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Modeling Fields of the FEL Steering Magnets by means of Additional magnets of the code ELOP

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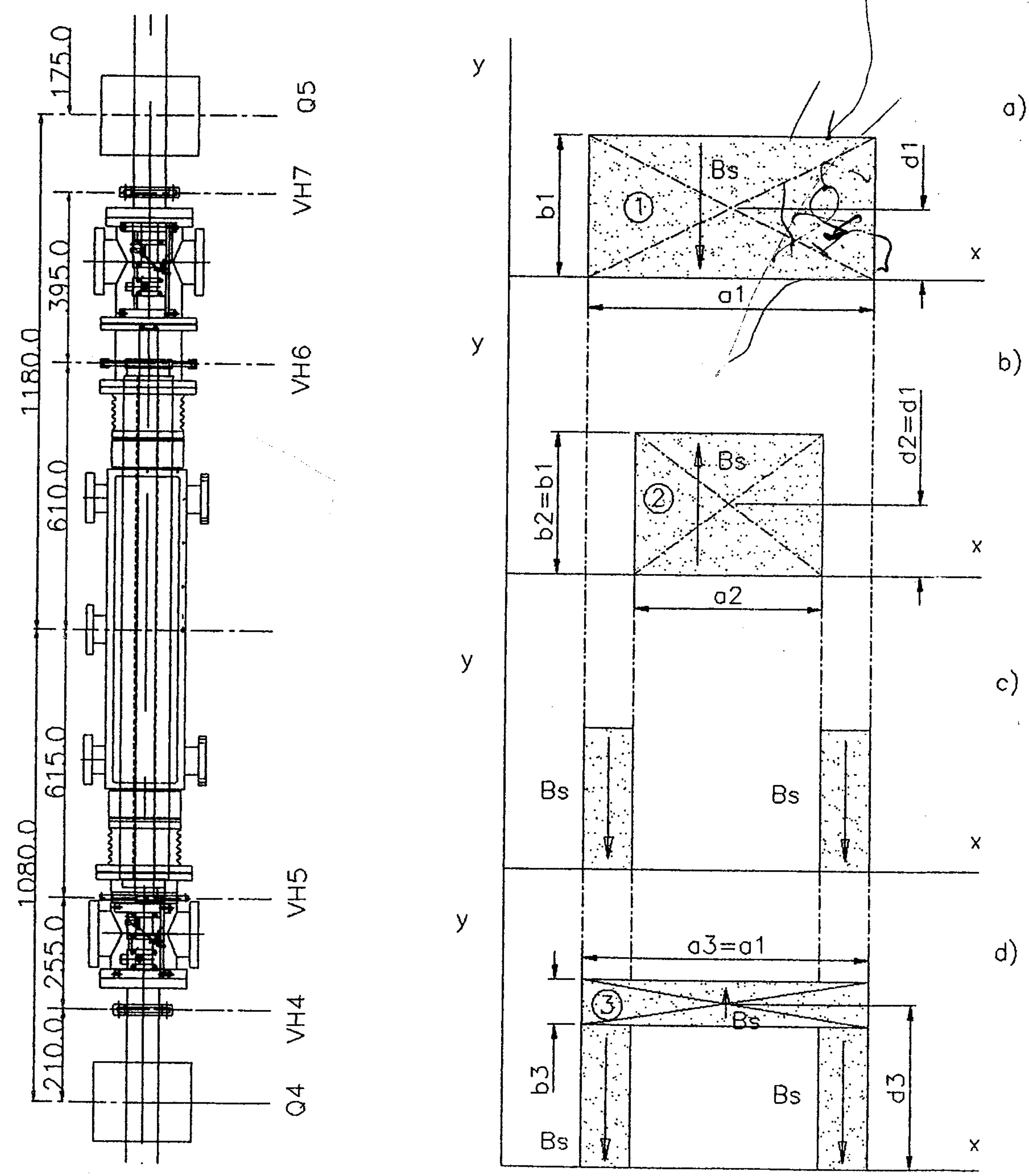

Fig1. Central part of the TAU FEL. Q4, Q5 - Quadrupoles, VH4, VH5, VH6, VH7 - steering coils (or their axis). a-d). Geometry of steering magnet model..

1. UCLA-type Steering magnet (VH4, VH7)

1.1. Two blocks model

Table 1.

UCLA-type steering coil parameters

	a	b	c	d	φ, deg	Bs, Gs
1.	123.5	50.75	11	25.375	180	4662.75
2.	101.5	50.75	11	25.375	0	4662.75

c is the magnet block size in z - direction (direction of beam moving)

$\int_z B_y^{exp} dz$=2452 Gs mm; $\int_z B_y^{sim} dz$=3034 Gs mm; $\delta = \int_z B_y^{exp} dz - \int_z B_y^{sim} dz$ = - 19.2%

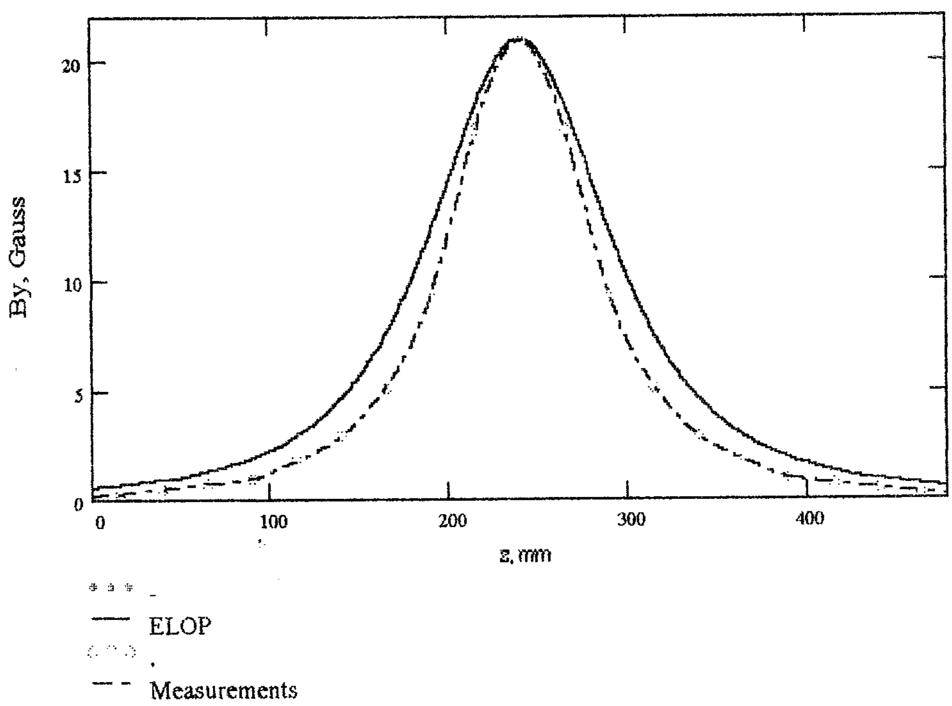

Fig.2. Two-block model for UCLA-type steerings (Table 1).

This is a bad fit therefore we will try a three block model.

1.2. Three blocks model of the UCLA-type magnet

Table 2.

UCLA-type steering coil parameters

	a	b	c	d	φ, deg	Bs, Gs
1.	123.5	50.75	11	25.375	180	1193.63
2.	101.5	50.75	11	25.375	0	1193.63
3.	123.5	11.	11.	56.25	0	1193.63

$\int_z B_y^{exp} dz$=2429 Gs mm; $\int_z B_y^{sim} dz$=1569 Gs mm; δ= 33.0%.
Experiment: $B_y(0)$=21Gs for I=1.6A.

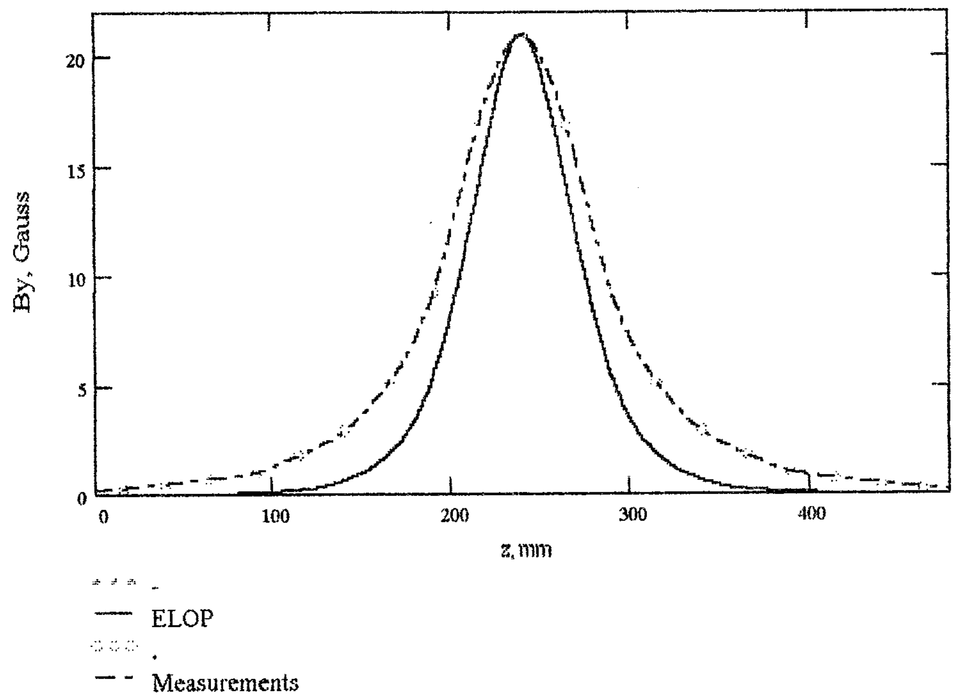

Fig.3. Three blocks model of the UCLA-type magnets (Table 2).

This is still a bad hit. Therefore we will relieve the model by changing the relative strength of magnet number 3.

2. Field optimization.

2.1. UCLA-type magnet. (VH4,VH7)

Table 3.

UCLA-type steering coil parameters after optimization of the ratio betveen the strengths of model magnets 1, 2 and 3.

	a	b	c	d	φ, deg	Bs, Gs
1.	123.5	50.75	11	25.375	180	3422.59
2.	101.5	50.75	11	25.375	0	3422.59
3.	123.5	11.	11.	56.25	0	426.68

$\int_z B_y^{exp} dz$=2453 Gs mm; $\int_z B_y^{sim} dz$=2609 Gs mm; δ= - 6.0%.

2609+25 (result of the linear extrapolation field tail out of the picture) =2634

2453+25=2478 Gs mm, then δ= - 5.9%

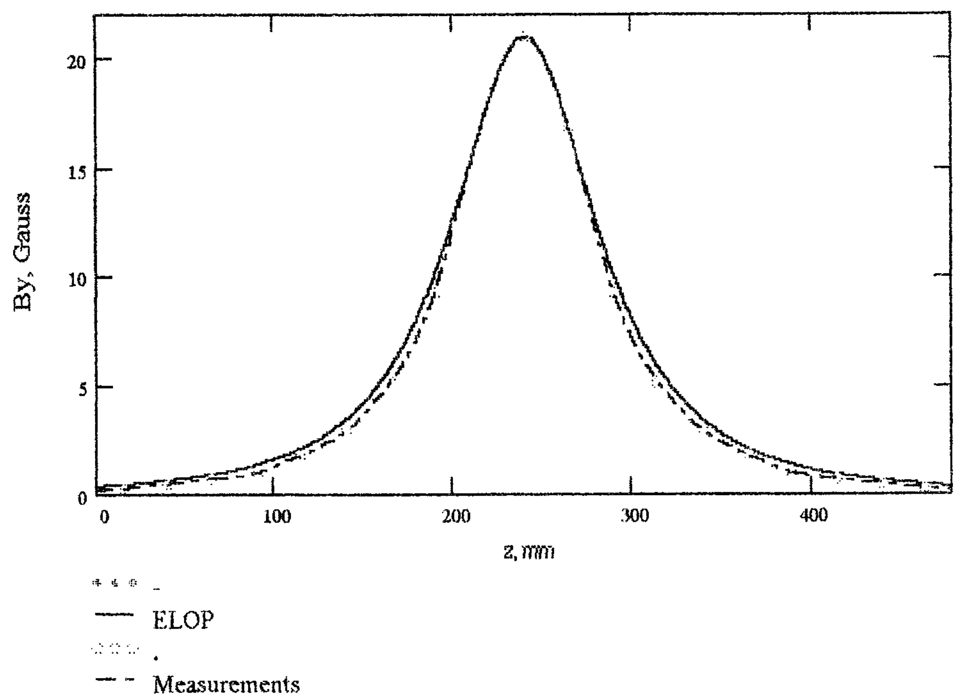

Fig.4. UCLA-type steering magnet model after optimization.

This is a satisfactory fit!

2.2. VH5 steering coil

Table 4.

Optimized model parameters of the steering magnet VH5

	a	b	c	d	φ, deg	Bs, Gs
1.	207	92.5	11	46.25	180	5872.89
2.	185	92.5	11	46.25	0	5872.89
3.	207	11	11	98	0	1049.49

$\int_z B_y^{exp} dz$=2668 Gs mm; $\int_z B_y^{sim} dz$=2628 Gs mm; δ=1.5%.

2628+160 (tail) =2788 Gs mm, then δ= - 4.3%

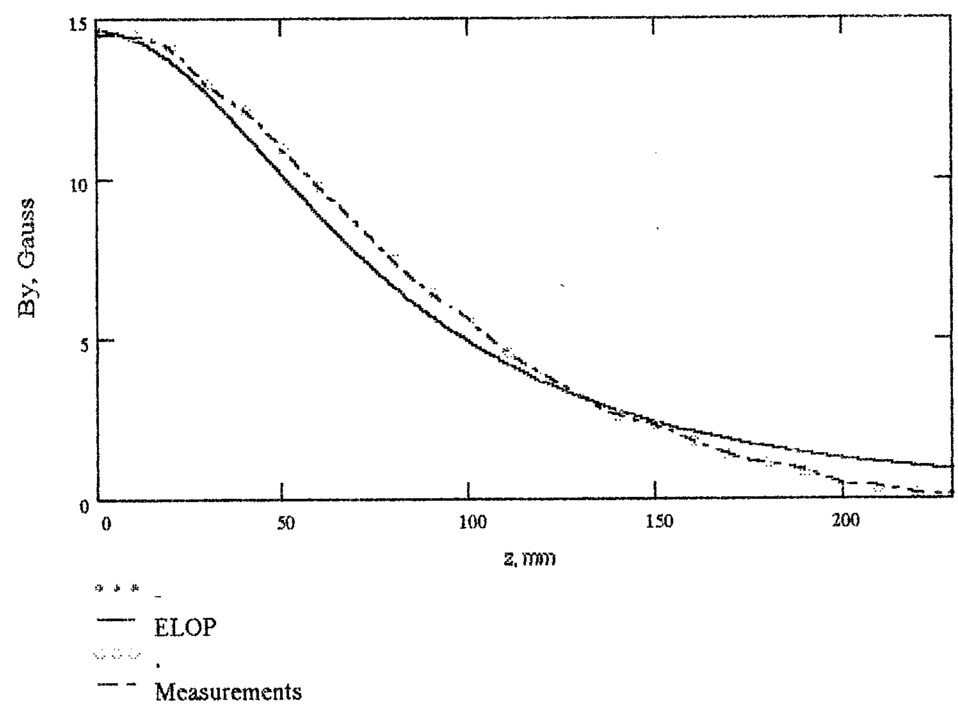

Fig. 6. VH 5 steering field displacement along the beam-axis.

2.3. VH6 steering magnet.

Table 5.

Optimized model parameters for the VH6 steering magnet

	a	b	c	d	φ, deg	Bs, Gs
1.	217	96.5	12	48.25	180	3496.75
2.	193	96.5	12	48.25	0	3496.75
3.	217	12	12	102.5	0	461.2

$\int_z B_y^{exp} dz$=1641 Gs mm; $\int_z B_y^{sim} dz$=1603 Gs mm; δ=2.3%.

1603+71=1674 Gs mm

1641+71=1712 Gs mm, then δ=2.2%.

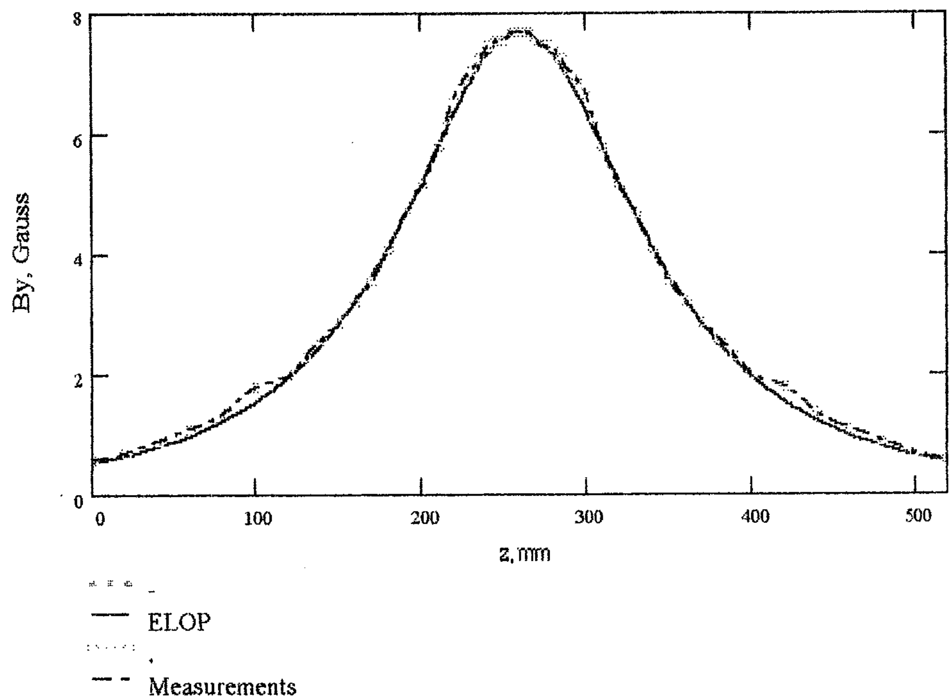

Fig. 6. VH 6 steering magnet field.

2.4. VH3 steering magnet (geometry is the same as VH5)

	a	b	c	d	φ, deg	Bs, Gs
1.	207	92.5	11	46.25	180	2752.29
2.	185	92.5	11	46.25	0	2752.29
3.	207	11	11	98	0	183.49

$\int_z B_y^{exp} dz$=1039+80 (tail) =1119 Gs mm;

$\int_z B_y^{sim} dz$=1033+45 (tail) = 1078 Gs mm; δ=3.7%.

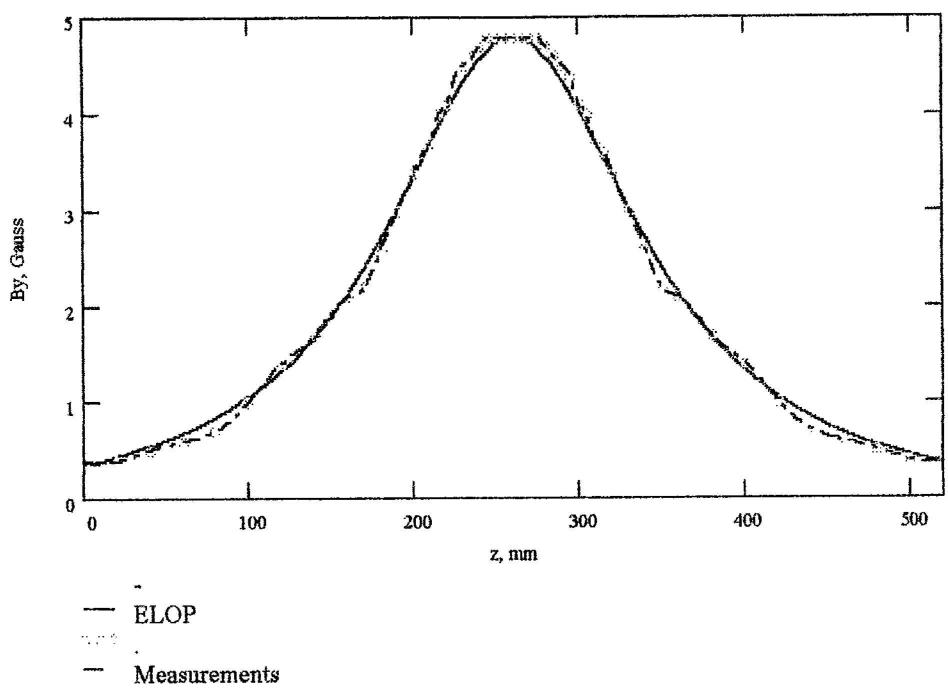

Fig. 7. VH3 steering magnet field .

3.Conclusion

3.1. Steering magnet UCLA -type (VH4, VH7) is equivalent for I=1A to magnets assembly of Table 6.

Table 6.

	a	b	c	d	φ, deg	Bs, Gs
1.	123.5	50.75	11	25.375	180	2139.12
2.	101.5	50.75	11	25.375	0	2139.12
3.	123.5	11.	11.	56.25	0	266.68

For both cases $\int_z B_y\,dz$=1646 Gs mm /A, that corresponds to full bending angle α=0.0268 rad./A for beam energy 1.4 MeV.

3.2. Steering coil VH5 - type is equivalent for I=1A to magnets assembly of Table 7.

Table 7.

	a	b	c	d	φ, deg	Bs, Gs
1.	207	92.5	11	46.25	180	6054.53
2.	185	92.5	11	46.25	0	6054.53
3.	207	11	11	98	0	1081.95

$\int_z B_y\,dz$=2874 Gs mm /A, that corresponds to bending angle α=0.0467rad./A for beam energy 1.4 MeV.

3.3. Steering coil VH6 - type for I=1A (Table 8).

Table 8.

	a	b	c	d	φ, deg	Bs, Gs
1.	217	96.5	12	48.25	180	1748.38
2.	193	96.5	12	48.25	0	1748.38
3.	217	12	12	102.5	0	230.6

$\int_z B_y\,dz$=837 Gs mm /A, that corresponds to bending angle α=0.0136 rad./A for beam energy 1.4 MeV.

3.4. Steering magnet VH3

Table 9.

	a	b	c	d	φ, deg	Bs, Gs
1.	207	92.5	11	46.25	180	688.07
2.	185	92.5	11	46.25	0	688.07
3.	207	11	11	98	0	45.86

$\int_z B_y\,dz$=269.5Gs mm/A, that corresponds to bending angle 0.0377 rad/A for E=43 kV (correspondently γ=1.084, β=0.386).

3.4. Optimization by first integral.

Table 9

Mechanical parameters

	Position	z , mm * AUTOCAD	z , mm * Wiggler center	z , mm * ELOP (parameter l)	Dimensions (external iron), mm^2	# Windings
VH4	After quads (UCLA)	-870	-860	282.275	123.5× 123.5	256
VH5	Wiggler entrance	-615	-605	27.275	207.0× 207.0	
VH6	Wiggler exit	610	620	53.385	217.0× 217.0	
VH7	Before quads (UCLA)	1005	1015	448.385	123.5× 123.5	256
VH3	After 208mm after tank wool				207× 207	

* z AUTOCAD - coordinate relative to the center of the wiggler center flange.

z wiggler center - coordinate relative to the wiggler center, located a -10mm relative to the AUTOCADE origin.

z ELOP (l) - Before the wiggler: positive distance of location before the center of the first wiggler periodic magnets -577.725mm relative to wiggler center.

- After the wiggler: Positive distance of location after the center of the last wiggler periodic magnets - +566.615mm relative to wiggler center.

Table 10.

Electron optical parameters

	$\frac{dB_s(1,2)}{dI}$ Gs/A	$\frac{dB_s(3)}{dI}$ Gs/A	$\frac{d\int_z B_y dz}{dI}$ Gs mm/A	$\frac{d\alpha}{dI}$ mrad/A	Max. current A	α_{max}, mrad
VH4	2117.51	263.92	1549	25.2	3.0	75.6
VH5	5794.18	1035.42	2750.5	44.7	1.5	67.04
VH6	1788.06	235.8	856.0	13.9	3.3	45.9
VH7	2117.51	263.92	1549	25.2	3.0	75.6
VH3	714.22	49.99	279.75	39.0 36.2 *	5.0	195 180.7 *

* for U_{gun} =50kV.

Field variation due to displacement in the x - direction was not studied carefully experimentally. Simulations by ELOP-code in x dimension (perpendicular to the B_y field) show, that the maximum B_y field component in a displacement distance 5mm from the z-axis exceeds the field on the z - axis no more than 1% for steering coils VH4 and VH7 (UCLA - type).

Polarization of the "Addition magnets" (option of the ELOP), which are used for modeling steering coils, allow presently to describe trajectory correction in the x - direction (direction of wiggling) only.