→ Peter Bigler / SL

10 .05.1995
Rev.19.03.96

THE PULSED DEFLECTION MAGNET BTM-BHZ10 PSB-PS TRANSFER LINE.

J.Borburgh, P.Bossard, H.Stucki

Table of contents

1) Introduction.

The preparation of the PS complex as LHC proton pre-injector needs the upgrading of the PSB-PS transport elements (magnets, septa,kickers) to 1.4 GeV.
Pulsed operation at higher peak currents calls for replacement of 8 non-laminated bending magnets by laminated ones.
The following computation checks if the old laminated ISR magnet VB4 (Fig.1 to 3) could be used in place of the non-laminated BTM-BHZ10 magnet.

2. Computation of the nominal magnetic flux density for 1.4 GeV and 1 GeV.

δ deflection angle = 0.3499 rad
ρ bending radius [m]
Bo nominal magnetic flux density in tesla [T]
Eo = 0.93826 GeV rest energy of particle [GeV]
T= kinetic energy of particle [GeV]

With the formulae (ref. 1) we find:

$B\,\rho\,(Tm) = 3.1297\,\beta\,\gamma$

For T = 1.4 GeV

$\beta=[\,1-(1+T/E_o\,)^{-2}\,]^{1/2} = 0.9159624$

$\gamma = 1 + T/Eo = 2.4921237$

$B\,\rho = 3.1297\,\beta\,\gamma = 7.1441399$ [Tm]

$\int Bdl = \delta\,.\,B\,\rho = 2.49973$ [Tm]

$B_{o(1.4GEV)} = \int B\,dl\,/\,L = 1.0637$ T
for L= 2.35 [m] magnetic length (estimated)

For T = 1.0 GeV

$\beta = 0.8750274$

$\gamma = 2.0658027$

$B\,\rho = 3.1297\,\beta\,\gamma = 5.657352$ [Tm]

$\int Bdl = \upsilon.\ B\,\rho = 1.98$ [Tm]

Bo = 0.842 T

3.Computation of the excitation current.

N I [ampere-turns] = $\{B_o\, h / \mu_o\} + \sim 3$ to 5%

h magnet mean gap height = 108 mm

N = 204 turns / magnet (2 coils)

$B_o = 1.0637$ T

$I \approx 460$ A

$N\,I \approx 46920$ Ampere turns / coil

Bo = 0.842 T

$I \approx 365$ A

$N\,I \approx 37286$ Ampere turns / coil

4.Computation of the Inductance

according MPS-SI Reich (ref.1)

$L_B\,[H] \approx N_B^{\,2}\,\mu_o\ w\ \ l_B / h_B$

$w = w_p + 1/2\ h_B = 320 + 1/2\ 108 = 374$ mm

$L_B \approx 204^2\ *4\pi*10^{-7} * 0.374\ *2.34 / 0.108 =$ ~~42 mH~~ 420 mH

according to G.Schnell (ref. 2)

$L = [(2*1*w^2*\mu_o)/h]\ (b + a/3)$

$L = [(2*2.35*204^2*\mu o) / 0.108](0.16 + 0.208/3)$ ~~≈52 mH~~ 520 mH

with l* = 2.35 m = (same as L page 2)

w = 204

h = 0.108 m

b = 0.16 m

a = 0.208 m

$\mu o = 4\,\pi 10^{-7}\ Hm^{-1}$

5.Magnetic field and cooling water computations

The results of the cooling water computation, according two different programs, are shown in Fig.4 and 5,
Fig.10 shows the variation of the field for the laminated ISR Magnet VB4 as computed with the " Flux2d" program.
The numerical values are shown in Fig.11 to 12.
Fig.6 to Fig.9 show the induction curves for I=455A and I=356.5 in the y=1 and y=50 mm plane.
Fig.13 and Fig.14 show the B values as a function of I as measured in 1969.

Recapitulation

Energy	T = 1.4 Gev	T = 1.0 Gev
Flux density	Bo = 1.0637 T	Bo = 0.842 T
Current estimated	I = 460 A	I = 365 A
Current accord. FLUX2d	I = 455 A	I =356.5 A
Current measured 1969	I = 457.5 A	I =357.7 A

6. Conclusion.

The characteristics (Fig.15) of the ISR Magnet VB4 are acceptible and the Magnet can be used in place of the non-laminated BTM-BHZ10 magnet.
The good field region of about 160 mm in the hor. plan is satisfying our needs.

7.References.

1) A SELECTION OF FORMULAE AND DATA USEFUL FOR THE DESIGN OF A.G. SYNCHROTRONS ;K.H.REICH AND ALL; MPS-SI/INT. DL/68-3
2) MAGNETE ; GRUNDLAGEN AUFBAU ANWENDUNGEN ; G. SCHNELL

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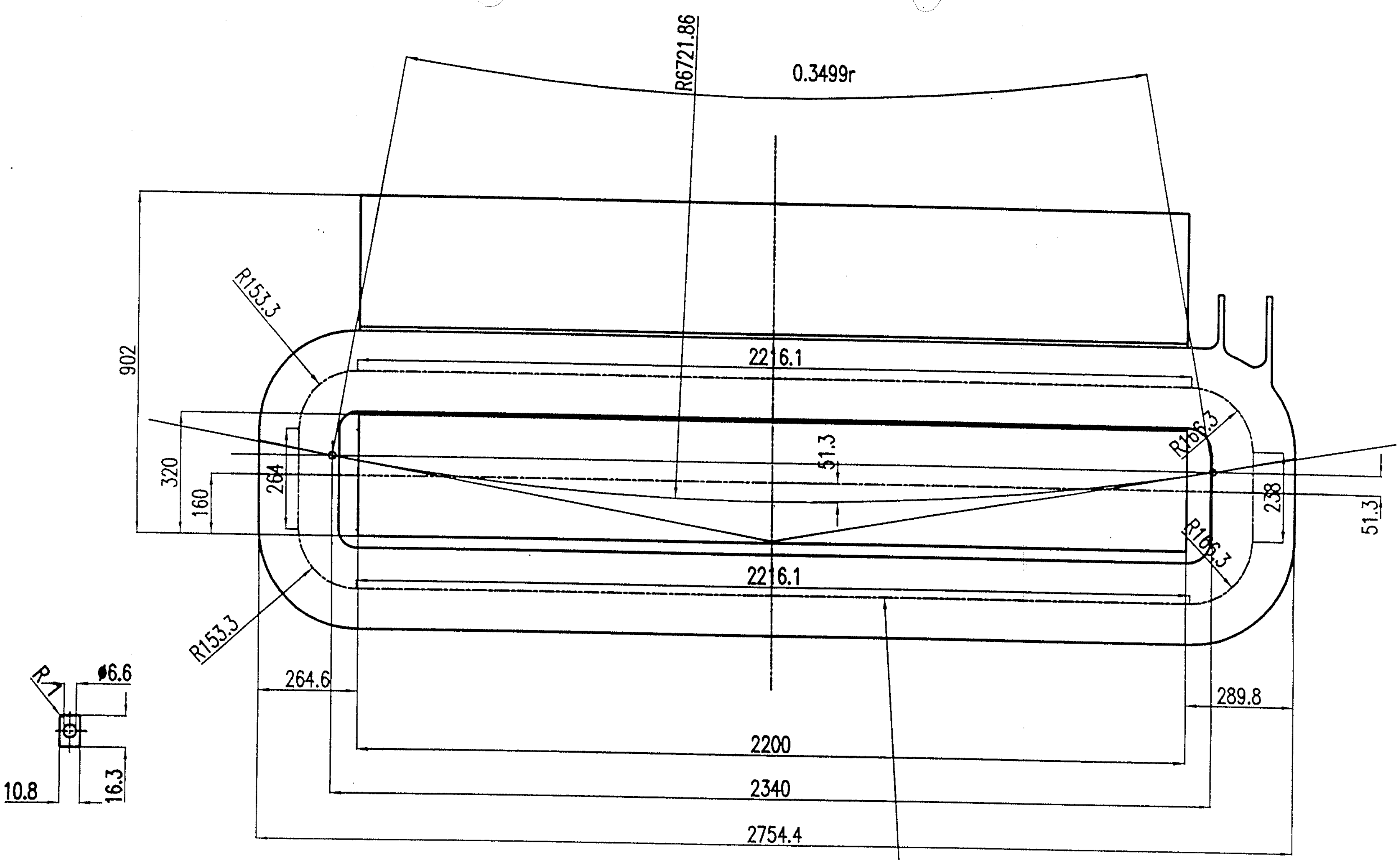


Fig. 1 AIMANT BHZ10

Long. d'une spire = 5908 mm

Nombre de spires par couche = 17

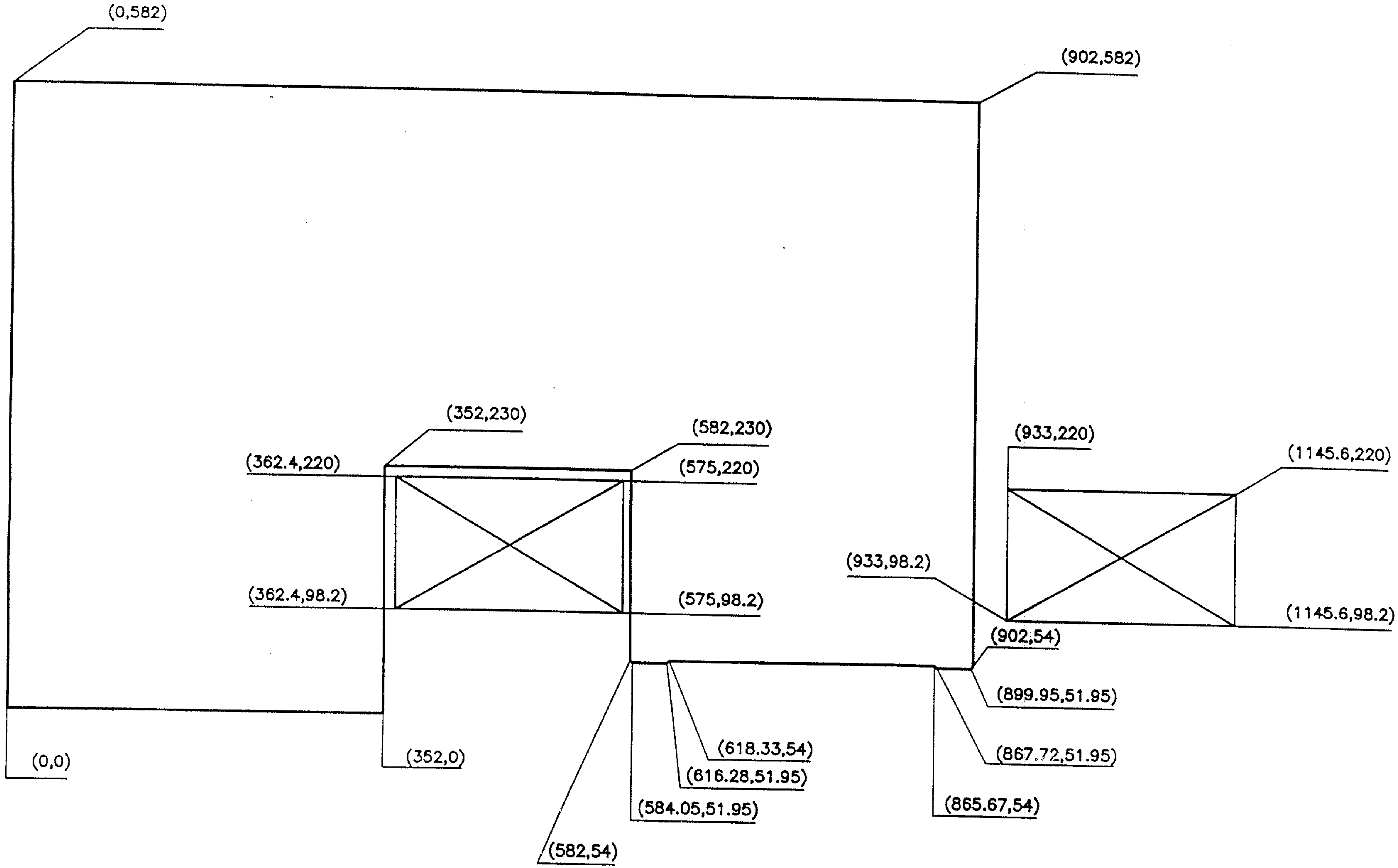


Fig. 2 AIMANT BHZ10

Magnetization Curve
Production ISR-MAG 69-41
Steel sheet

B (T)	H (Oersted)	H (A/m)
0	0.00	0.00
0.01	0.10	7.96
0.022	0.20	15.92
0.056	0.30	23.87
0.11	0.40	31.83
0.185	0.50	39.79
0.29	0.60	47.75
0.48	0.80	63.66
0.635	1.00	79.58
0.75	1.20	95.49
0.845	1.40	111.41
0.92	1.60	127.32
1.042	2.00	159.15
1.13	2.40	190.98
1.22	3.00	238.73
1.308	4.00	318.30
1.44	6.00	477.46
1.475	8.00	636.62
1.508	10.00	795.77
1.55	15.00	1193.66
1.575	20.00	1591.55
1.59	24.00	1909.86
1.594	25.00	1989.40
1.65	40.00	3183.10
1.675	50.00	3978.87
1.7	60.00	4774.65
1.78	100.00	7957.75
1.855	150.00	11936.62
1.922	200.00	15915.50
1.97	240.00	19098.60
2.01	280.00	22281.70

Fig. 3

Tube J. Borburgh 29/3/94. viscosite est fixe

pw prot. jb

TUBE

Données générales		
Longueur hydraulique (m)	100.5	
Longueur electrique (m)	100.5	
Courant efficace (A)	365	
Pression differentielle (bar)	15	
Dimensions exterieures		
Forme exterieure (circ,carre,rec)	rec	:circulaire,carre,rectangulaire
Cote horizontal (mm)	10.8	
Cote vertical (mm)	16.3	
Dimensions du passage d'eau		
Trou (pu, carre, circ, rec)	circ	pu: parois uniforme
Diametre minimale trou (mm)	6.5	
Diametre maximale trou (mm)	6.7	

Diametre trou (mm)		J (A/mm2)	WJS (W)	V (m/s)	Reynolds	Debit (l/min)	dt eau (K)	dt cuivre (K)	Tau (s)
6.5		2.56	1593	2.6	20205	5.22	4.37	4.45	179.940
6.52		2.56	1596	2.6	20312	5.26	4.34	4.41	178.496
6.54		2.56	1598	2.6	20419	5.31	4.31	4.38	177.068
6.56		2.57	1600	2.6	20526	5.35	4.28	4.36	175.657
6.58		2.57	1603	2.6	20633	5.40	4.25	4.33	174.261
6.6		2.57	1605	2.7	20741	5.44	4.22	4.30	172.881
6.62		2.58	1607	2.7	20849	5.49	4.20	4.27	171.516
6.64		2.58	1610	2.7	20957	5.53	4.17	4.24	170.166
6.66		2.58	1612	2.7	21065	5.58	4.14	4.21	168.831
6.68		2.59	1614	2.7	21174	5.62	4.11	4.18	167.511
6.7		2.59	1617	2.7	21283	5.67	4.09	4.16	166.205

Fig. 4 a

Tube J. Borburgh 29/3/94. viscosite est fixe

pw prot. jb

TUBE

Données générales		
Longueur hydraulique (m)	100.5	
Longueur electrique (m)	100.5	
Courant efficace (A)	460	
Pression differentielle (bar)	15	
Dimensions exterieures		
Forme exterieure (circ,carre,rec)	rec	:circulaire,carre,rectangulaire
Cote horizontal (mm)	10.8	
Cote vertical (mm)	16.3	
Dimensions du passage d'eau		
Trou (pu, carre, circ, rec)	circ	pu: parois uniforme
Diametre minimale trou (mm)	6.5	
Diametre maximale trou (mm)	6.7	

Diametre trou (mm)		J (A/mm2)	WJS (W)	V (m/s)	Reynolds	Debit (l/min)	dt eau (K)	dt cuivre (K)	Tau (s)
6.5		3.22	2531	2.6	20205	5.22	6.94	7.06	179.940
6.52		3.22	2534	2.6	20312	5.26	6.89	7.01	178.496
6.54		3.23	2538	2.6	20419	5.31	6.85	6.96	177.068
6.56		3.23	2542	2.6	20526	5.35	6.80	6.92	175.657
6.58		3.24	2545	2.6	20633	5.40	6.75	6.87	174.261
6.6		3.24	2549	2.7	20741	5.44	6.71	6.83	172.881
6.62		3.25	2553	2.7	20849	5.49	6.66	6.78	171.516
6.64		3.25	2556	2.7	20957	5.53	6.62	6.73	170.166
6.66		3.26	2560	2.7	21065	5.58	6.58	6.69	168.831
6.68		3.26	2564	2.7	21174	5.62	6.53	6.65	167.511
6.7		3.27	2568	2.7	21283	5.67	6.49	6.60	166.205

Fig. 4 b

Date: 19.03.96

MAGNET COIL DESIGN

MAGNET TYPE: BTM-BHZ10

COIL:		**I=460A**	**I=365 A**
Conductor Height	[mm]	16.3	16.3
Conductor Width	[mm]	10.8	10.8
Cooling Hole Diam.	[mm]	6.6	6.6
Conductor Length	[m]	100.5	100.5
Conductor Area	[mm2]	141.04	141.04
Resist. of Coil (hot)	[ohm]	1.24E-02	1.24E-02
rms Current	[A]	460	365
Dis.Power/Coil	[kW]	2.63	1.65
Weight of Coil	[kg]	126.2	126.2
COOLING:			
# of Cooling Circuits/Coil		1	1
Pressure Drop	[bar]	15	15
Velocity	[m/s]	2.68	2.68
Flow/Cooling Circuit	[l/min]	5.5	5.5
Temperature Drop	[oC]	6.8	4.29
MAGNET:			
Resist./Magnet (full load)	[ohm]	0.149	0.1487
Dissp.Power/Magnet	[kW]	31.62	19.81

Fig. 5

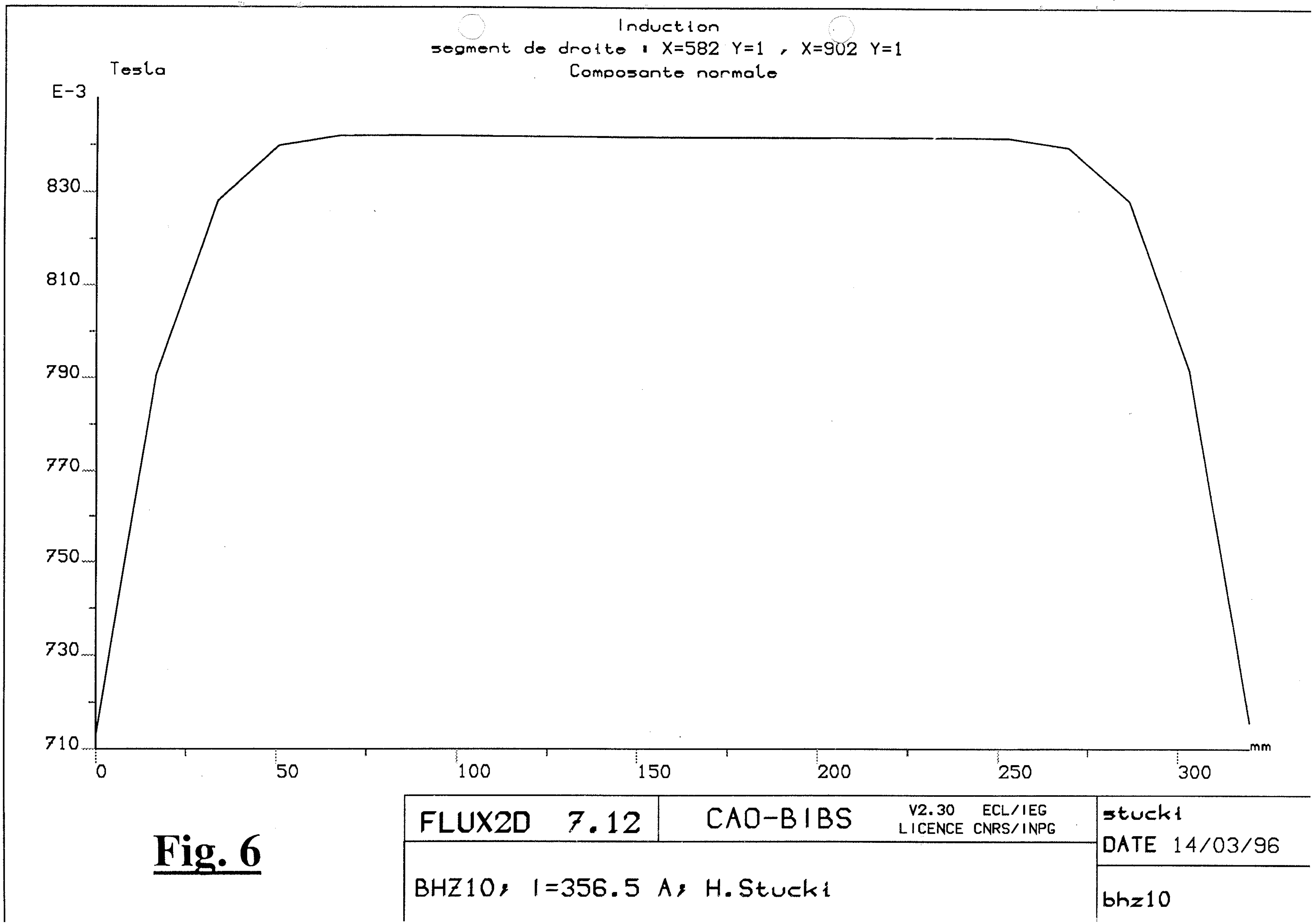

Induction
segment de droite : X=582 Y=1 , X=902 Y=1
Composante normale
Tesla
E-3
830
810
790
770
750
730
710
0
50
100
150
200
250
300
mm
FLUX2D 7.12
CAO-BIBS
V2.30 ECL/IEG
LICENCE CNRS/INPG
stucki
DATE 14/03/96
BHZ10; I=356.5 A; H.Stucki
bhz10

Fig. 6

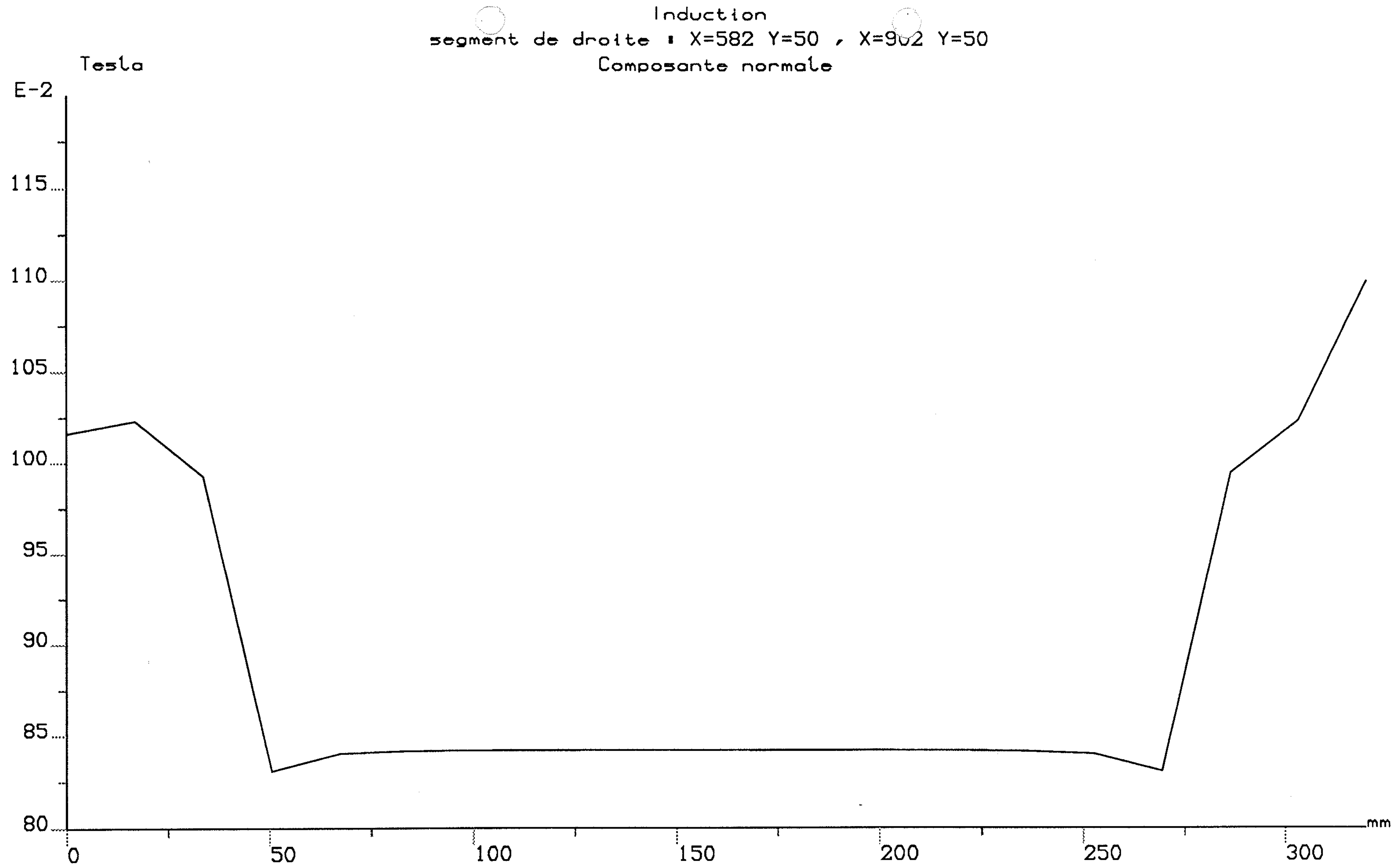
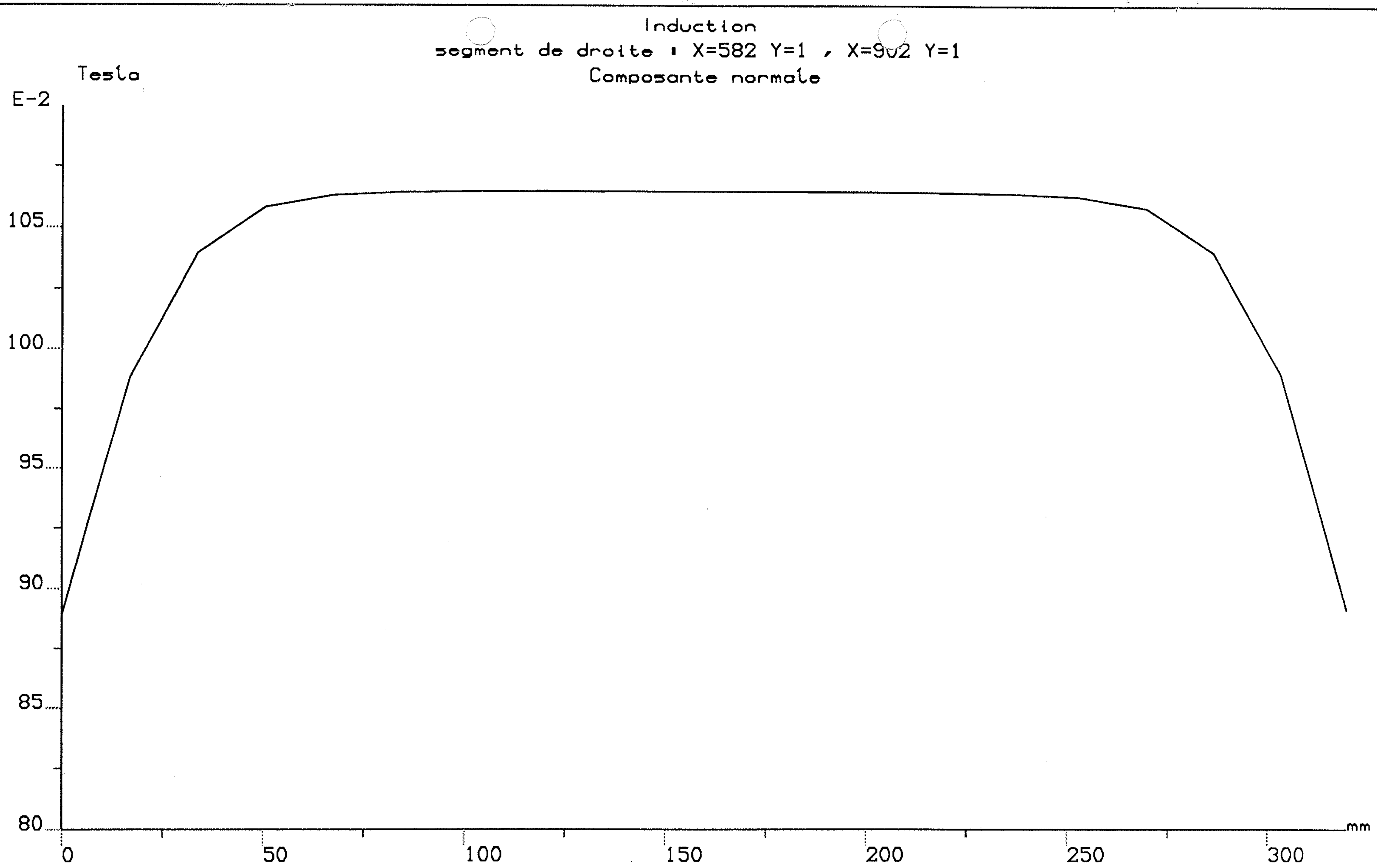


Fig. 7

FLUX2D 7.12	CAO-BIBS V2.30 ECL/IEG LICENCE CNRS/INPG	stucki DATE 14/03/96
BHZ10, I=365.5 A , H.Stucki		bhz10



FLUX2D 7.12	CAO-BIBS	V2.30 ECL/IEG LICENCE CNRS/INPG	stucki DATE 14/03/96
BHZ10, I=455 A , H.Stucki			phz10

Fig. 8

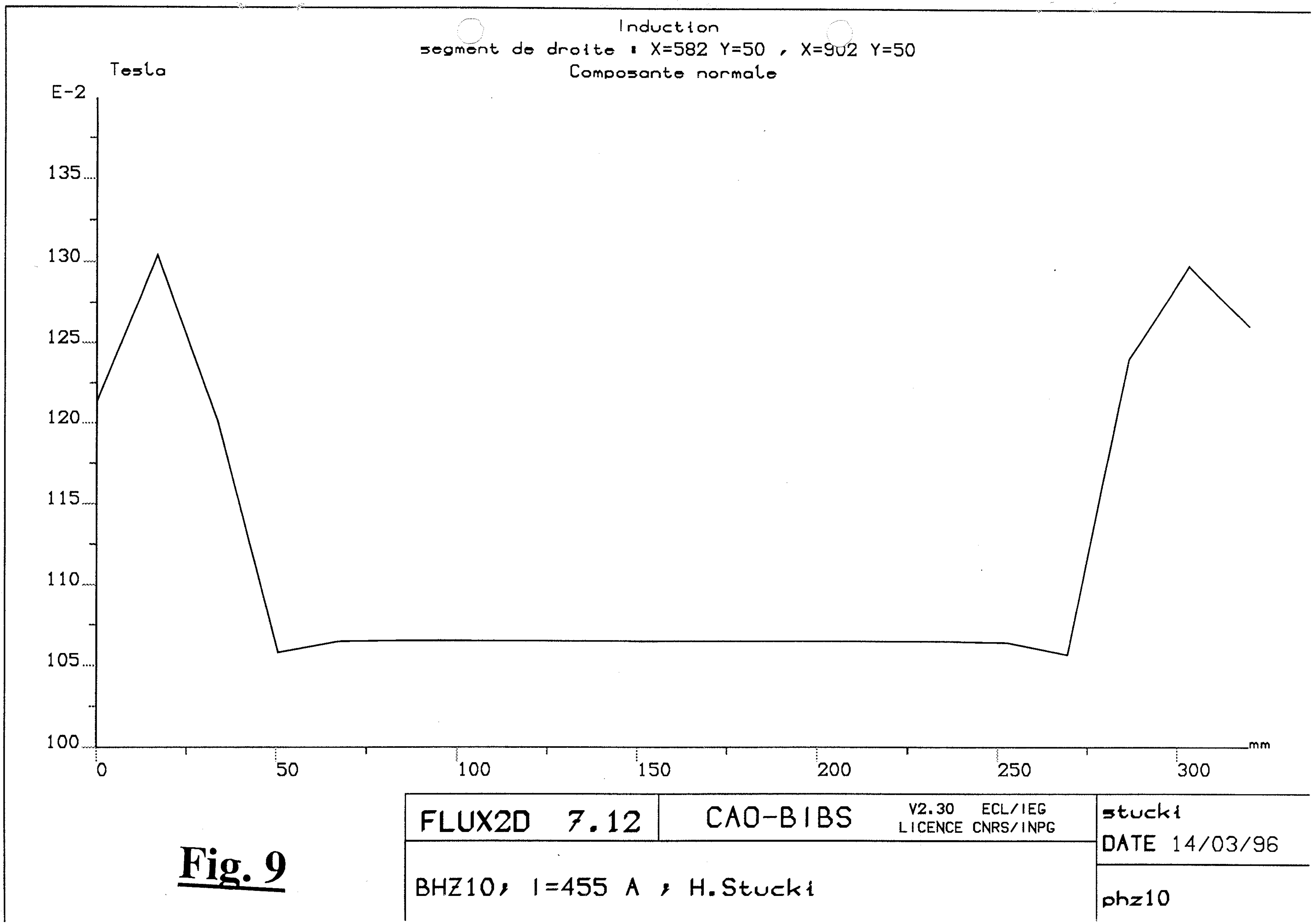
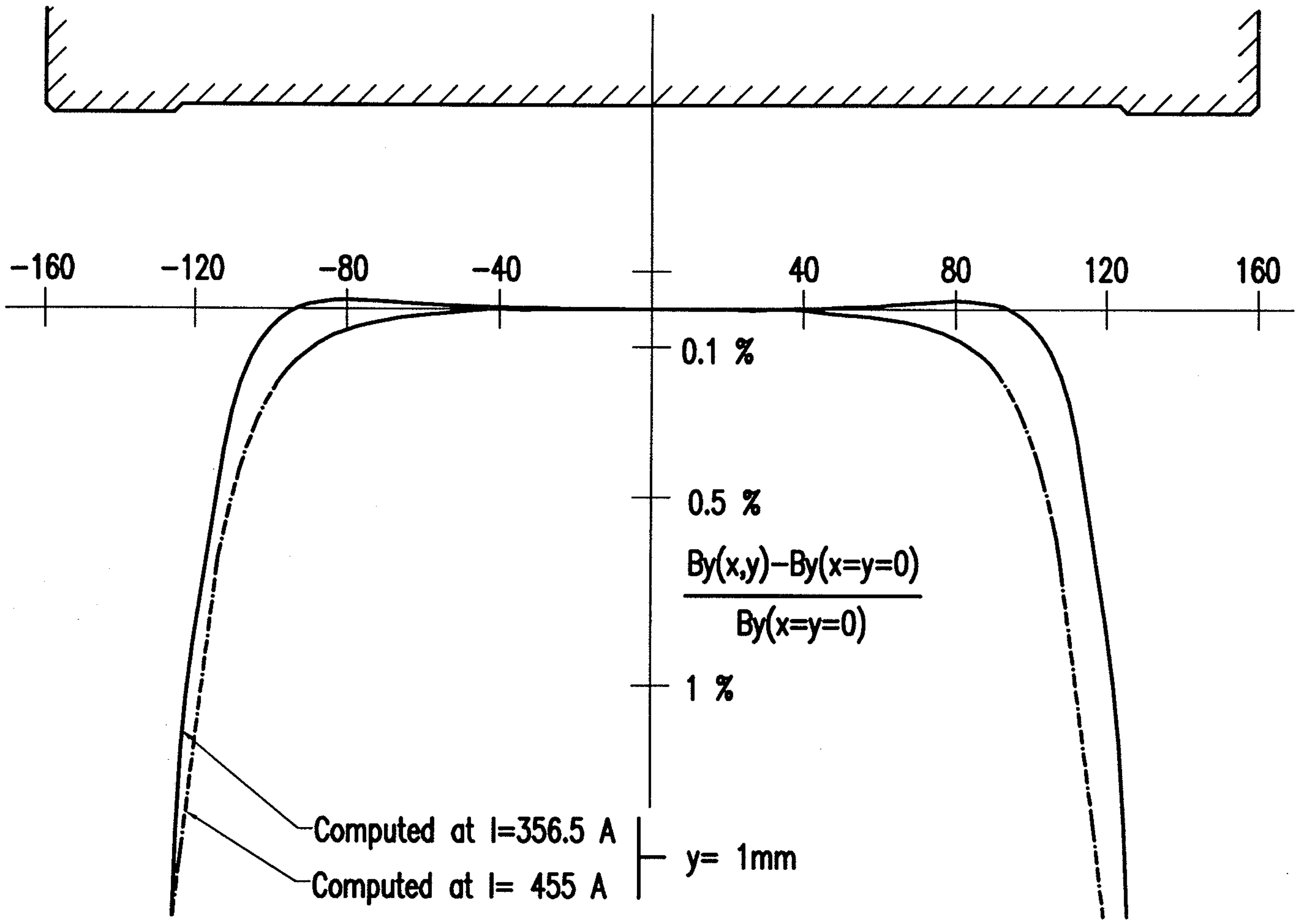

Induction
segment de droite : X=582 Y=50 , X=902 Y=50
Composante normale
Tesla
E-2
135
130
125
120
115
110
105
100
0
50
100
150
200
250
300
mm
FLUX2D 7.12
CAO-BIBS
V2.30 ECL/IEG
LICENCE CNRS/INPG
stucki
DATE 14/03/96
BHZ10, I=455 A , H.Stucki
phz10

Fig. 9



BHZ10 FIELD VARIATION

CURBHZ10

Fig. 10

Induction I=455 A

Segment de droite : X=582 Y=1 , X=772 Y=1

Abscisse mm	Module Tesla	C. Normale Tesla	C. Tangentielle Tesla	ΔB/Bo *10E-4
.0000000	.8891432	.8891137	.7241258E-02	
10.00000	.9535066	.9534930	.5108807E-02	
20.00000	1.001704	1.001695	.4212154E-02	
30.00000	1.032044	1.032041	.2273808E-02	311.576
40.00000	1.049328	1.049327	.1345803E-02	149.301
50.00000	1.058041	1.058040	.5333755E-03	67.506
60.00000	1.061892	1.061892	.2816333E-03	31.345
70.00000	1.063637	1.063637	.1106589E-03	14.654
80.00000	1.064418	1.064418	.5776021E-04	7.632
90.00000	1.064782	1.064782	.2357757E-04	4.215
100.0000	1.064986	1.064986	.1466771E-04	2.300
110.0000	1.065095	1.065095	.8012433E-05	1.267
120.0000	1.065158	1.065158	.4033950E-05	0.685
130.0000	1.065195	1.065195	.2572980E-05	0.329
140.0000	1.065216	1.065216	.1711542E-05	0.141
150.0000	1.065227	1.065227	.4788311E-06	0.038
160.0000	1.065231	Bo= 1.065231	-.3318825E-07	0.0
170.0000	1.065228	1.065228	-.7582139E-06	0.028
180.0000	1.065217	1.065217	-.1880357E-05	0.131
190.0000	1.065197	1.065197	-.2784575E-05	0.319
200.0000	1.065162	1.065162	-.4634220E-05	0.648
210.0000	1.065105	1.065105	-.8052923E-05	1.183
220.0000	1.065005	1.065005	-.1238558E-04	2.122
230.0000	1.064835	1.064835	-.2129790E-04	3.718
240.0000	1.064507	1.064507	-.5105250E-04	6.797
250.0000	1.063847	1.063847	-.6180707E-04	12.992
260.0000	1.062213	1.062213	-.2335240E-03	28.332
270.0000	1.058526	1.058526	-.5724066E-03	62.944
280.0000	1.050204	1.050204	-.1337287E-02	141.068
290.0000	1.033124	1.033122	-.2296504E-02	301.428
300.0000	1.003775	1.003768	-.3893347E-02	
310.0000	.9563472	.9563295	-.5820965E-02	
320.0000	.8919708	.8919414	-.7251979E-02	

Fig. 11

Induction I=356.5 A

Segment de droite : X=0 Y=1 , X=320 Y=1

Abscisse mm	Module Tesla	C. Normale Tesla	C. Tangentielle Tesla	ΔB/Bo *10E-4
.0000000E+00	.7127484	.7127269	.5540560E-02	
9.999999	.7644306	.7644177	.4445416E-02	
20.00000	.8008424	.8008375	.2818075E-02	
30.00000	.8228347	.8228336	.1331246E-02	228.142
40.00000	.8345730	.8345726	.8364943E-03	88.732
50.00000	.8397651	.8397651	.9576404E-04	27.066
60.00000	.8416115	.8416115	.1014718E-03	5.139
69.99999	.8421476	.8421476	.2489015E-04	- 1.228
79.99999	.8422402	.8422402	-.1152084E-06	- 2.328
89.99999	.8422025	.8422025	-.5342436E-05	- 1.880
99.99999	.8421507	.8421507	-.4697436E-05	- 1.265
110.0000	.8421112	.8421112	-.3231628E-05	- 0.796
120.0000	.8420851	.8420851	-.1893742E-05	- 0.486
130.0000	.8420684	.8420684	-.1353686E-05	- 0.287
140.0000	.8420572	.8420572	-.9906967E-06	- 0.154
150.0000	.8420496	.8420496	-.7371308E-06	- 0.064
160.0000	.8420442	Bo=.8420442	-.5322610E-06	0.0
170.0000	.8420407	.8420407	-.3336841E-06	0.042
180.0000	.8420398	.8420398	-.6796552E-07	0.052
190.0000	.8420434	.8420434	.7081620E-06	0.010
200.0000	.8420539	.8420539	.1204506E-05	- 0.115
210.0000	.8420759	.8420759	.2796110E-05	- 0.376
220.0000	.8421153	.8421153	.4866994E-05	- 0.844
230.0000	.8421738	.8421738	.6503375E-05	- 1.539
240.0000	.8422287	.8422287	.2791337E-06	- 2.191
250.0000	.8421566	.8421566	-.2730961E-04	- 1.335
260.0000	.8416751	.8416751	-.9628264E-04	4.383
270.0000	.8399522	.8399521	-.2696700E-03	24.845
280.0000	.8349009	.8349004	-.8733519E-03	84.839
290.0000	.8233425	.8233400	-.1680849E-02	222.128
300.0000	.8021191	.8021144	-.2760122E-02	
310.0000	.7663160	.7663028	-.4496159E-02	
320.0001	.7156482	.7156261	-.5630788E-02	

Fig. 12

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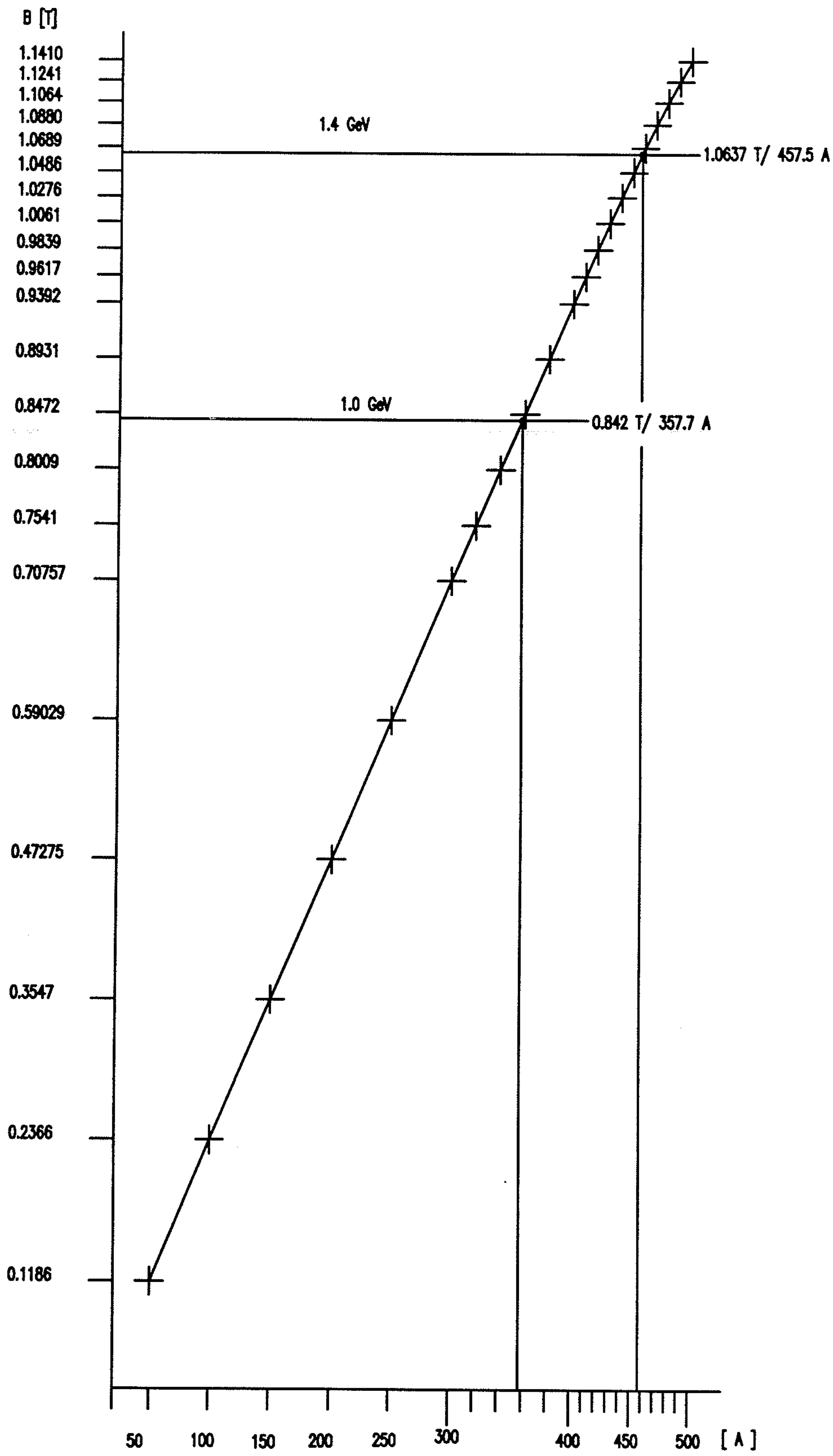
B as function of I PVB4

I	(B)	B [T]
50	-04967. e-4	0.1186
100	-09904. e-4	0.2366
150	-14848. e-4	0.3547
200	-19792. e-4	0.47275
250	-24713. e-4	0.59029
300	-29623. e-4	0.70757
320	-03157. e-3	0.7541
340	-03353. e-3	0.8009
360	-03547. e-3	0.8472
380	-03739. e-3	0.8931
400	-03932. e-3	0.9392
410	-04026. e-3	0.9617
420	-04119. e-3	0.9839
430	-04212. e-3	1.0061
440	-04302. e-3	1.0276
450	-04390. e-3	1.0486
460	-04475. e-3	1.0689
470	-04555. e-3	1.0880
480	-04632. e-3	1.1064
490	-04706. e-3	1.1241
500	-04777. e-3	1.1410
510	-04844. e-3	1.1570
520	-04910. e-3	1. ~~[illegible]~~ 1728
530	-04973. e-3	1.1879
540	-05033. e-3	1.2022
550	-05093. e-3	1.2165
560	-05151. e-3	1.2304
570	-05207. e-3	1. ~~[illegible]~~ 2437
580	-05262. e-3	1.2569
590	-05316. e-3	1.2698
600	-05369. e-3	1.2824
610	-05422. e-3	1.2951
620	-05473. e-3	1.3073
630	-05525. e-3	1.3197
640	-05574. e-3	1.3314
650	-05624. e-3	1.3433

Measured using the Septum Michach.

Fig. 13



B as function of I PVB4

30/4/69

Fig. 14

THE PULSED DEFLECTION MAGNET BTM-BHZ10 MAIN PARAMETERS

Pole width	320	mm
Centre gap height	108	mm
Minimum gap height	103.9	mm
Shim height	2.05	mm
Shim width	32.23	mm
Core length	2200	mm
Number of turns per pole	102	
Conductor width	10.8	mm
Conductor height	16.3	mm
Conductor cooling hole ∅	6.6	mm
Resistance at 20 ° C (full load)	149.	mΩ
Inductance	~50	mH
Max. current (pulsed or continuous dc)	480	A
Water flow rate maximum current	66	l/min
Temperature rise at maximum current	6.8	°C
Pressure drop at maximum current	15	bar
Nominal current (Measured 1969)	457.5/357.7	A
Field at nominal current (at center)	1.06/0.84	tesla
Dissp.Power/Magnet	35.6/19.8	kW
Integrated field at nominal current (at center)	2.499/1.98	Tm

Fig. 15