' SOLUTIONS)

BEFORE CORRECTION

[1] Orbit distortions due to a different type of errors (all in mm, 9 statistical samples). Δ represents a standard deviation with respect to that parameter.

(1) Positron 'IN' solution

(i) Displacement errors (Δx, Δy, Δs = 0.2 mm)

$X_{rms} = 3.34 \pm 1.62$ $Z_{rms} = 2.54 \pm 0.96$

$X_{max} = 7.94 \pm 3.93$ $Z_{max} = 8.30 \pm 3.87$

(ii) Angular misplacement errors ($\Delta\theta$, $\Delta\varphi$, $\Delta\psi$ = 0.25 mrad)

$X_{rms} = 0.87 \pm 0.39$ $Z_{rms} = 1.68 \pm 0.65$

$X_{max} = 2.31 \pm 0.92$ $Z_{max} = 5.40 \pm 2.44$

(iii) Field errors ($\Delta B / B = 5.0 \times 10^{-4}$)

$X_{rms} = 4.26 \pm 2.38$ $Z_{rms} = 0.17 \pm 0.10$

$X_{max} = 11.99 \pm 6.12$ $Z_{max} = 0.53 \pm 0.34$

(iv) All of the above

$X_{rms} = 5.31 \pm 1.50$ $Z_{rms} = 3.09 \pm 1.27$

$X_{max} = 15.61 \pm 5.05$ $Z_{max} = 11.38 \pm 5.25$

(2) Electron 'IN' solution

(i) Displacement errors (Δx, Δy, Δs = 0.2 mm)

$X_{rms} = 5.99 \pm 2.15$ $Z_{rms} = 2.03 \pm 0.99$

$X_{max} = 21.37 \pm 7.00$ $Z_{max} = 6.25 \pm 3.16$

(ii) Angular misplacement errors ($\Delta\theta$, $\Delta\varphi$, $\Delta\psi$ = 0.25 mrad)

$X_{rms} = 1.49 \pm 0.59$ $Z_{rms} = 1.32 \pm 0.54$

$X_{max} = 5.37 \pm 2.01$ $Z_{max} = 4.82 \pm 2.33$

(iii) Field errors ($\Delta B / B = 5.0 \times 10^{-4}$)

X_{rms} = 4.40 ± 2.00 Z_{rms} = 0.17 ± 0.12

X_{max} = 17.59 ± 8.02 Z_{max} = 0.48 ± 0.35

(iv) All of the above

X_{rms} = 6.63 ± 3.10 Z_{rms} = 2.39 ± 1.14

X_{max} = 24.89 ± 11.61 Z_{max} = 7.27 ± 5.31

[2] Varying the amount of field errors while other parameters are fixed.
(Δx, Δy, Δs = 0.3 mm, $\Delta\theta$, $\Delta\varphi$, $\Delta\psi$ = 0.5 mrad)

(1) Positron 'IN' solution

(i) $\Delta B / B = 5.0 \times 10^{-4}$

X_{rms} = 6.92 ± 1.70 Z_{rms} = 45.00± 2.04

X_{max} = 20.18 ± 5.77 Z_{max} = 17.89 ± 8.16

(i) $\Delta B / B = 1.0 \times 10^{-3}$

X_{rms} = 9.43 ± 3.06 Z_{rms} = 5.05 ± 2.08

X_{max} = 27.83 ± 9.92 Z_{max} = 18.04 ± 8.33

(i) $\Delta B / B = 5.0 \times 10^{-3}$

X_{rms} = 32.79 ± 18.62 Z_{rms} = 5.65 ± 2.12

X_{max} = 91.66 ± 48.36 Z_{max} = 19.63 ± 9.08

(2) Electron 'IN' solution

(i) $\Delta B / B = 5 \times 10^{-4}$

X_{rms} = 9.15 ± 4.77 Z_{rms} = 4.04 ± 1.93

X_{max} = 28.17 ± 15.06 Z_{max} = 12.44 ± 8.89

(i) $\Delta B / B = 1 \times 10^{-3}$

X_{rms} = 10.84 ± 5.30 Z_{rms} = 4.06± 1.90

X_{max} = 40.34 ± 19.59 Z_{max} = 12.52 ± 8.82

(i) $\Delta B / B = 5 \times 10^{-3}$

$X_{rms} = 37.86 \pm 19.70$ $Z_{rms} = 4.30 \pm 1.65$

$X_{max} = 143.74 \pm 78.47$ $Z_{max} = 13.72 \pm 7.59$

AFTER CORRECTION

(1) Positron 'IN' solution

Maximum strengths of correctors in each plane (in mrad)

$\alpha^{(h)}\ max = 1.41 \pm 0.38;$ $\alpha^{(v)}\ max = 1.22 \pm 0.41$

then

$X_{rms} = 0.50 \pm 0.06$ $Z_{rms} = 0.39 \pm 0.08$

$X_{max} = 1.63 \pm 0.24$ $Z_{max} = 1.63 \pm 0.44$

Applied to the "open" orbit

$X_{max} = 1.52 \pm 0.31$ $Z_{max} = 0.65 \pm 0.14$

(1) Electron 'IN' solution

Maximum strengths of correctors in each plane (in mrad)

$\alpha^{(h)}\ max = 0.79 \pm 0.18;$ $\alpha^{(v)}\ max = 1.43 \pm 0.38$

then

$X_{rms} = 0.62 \pm 0.19$ $Z_{rms} = 0.38 \pm 0.03$

$X_{max} = 1.65 \pm 0.54$ $Z_{max} = 1.55 \pm 0.34$

Applied to the "open" orbit

$X_{max} = 1.53 \pm 0.56$ $Z_{max} = 1.06 \pm 0.45$

TABLE 6 - ERROR ESTIMATES AND ORBIT CORRECTIONS ('OUT' SOLUTIONS)

BEFORE CORRECTION

[1] Orbit distortions due to a different type of errors (all in mm, 9 statistical samples). Δ represents a standard deviation with respect to that parameter.

(1) Positron 'OUT' solution

Note: Due to the limiting error-handling ability of MAD program, all the errors for this solution have been scaled down by a factor of five. Therefore all the error estimates and corrector strengths should be multiplied by five to obtain correct numbers. The test results for scaling are given in Table 7.

(i) All the errors (Δx, Δy, Δs = 0.03 mm, $\Delta\theta$, $\Delta\varphi$, $\Delta\psi$ = 0.05 mrad, $\Delta B / B = 2.0 \times 10^{-4}$)

X_{rms} = 13.16 ± 8.28 Z_{rms} = 0.61 ± 0.29

X_{max} = 30.83 ± 19.47 Z_{max} = 1.67 ± 0.78

(2) Electron 'OUT' solution

(i) All the errors (Δx, Δy, Δs = 0.15 mm, $\Delta\theta$, $\Delta\varphi$, $\Delta\psi$ = 0.25 mrad, $\Delta B / B = 1.0 \times 10^{-3}$)

X_{rms} = 20.57 ± 3.77 Z_{rms} = 2.58 ± 0.66

X_{max} = 68.85 ± 13.83 Z_{max} = 8.19 ± 3.06

AFTER CORRECTION

(1) Positron 'OUT' solution

Maximum strengths of correctors in each plane (in mrad)

$\alpha^{(h)}$ max = 0.22 ± 0.045; $\alpha^{(v)}$ max = 0.10 ± 0.026

(× 5 = 1.1 ± 0.225; = 0.5 ± 0.13)

X_{rms} = 0.62 ± 0.19 Z_{rms} = 0.38 ± 0.03

X_{max} = 1.65 ± 0.54 Z_{max} = 1.55 ± 0.34

(× 5)

X_{rms} = 3.1 ± 0.95 Z_{rms} = 1.9 ± 0.15

X_{max} = 8.25 ± 2.70 Z_{max} = 7.75 ± 1.70

(1) Electron 'OUT' solution

Maximum strengths of correctors in each plane (in mrad)

$\alpha^{(h)}$ max = 3.87 ± 1.54; $\alpha^{(v)}$ max = 0.89 ± 0.38

X_{rms} = 1.70 ± 0.85 Z_{rms} = 0.43 ± 0.13

X_{max} = 11.37 ± 6.26 Z_{max} = 2.28 ± 1.03

TABLE 7 - SCALING TEST FOR POSITRON 'OUT' LINE

The unit errors (SCALE = 1) are:
Δx, Δy, Δs = 0.015 mm, $\Delta\theta$, $\Delta\varphi$, $\Delta\psi$ = 0.025 mrad, $\Delta B / B = 1.0 \times 10^{-4}$

SCALE	X_{rms}	$X_o \times$ SCALE	Z_{rms}	$Z_o \times$ SCALE
1	3.66 = X_o		0.68 = Z_o	
2	6.90	7.32	1.35	1.36
3	9.85	10.98	2.03	2.04
4	12.61	14.64	2.70	2.72
5	15.23	18.30	3.37	3.40
6	17.73	21.96	4.03	4.08
7	20.16	25.62	4.70	4.76
8	22.51	29.28	5.37	5.44
9	24.82	32.94	6.03	6.12
10	27.09	36.60	6.70	6.80