Case Study: Summing up

(ALBA – Magnet)

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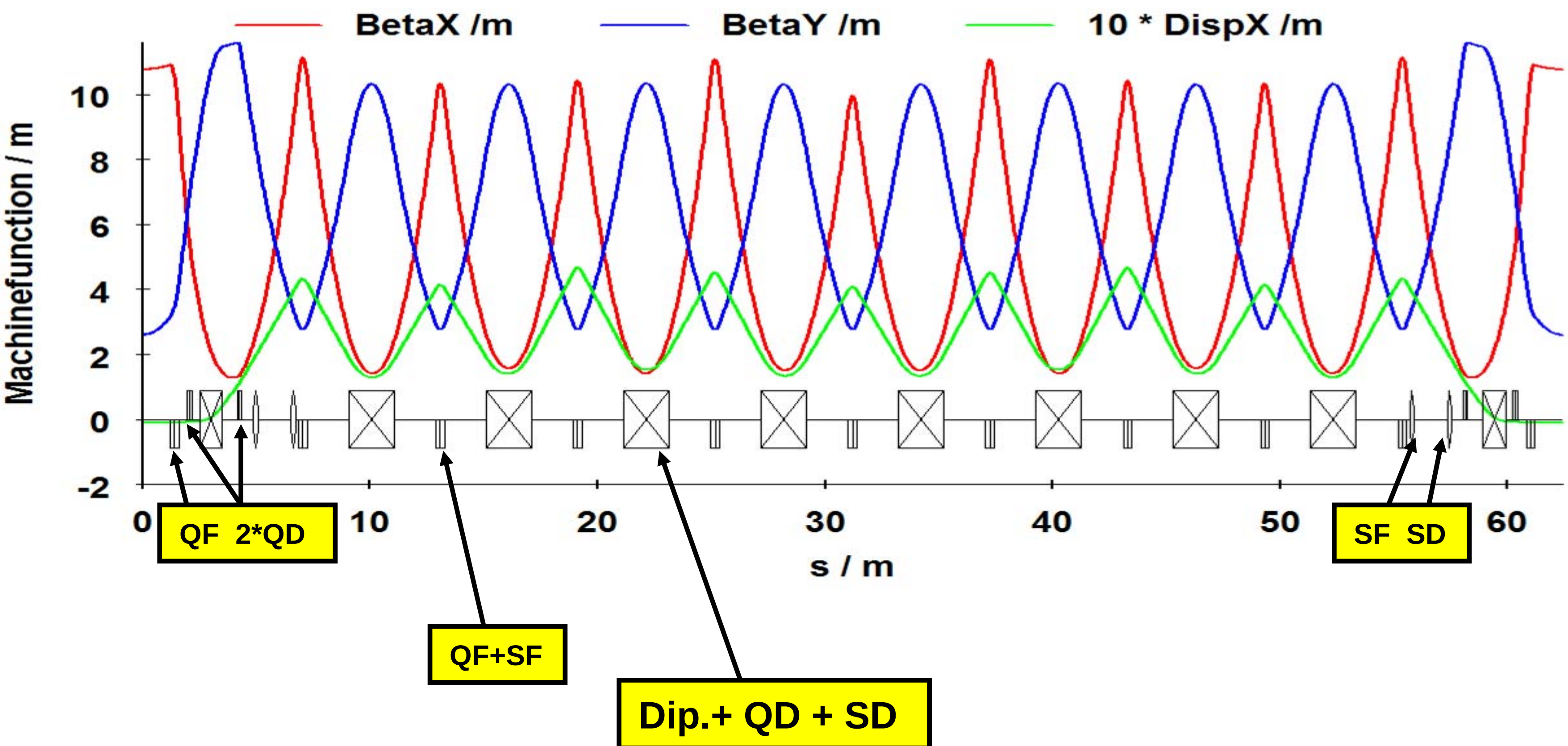
CELLS/Barcelona

Booster Lattice



This magnet has been chosen for the "Case Study"

The specifications of the bending magnet are the following:

1.) The deflection angle is:

$$\varphi = 10\_\deg. = 0.174533\_rad$$

2.) The corresponding integrated flux density is:

$$\int B \bullet ds = -1.74652\_Tm$$

1.) and 2.) are the same specifications.

We have chosen a field of B(0) = 0.87326 T (like that one of the SLS booster synchrotron) which gives a deflection radius of 11.4592 m. With this values the effective length of the bending is L(eff.) = 2.00 m

This value is not the optimum one. The booster is ramping from 0.1 GeV to 3.0 GeV; most of the problems with the ramping are in connection with the start of the ramping and the field should be as high as possible. Therefore the field at which the saturation starts should be chosen. This is roughly at 1.3 to 1.4 T, with some margin the field B(0) should be between 1.0 and 1.1 T

The specifications of the bending magnet are the following:

3.) The integrated gradient is:

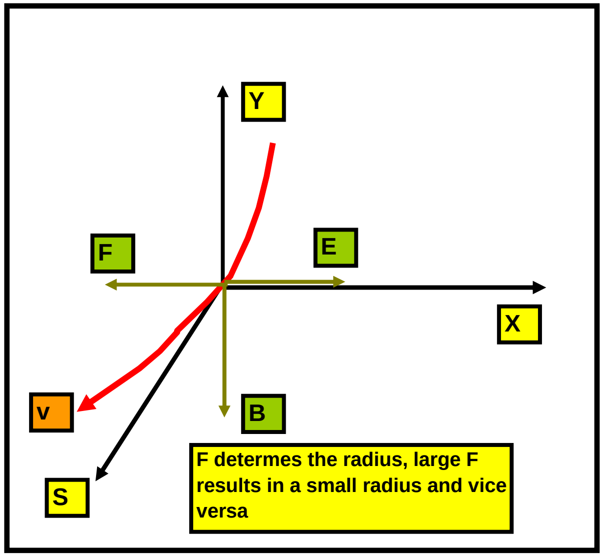
$$\int G \bullet ds = 4.58\_T$$

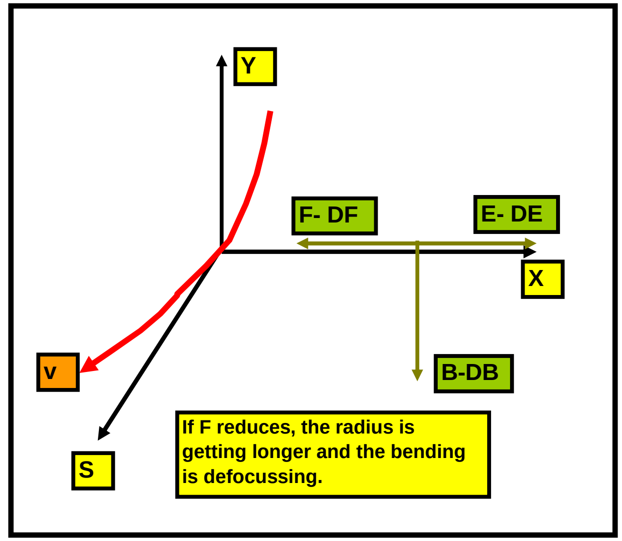
4.) The integrated sextupole component is:

$$\int \frac{1}{2} \bullet B'' \bullet ds = 18\_T/m$$

With L(eff.) = 2.00 m, one gets from 3.) and 4.) the values: G(0) = 2.29 T/m and B'' = 18 T/m^2

Design of a defocusing Bending Magnet (clock wise)



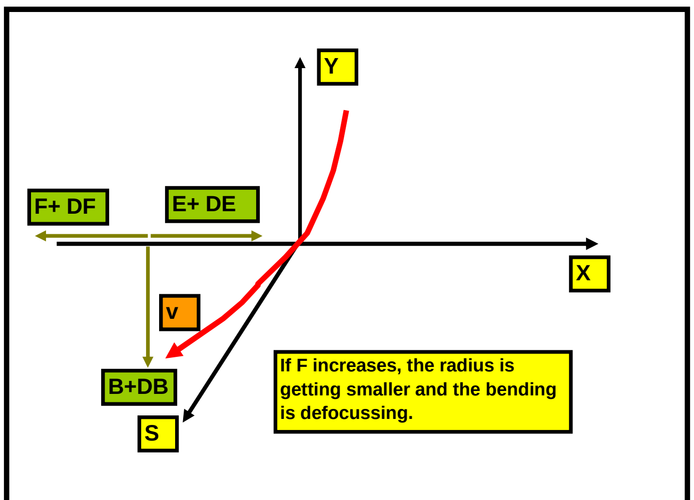


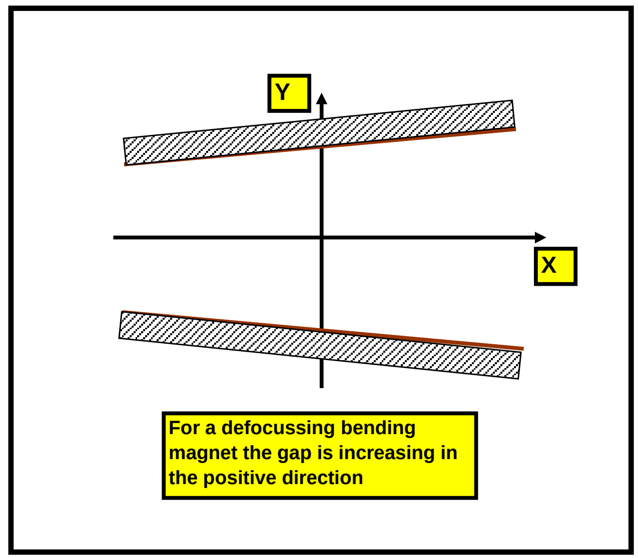
The results are:

B = negat.

G= posit.

B'' = posit.





For an anti clockwise rotation it is vice versa:

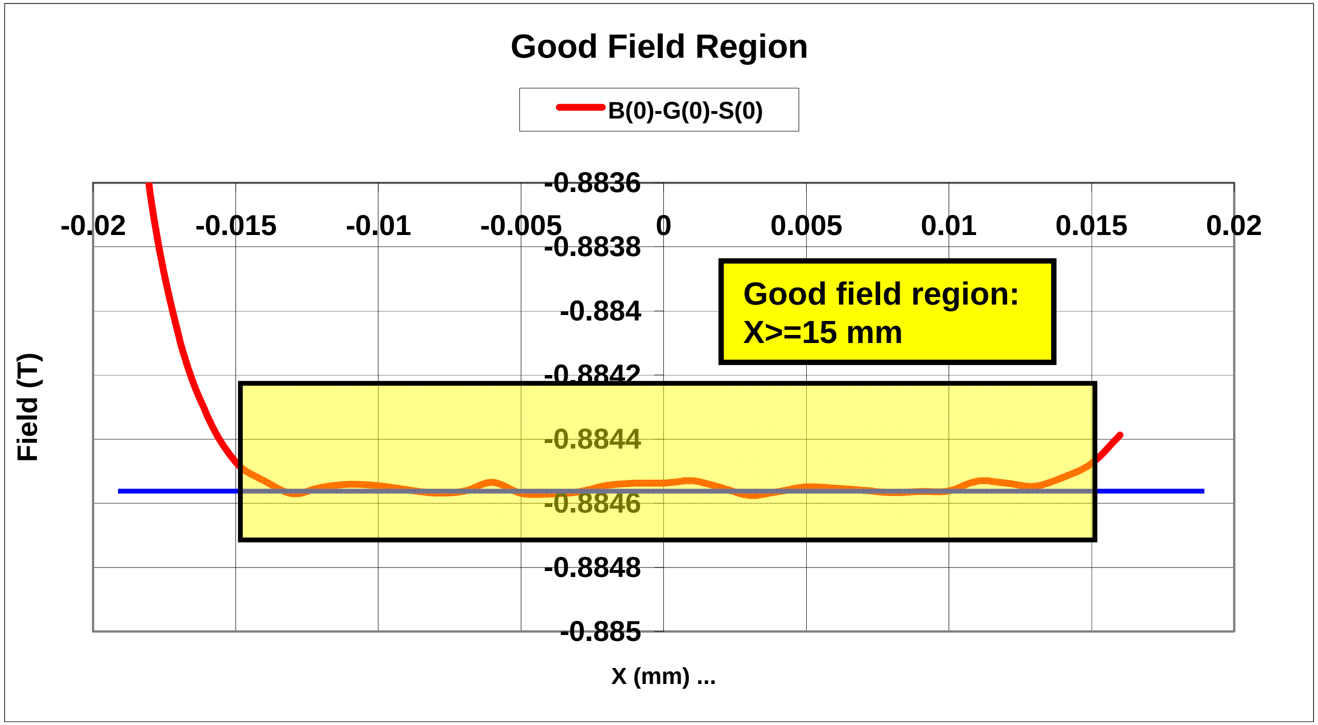
B = posit..

G= negat.

B'' = negat..

The specifications of the bending magnet are the following:

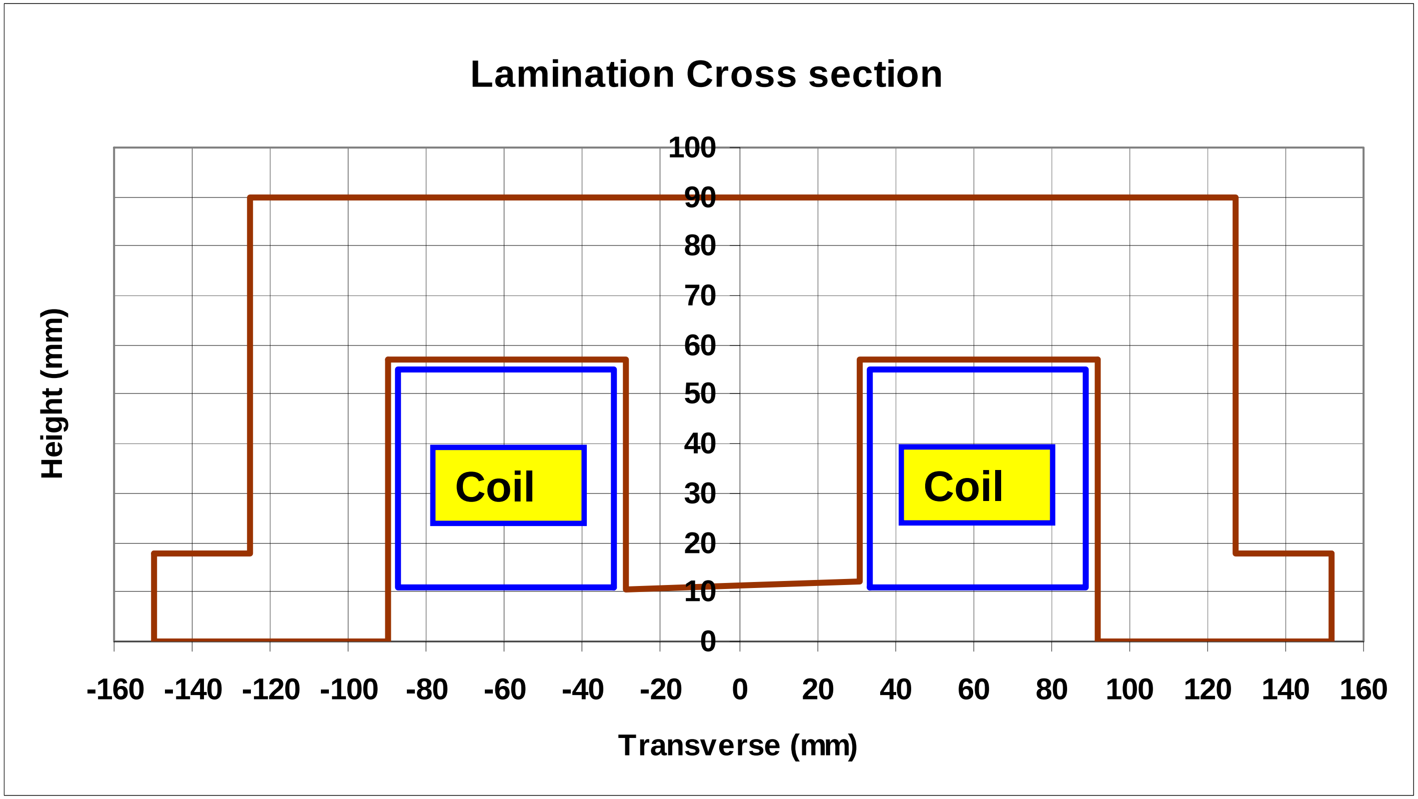
6.) The good field region is:



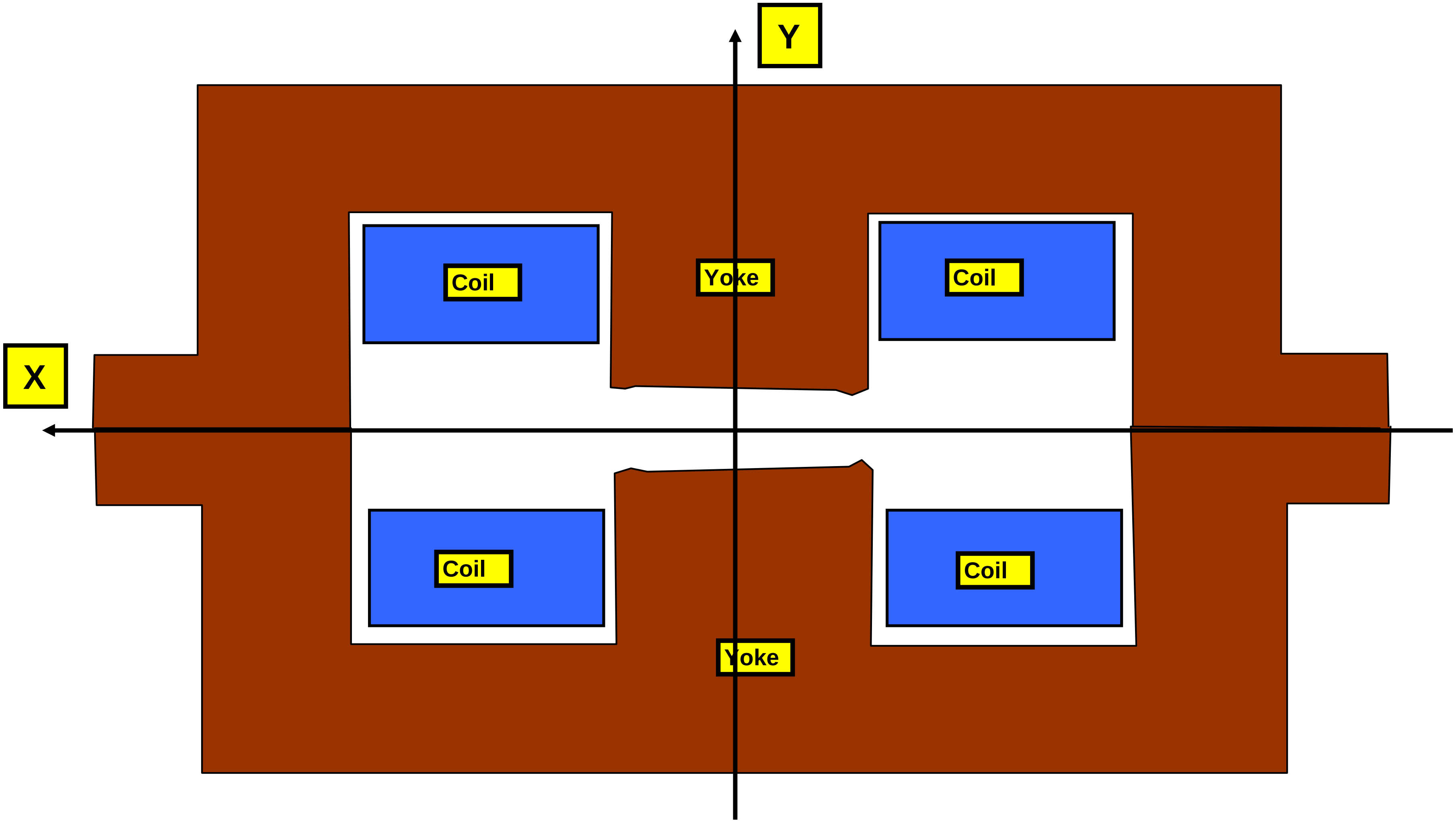
This is a result coming from the "Beam Dynamics Group"

Cross Section of the Lamination

X	y
0	11.3
31	12
31	57
92	57
92	0
152	0
152	18
127	18
127	90
0	90
-125	90
-125	18
-150	18
-150	0
-90	0
-90	57
-29	57
-29	10.5
0	11.3

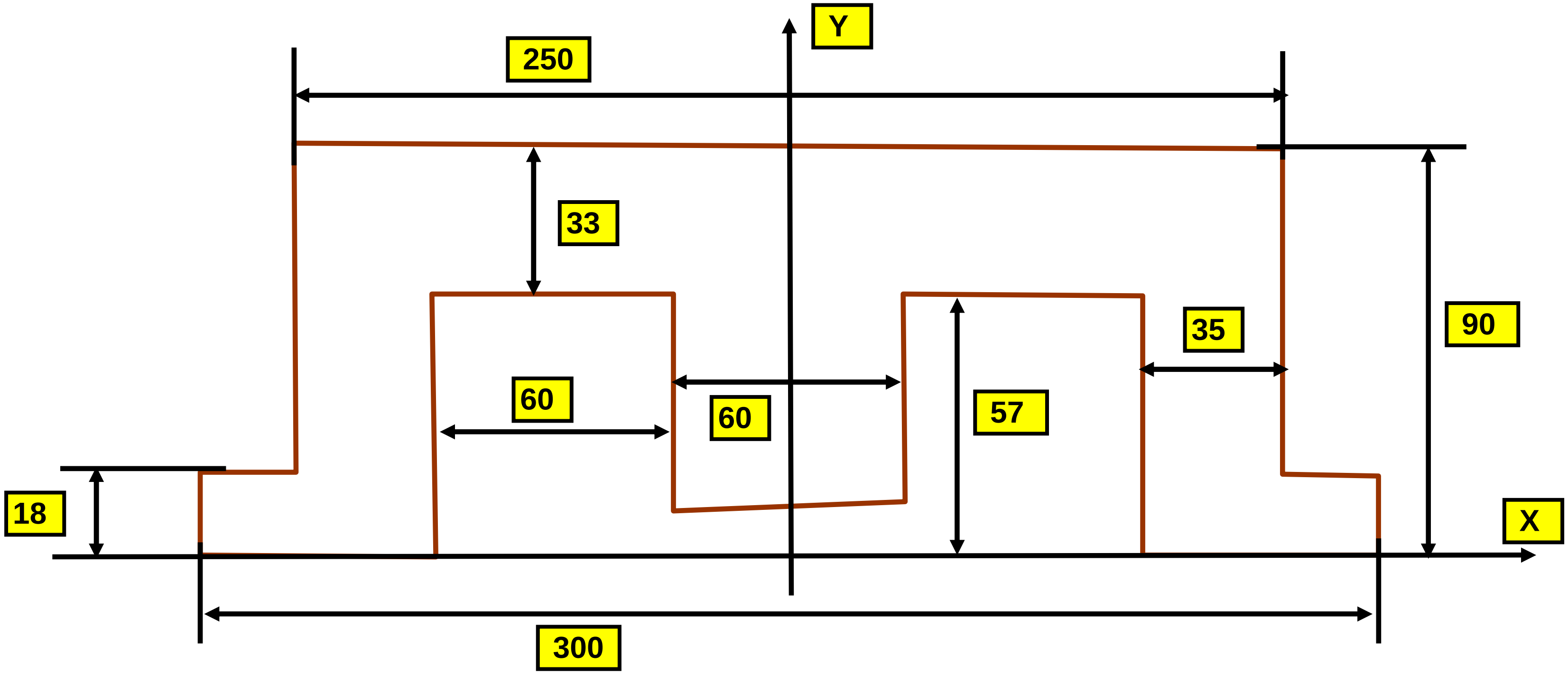


Cross Section of the Bending Magnet

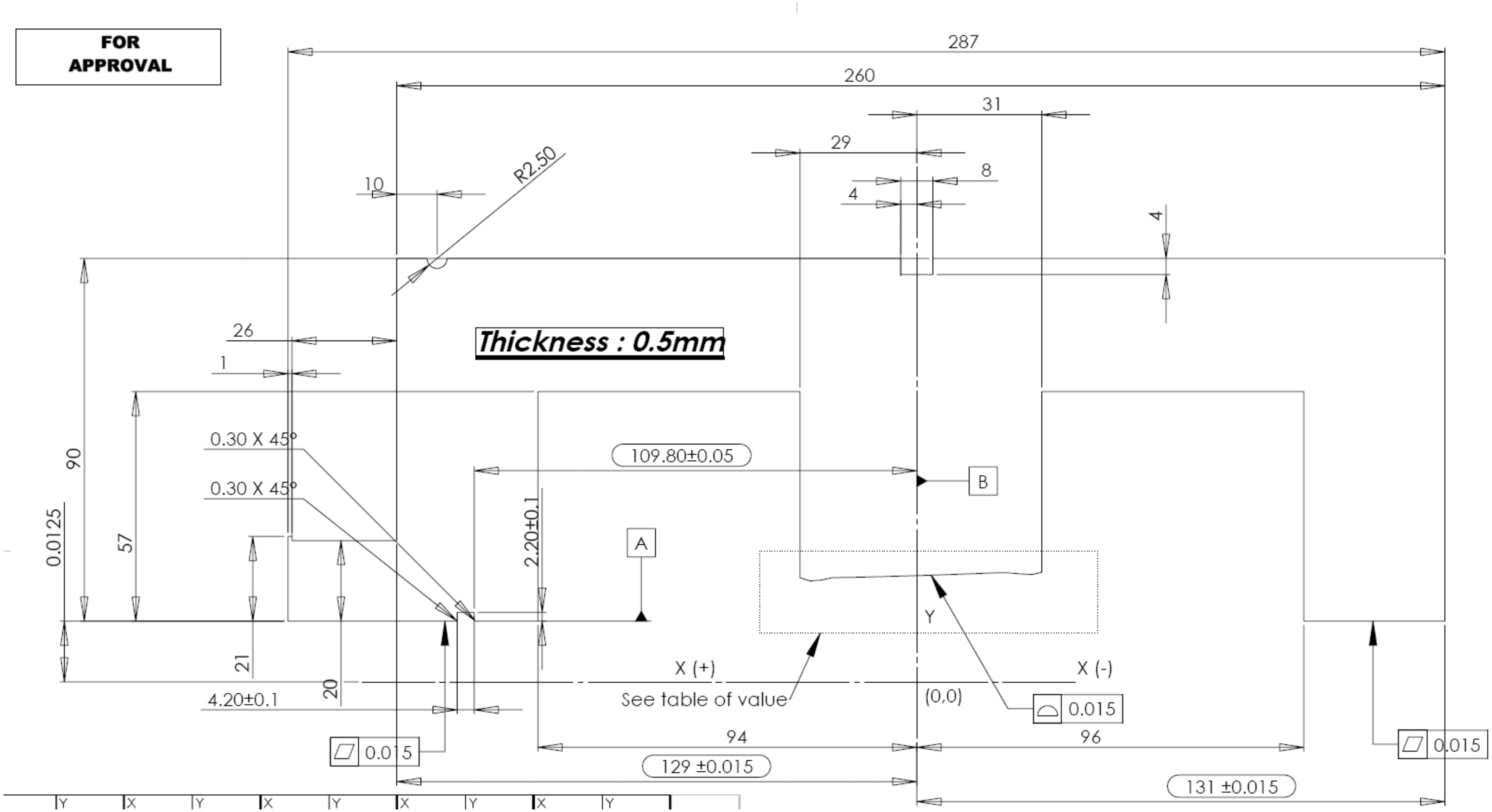


Dimensions of the Lamination

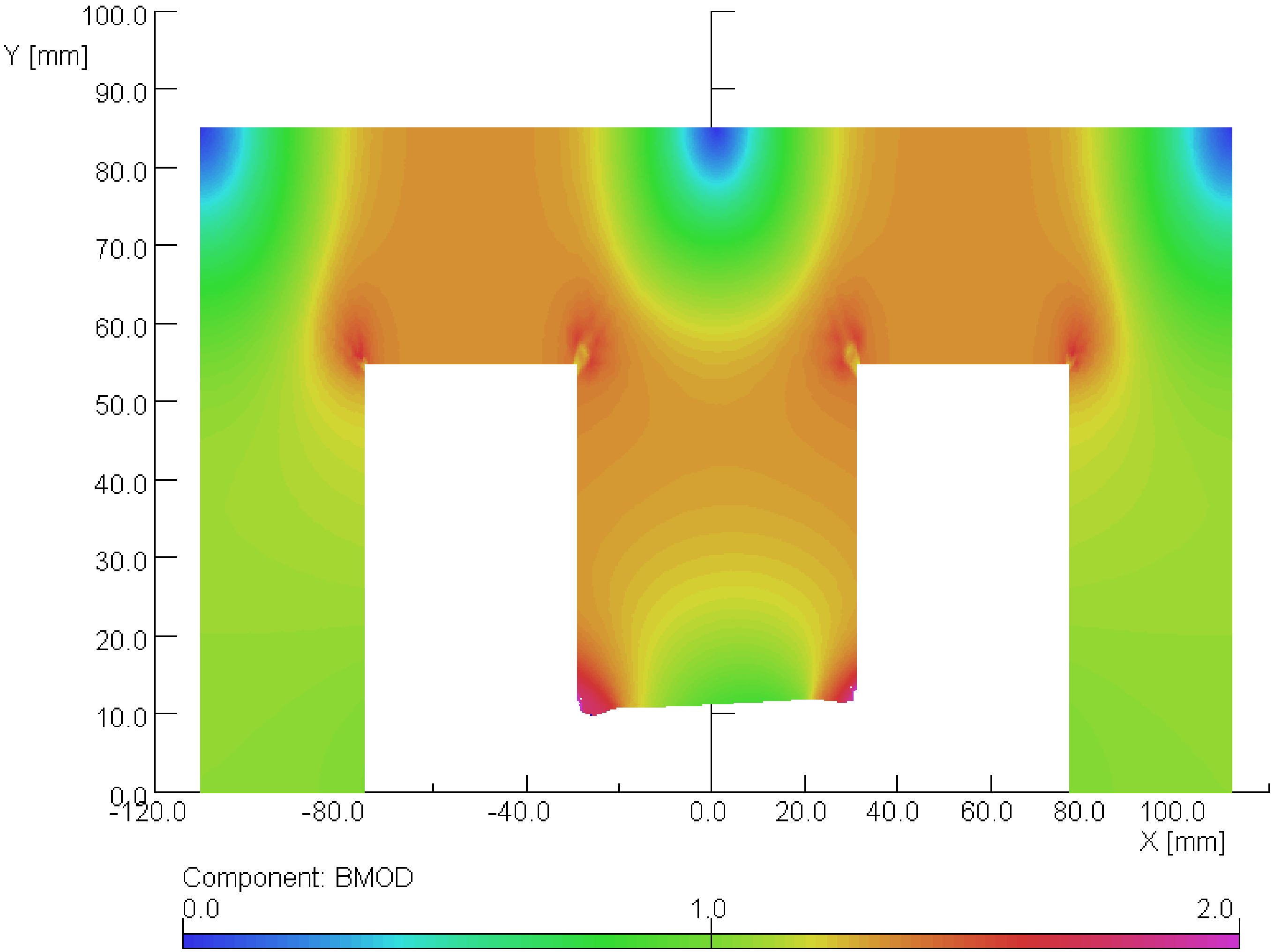
The good field region are determined by the pole profile and the cross section of the lamination.



Manufacturing Drawing of the Lamination



Field Distribution within the Lamination



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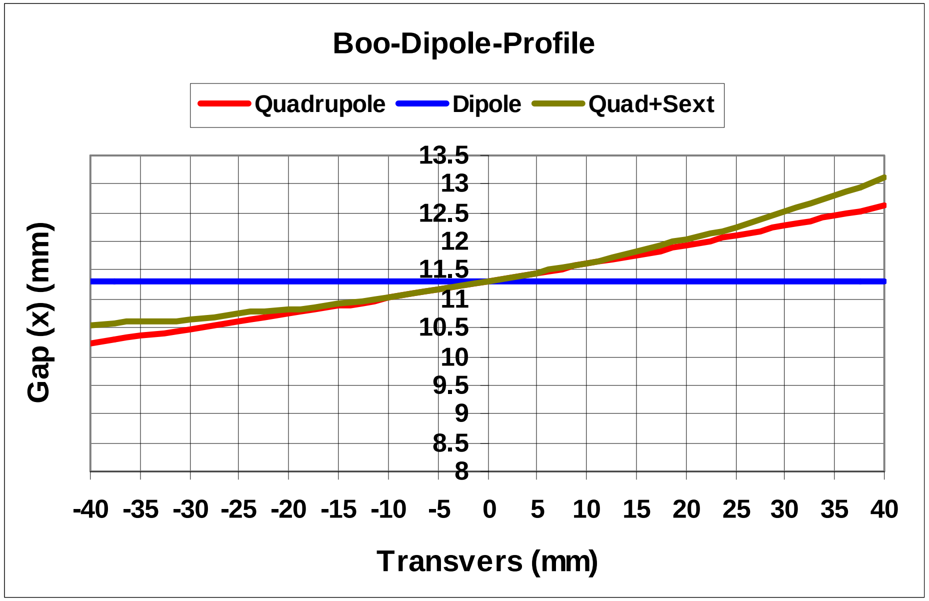
Pole profile in a bending with: a gradient and a sextupole component

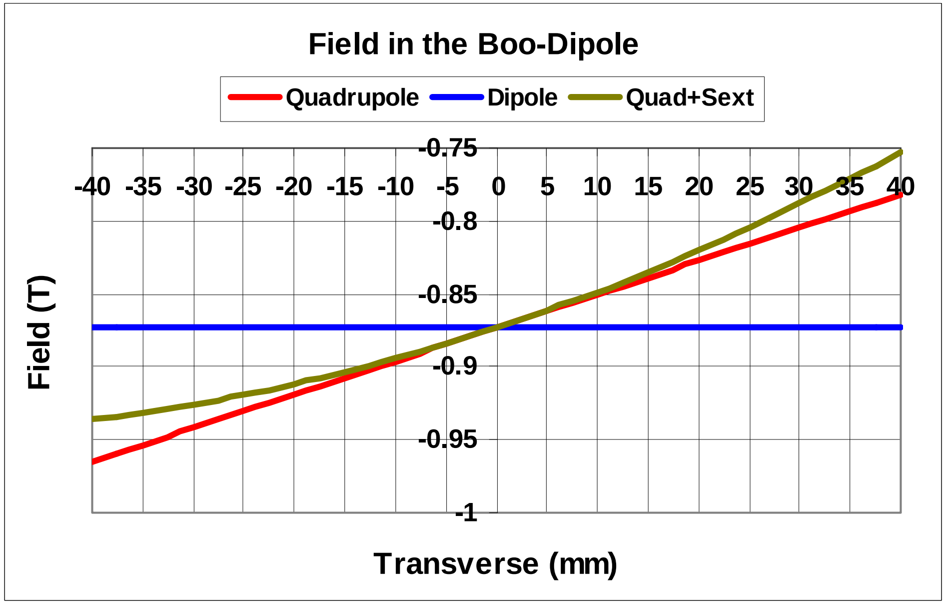
B = -0.87326 T
G = 2.29 T/m
h(0)= 11.3 mm

X(0)= 381.3362 mm

B(0) = -0.87326 T
B'' = 18 T/m^2
h(0)= 11.3 mm

X(1)^2= 97028.89 mm^2





Pole profile in a bending with: a gradient and a sextupole component

X	X(0)	F1=x/X(0)	X(1)^2	F2=x^2/[X(1)^2]	1-F1-F2	h(0)	h(s)	B(0)	B(0)*h(0)	B(s)
-40	381.3362	-0.1048943	97028.889	0.016489934	1.088404	11.3	10.38217	-0.87326	-9.867838	-0.95046
-37.5	381.3362	-0.09833841	97028.889	0.014493106	1.083845	11.3	10.42584	-0.87326	-9.867838	-0.9464788
-35	381.3362	-0.09178252	97028.889	0.012625106	1.079157	11.3	10.47113	-0.87326	-9.867838	-0.942385
-32.5	381.3362	-0.08522662	97028.889	0.010885933	1.074341	11.3	10.51808	-0.87326	-9.867838	-0.9381788
-30	381.3362	-0.07867073	97028.889	0.009275588	1.069395	11.3	10.56672	-0.87326	-9.867838	-0.93386
-27.5	381.3362	-0.07211483	97028.889	0.00779407	1.064321	11.3	10.6171	-0.87326	-9.867838	-0.9294288
-25	381.3362	-0.06555894	97028.889	0.006441381	1.059118	11.3	10.66926	-0.87326	-9.867838	-0.924885
-22.5	381.3362	-0.05900305	97028.889	0.005217518	1.053786	11.3	10.72324	-0.87326	-9.867838	-0.9202288
-20	381.3362	-0.05244715	97028.889	0.004122484	1.048325	11.3	10.7791	-0.87326	-9.867838	-0.91546
-17.5	381.3362	-0.04589126	97028.889	0.003156276	1.042735	11.3	10.83689	-0.87326	-9.867838	-0.9105788
-15	381.3362	-0.03933536	97028.889	0.002318897	1.037016	11.3	10.89664	-0.87326	-9.867838	-0.905585
-12.5	381.3362	-0.03277947	97028.889	0.001610345	1.031169	11.3	10.95844	-0.87326	-9.867838	-0.9004788
-10	381.3362	-0.02622358	97028.889	0.001030621	1.025193	11.3	11.02232	-0.87326	-9.867838	-0.89526
-7.5	381.3362	-0.01966768	97028.889	0.000579724	1.019088	11.3	11.08835	-0.87326	-9.867838	-0.8899288
-5	381.3362	-0.01311179	97028.889	0.000257655	1.012854	11.3	11.15659	-0.87326	-9.867838	-0.884485
-2.5	381.3362	-0.00655589	97028.889	6.44138E-05	1.006491	11.3	11.22712	-0.87326	-9.867838	-0.8789288
0	381.3362	0	97028.889	0	1	11.3	11.3	-0.87326	-9.867838	-0.87326
2.5	381.3362	0.006555894	97028.889	6.44138E-05	0.99338	11.3	11.37531	-0.87326	-9.867838	-0.8674788
5	381.3362	0.013111788	97028.889	0.000257655	0.986631	11.3	11.45312	-0.87326	-9.867838	-0.861585
7.5	381.3362	0.019667682	97028.889	0.000579724	0.979753	11.3	11.53352	-0.87326	-9.867838	-0.8555788
10	381.3362	0.026223576	97028.889	0.001030621	0.972746	11.3	11.6166	-0.87326	-9.867838	-0.84946
12.5	381.3362	0.03277947	97028.889	0.001610345	0.96561	11.3	11.70244	-0.87326	-9.867838	-0.8432288
15	381.3362	0.039335364	97028.889	0.002318897	0.958346	11.3	11.79115	-0.87326	-9.867838	-0.836885
17.5	381.3362	0.045891258	97028.889	0.003156276	0.950952	11.3	11.88282	-0.87326	-9.867838	-0.8304288
20	381.3362	0.052447152	97028.889	0.004122484	0.94343	11.3	11.97757	-0.87326	-9.867838	-0.82386
22.5	381.3362	0.059003046	97028.889	0.005217518	0.935779	11.3	12.0755	-0.87326	-9.867838	-0.8171788
25	381.3362	0.06555894	97028.889	0.006441381	0.928	11.3	12.17673	-0.87326	-9.867838	-0.810385
27.5	381.3362	0.072114834	97028.889	0.00779407	0.920091	11.3	12.28139	-0.87326	-9.867838	-0.8034788
30	381.3362	0.078670728	97028.889	0.009275588	0.912054	11.3	12.38962	-0.87326	-9.867838	-0.79646
32.5	381.3362	0.085226622	97028.889	0.010885933	0.903887	11.3	12.50156	-0.87326	-9.867838	-0.7893288
35	381.3362	0.091782516	97028.889	0.012625106	0.895592	11.3	12.61735	-0.87326	-9.867838	-0.782085
37.5	381.3362	0.09833841	97028.889	0.014493106	0.887168	11.3	12.73715	-0.87326	-9.867838	-0.7747288
40	381.3362	0.104894304	97028.889	0.016489934	0.878616	11.3	12.86114	-0.87326	-9.867838	-0.76726

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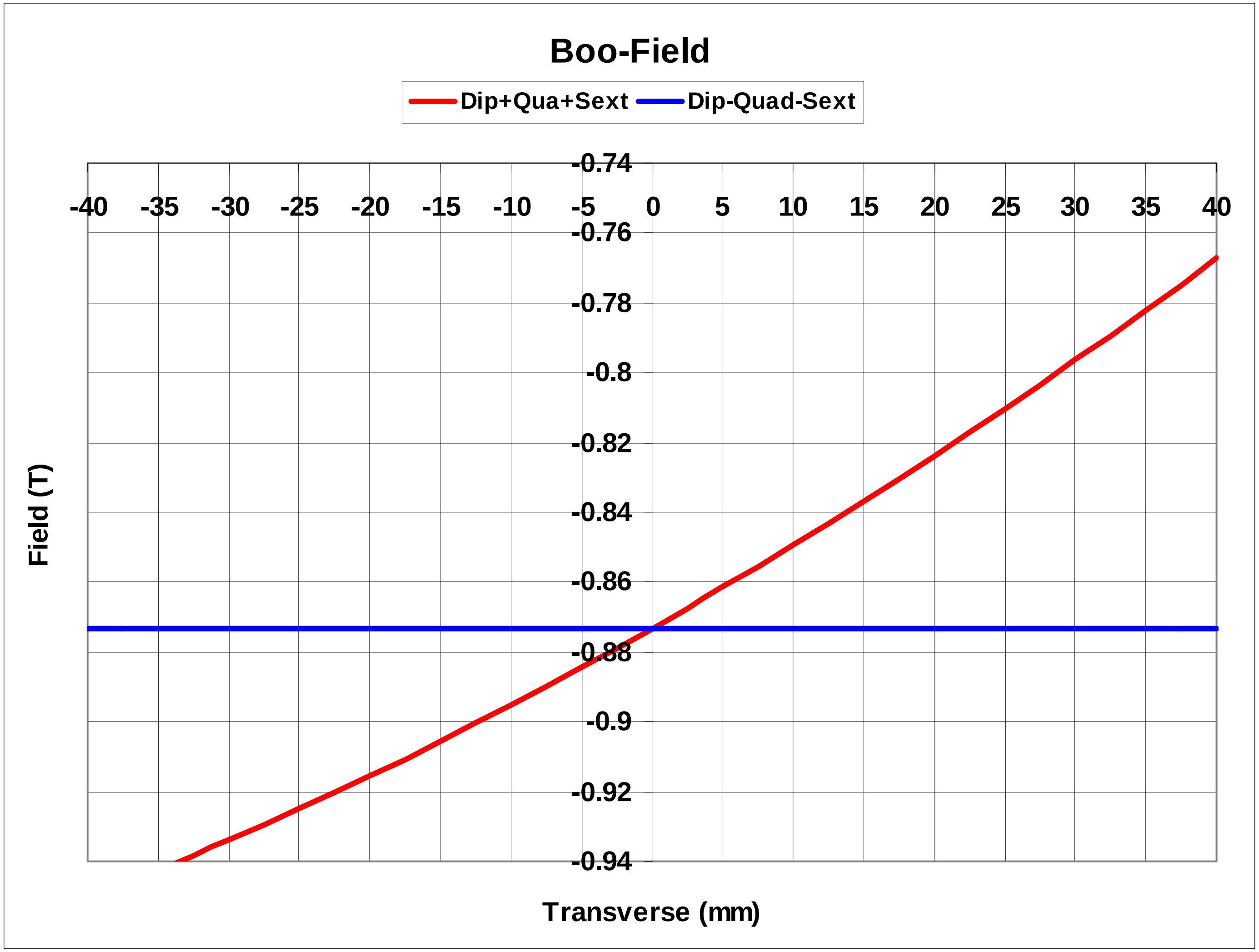
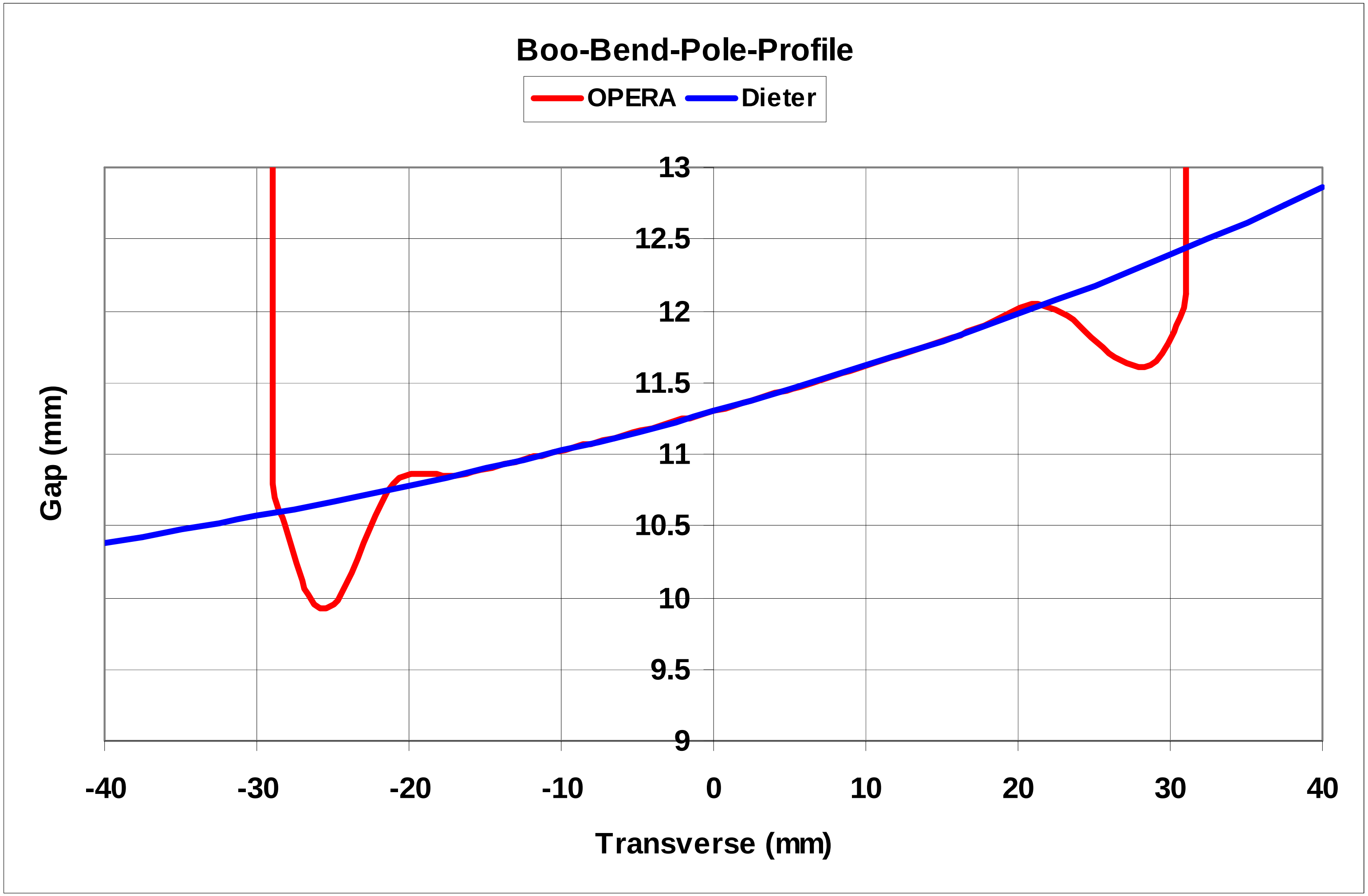
Pole profile in a bending with: a gradient and a sextupole component

B(s)	X	G(X)	B(quad)	B''	B(Sext)	B
-0.95046	-40	2.29	-0.0916	18	0.0144	-0.87326
-0.9464788	-37.5	2.29	-0.085875	18	0.0126563	-0.87326
-0.942385	-35	2.29	-0.08015	18	0.011025	-0.87326
-0.9381788	-32.5	2.29	-0.074425	18	0.0095063	-0.87326
-0.93386	-30	2.29	-0.0687	18	0.0081	-0.87326
-0.9294288	-27.5	2.29	-0.062975	18	0.0068063	-0.87326
-0.924885	-25	2.29	-0.05725	18	0.005625	-0.87326
-0.9202288	-22.5	2.29	-0.051525	18	0.0045563	-0.87326
-0.91546	-20	2.29	-0.0458	18	0.0036	-0.87326
-0.9105788	-17.5	2.29	-0.040075	18	0.0027563	-0.87326
-0.905585	-15	2.29	-0.03435	18	0.002025	-0.87326
-0.9004788	-12.5	2.29	-0.028625	18	0.0014063	-0.87326
-0.89526	-10	2.29	-0.0229	18	0.0009	-0.87326
-0.8899288	-7.5	2.29	-0.017175	18	0.0005063	-0.87326
-0.884485	-5	2.29	-0.01145	18	0.000225	-0.87326
-0.8789288	-2.5	2.29	-0.005725	18	5.625E-05	-0.87326
-0.87326	0	2.29	0	18	0	-0.87326
-0.8674788	2.5	2.29	0.005725	18	5.625E-05	-0.87326
-0.861585	5	2.29	0.01145	18	0.000225	-0.87326
-0.8555788	7.5	2.29	0.017175	18	0.0005063	-0.87326
-0.84946	10	2.29	0.0229	18	0.0009	-0.87326
-0.8432288	12.5	2.29	0.028625	18	0.0014063	-0.87326
-0.836885	15	2.29	0.03435	18	0.002025	-0.87326
-0.8304288	17.5	2.29	0.040075	18	0.0027563	-0.87326
-0.82386	20	2.29	0.0458	18	0.0036	-0.87326
-0.8171788	22.5	2.29	0.051525	18	0.0045563	-0.87326
-0.810385	25	2.29	0.05725	18	0.005625	-0.87326
-0.8034788	27.5	2.29	0.062975	18	0.0068063	-0.87326
-0.79646	30	2.29	0.0687	18	0.0081	-0.87326
-0.7893288	32.5	2.29	0.074425	18	0.0095063	-0.87326
-0.782085	35	2.29	0.08015	18	0.011025	-0.87326
-0.7747288	37.5	2.29	0.085875	18	0.0126563	-0.87326
-0.76726	40	2.29	0.0916	18	0.0144	-0.87326

Pole profile in a bending with: a gradient and a sextupole component

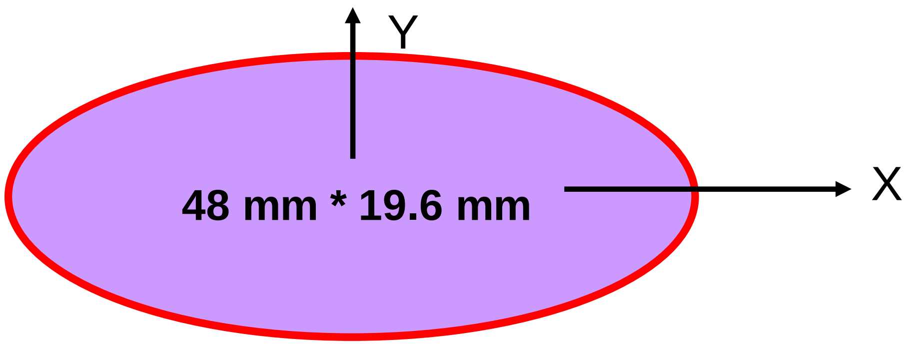


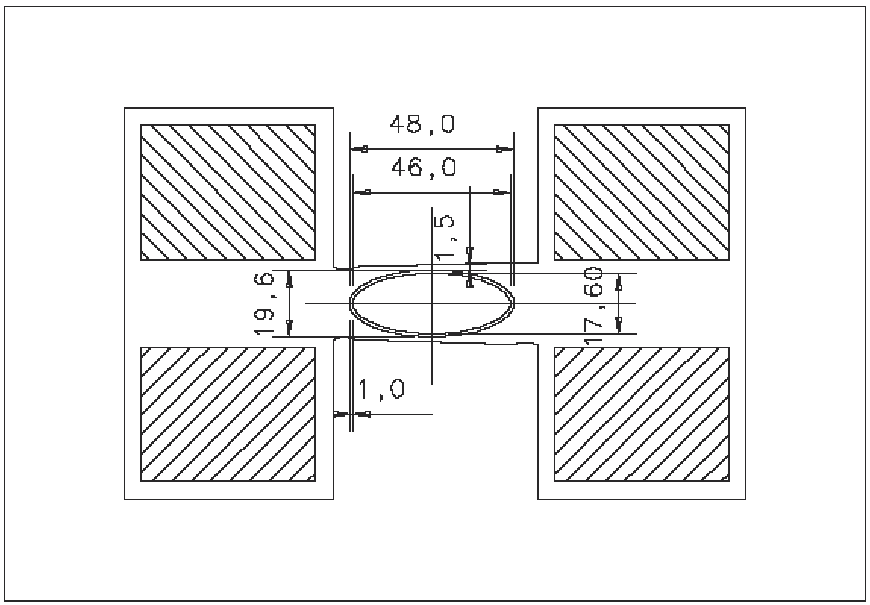
Pole Profile of the Bending Magnet



The specifications of the bending magnet are the following

7.) The size of the vacuum chamber (outer dimensions) is:





The gap should be as small as possible because it determines the overall excitation (N*I)

The size of the vacuum chamber is coming from the Beam Dynamic Group. With a space between the chamber and the pole of 1.35 mm, the gap is 22.3 mm.

The specifications of the bending magnet are the following

8.) The temperature and pressure drop is :

$$\Delta \vartheta = 11\_{}^{0}C\_and\_\Delta p = 7bar$$

These values are given by the overall cooling system

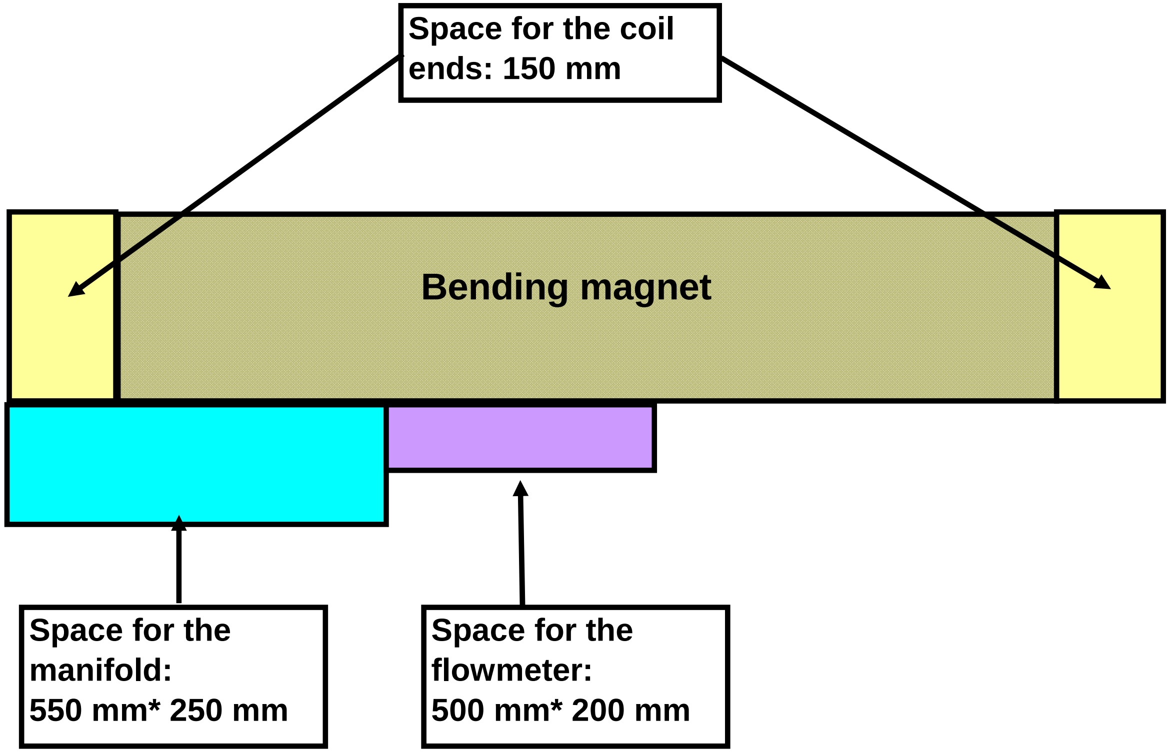
9.) The repetition rate is :

$$f(rept.) = 3\_Hz$$

These values are given by the regulation technology of the power supplies.

The specifications of the bending magnet are the following

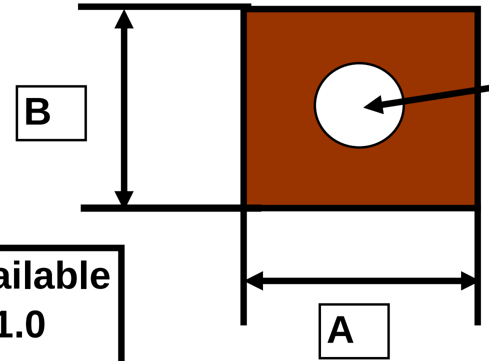
10.) Available space around the :



The space required for the coils, manifold and flow meter should be as small as possible.

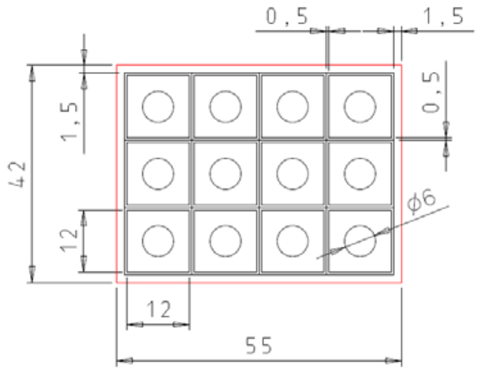
The specifications of the bending magnet are the following

11.) Sizes of the conductor :



Diameter is a vailable with steps of 0.5 mm

A and B are vailable with steps of 1.0 mm

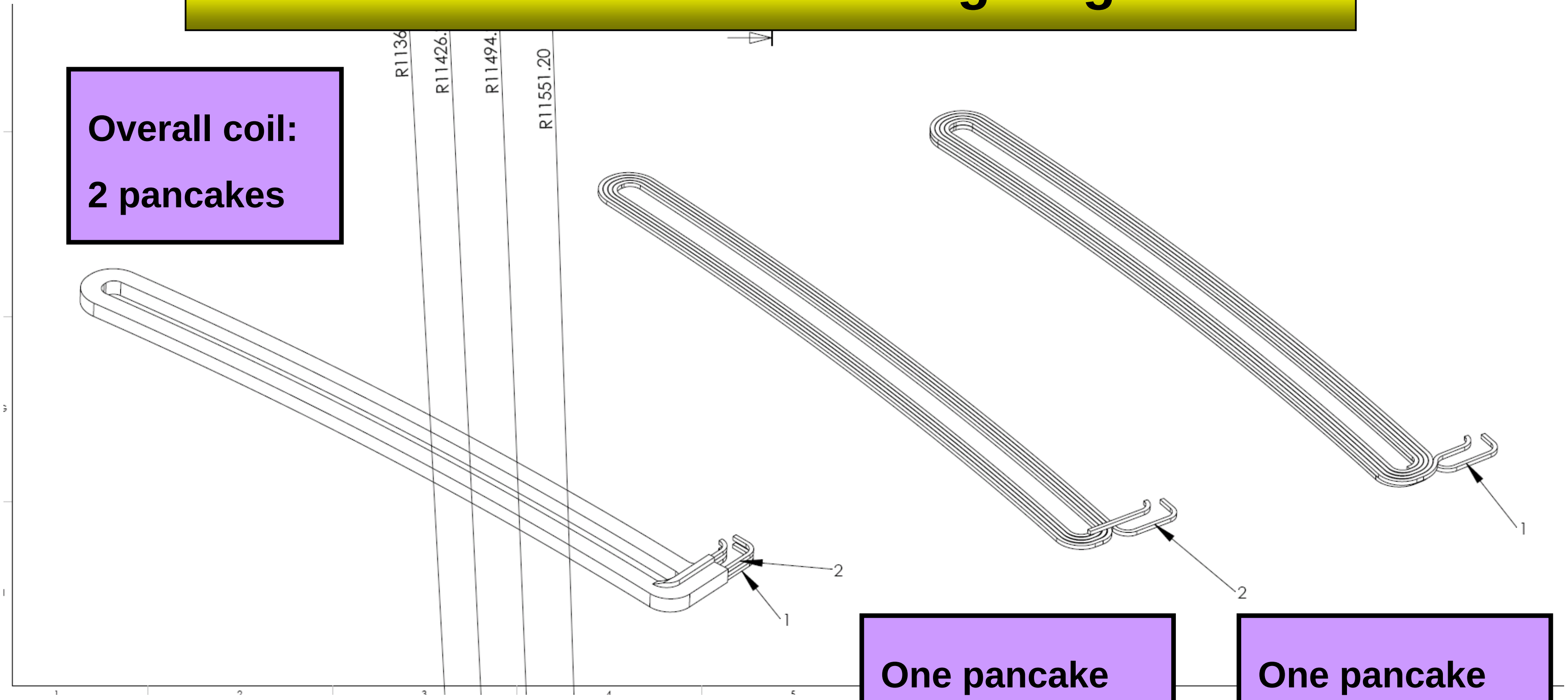


Each pole has one coil, each coil exist of two pancakes. One pancake with 1 layer and an other one with two layers. The dimension of the conductors (copper) are; 12 * 12 mm², with a cooling diameter of 6 mm. Per coil there is one cooling circuit.

The Coils of the Bending Magnet

Overall coil:

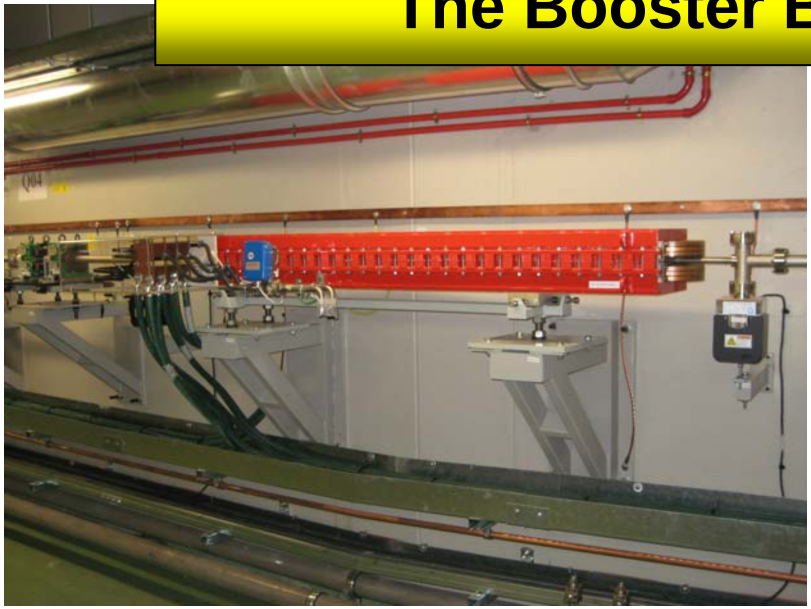
2 pancakes

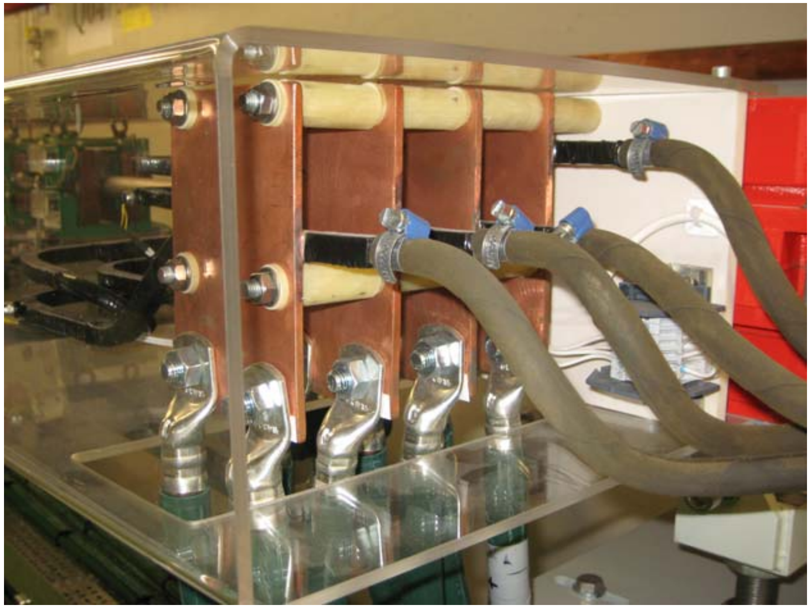


One pancake with one layer

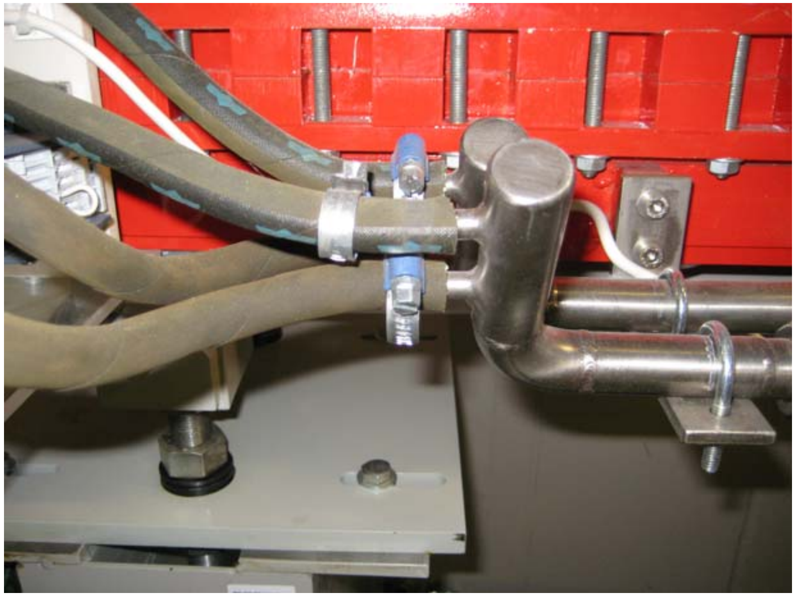
One pancake with two layer

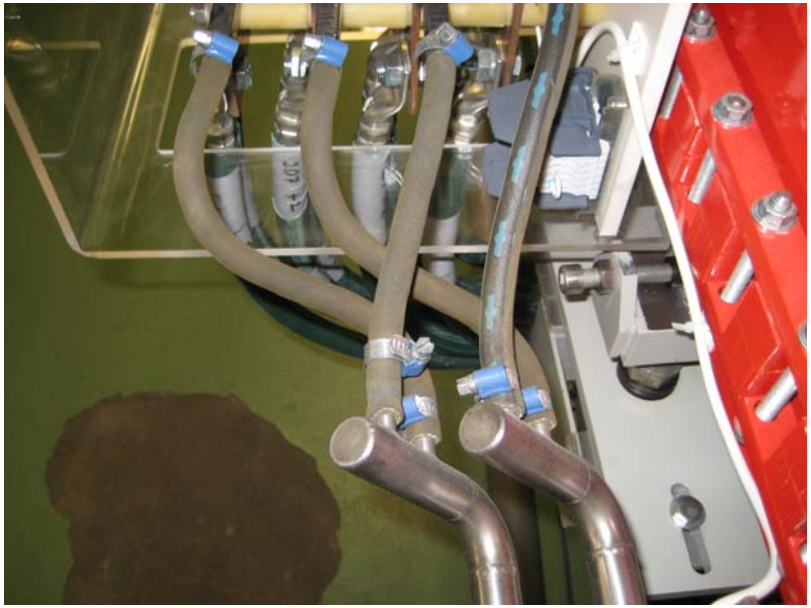
The Booster Bending Magnet





The Manifold of the Bending Magnet

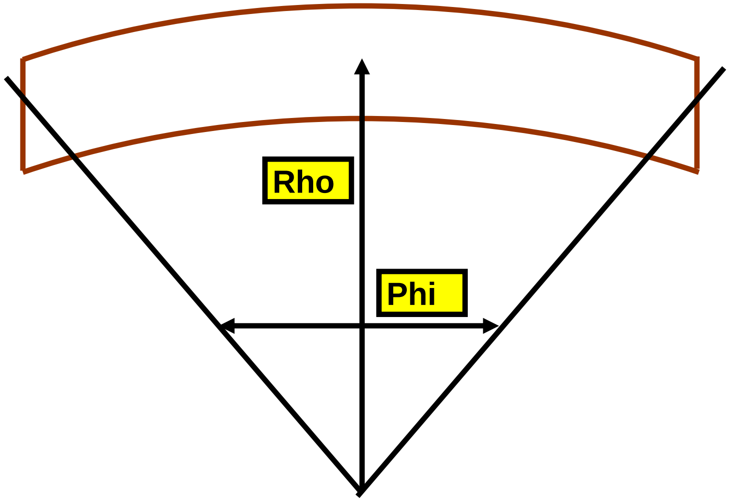




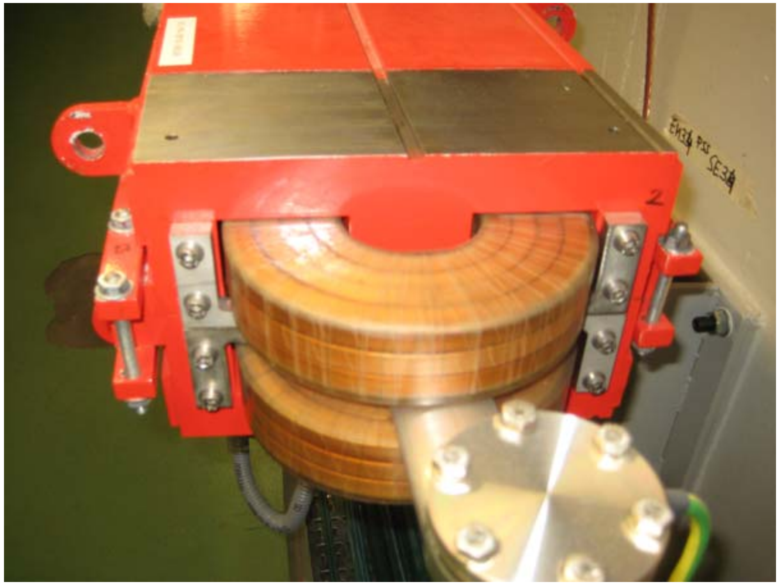
The specifications of the bending magnet are the following

12.) Shape of the magnet :

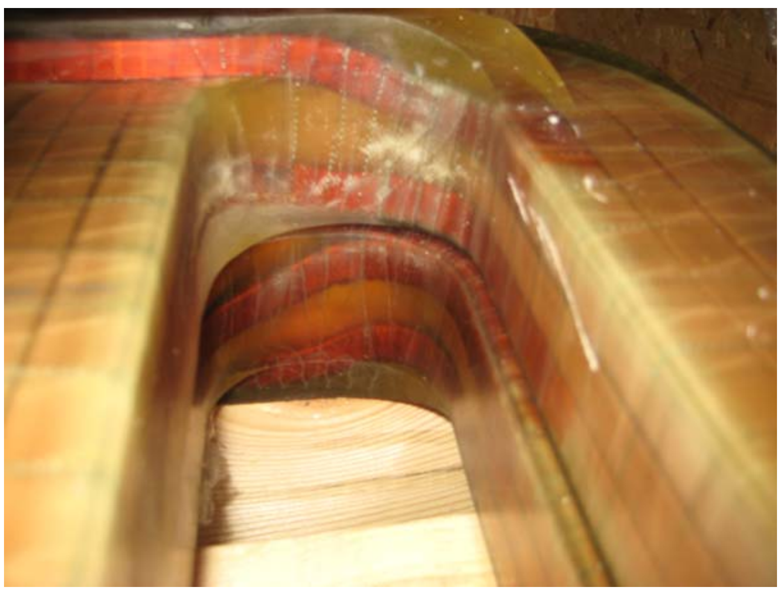
It is a so called "curved rectangular bending magnet"



The Booster Bending Magnet

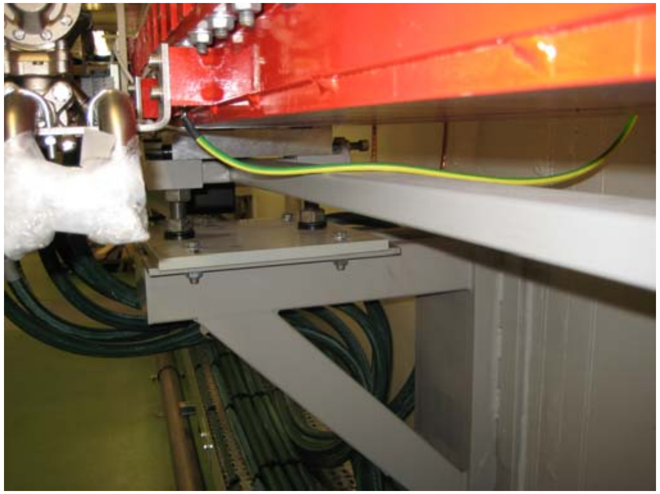


Coils of the Bending Magnet

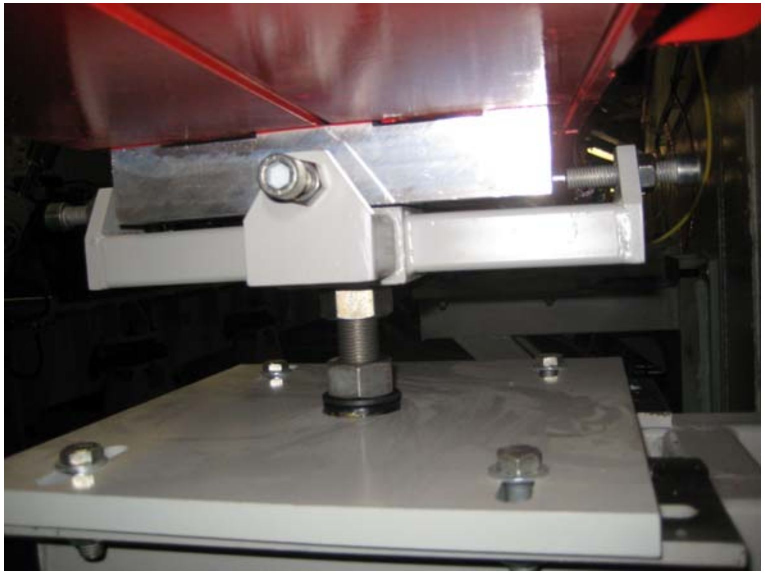


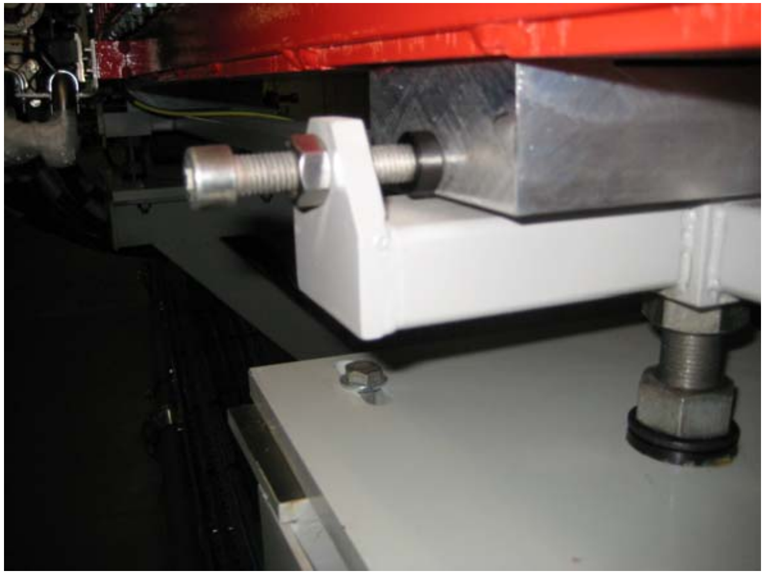
Coils of the Bending Magnet

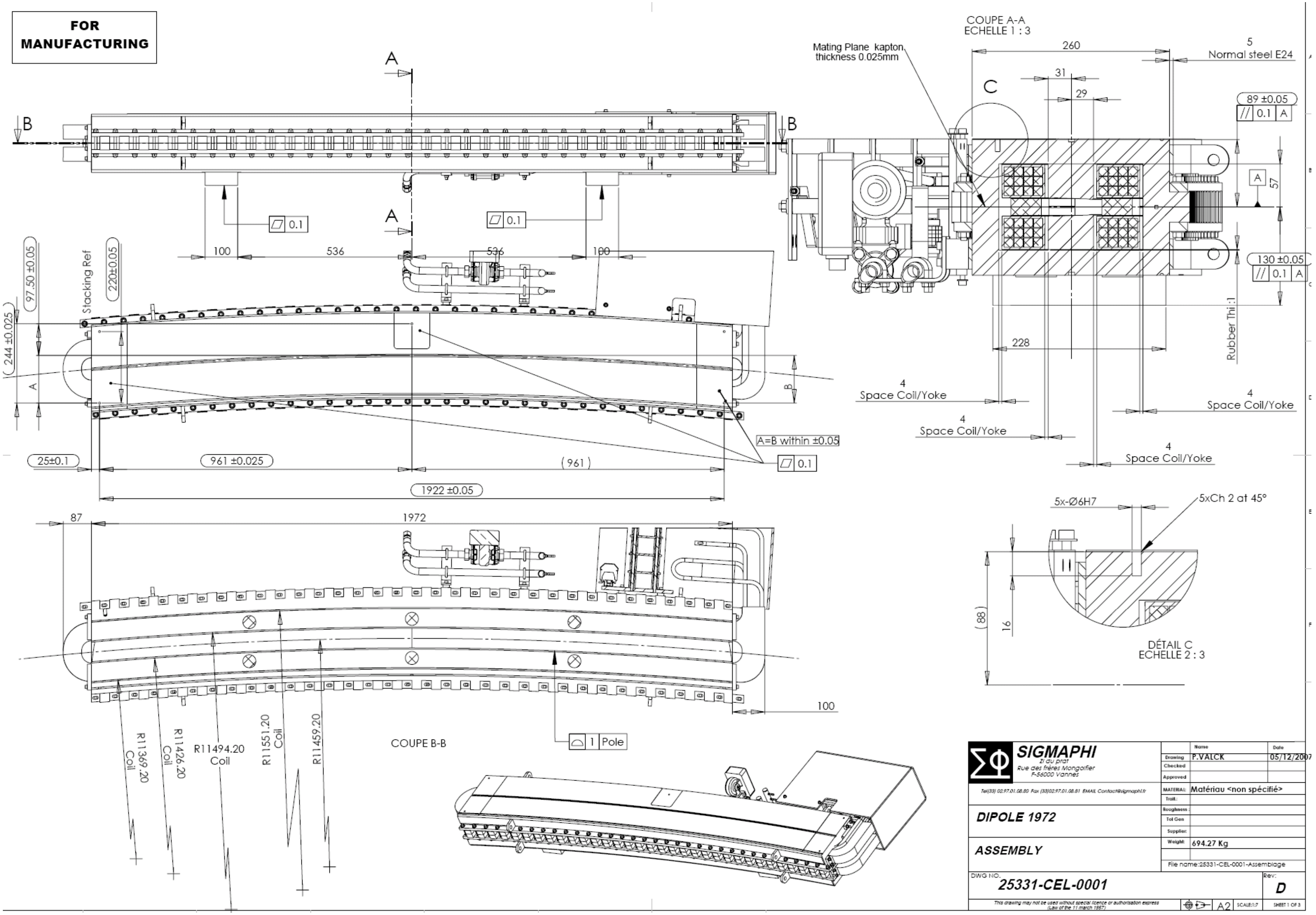
Supports of the Bending Magnet



Supports of the Bending Magnet






FOR MANUFACTURING
COUPE A-A
ECHELLE 1 : 3
Mating Plane kapton thickness 0.025mm
Normal steel E24
Stacking Ref
A=B within ±0.05
1922 ±0.05
961 ±0.025
25±0.1
1972
COUPE B-B
R11369.20 Coil
R11426.20 Coil
R11494.20 Coil
R11551.20 Coil
R11459.20
1 Pole
Space Coil/Yoke
Rubber Thi :1
5x-Ø6H7
5xCh 2 at 45°
DÉTAIL C
ECHELLE 2 : 3
SIGMAPHI
DIPOLE 1972
ASSEMBLY
P.VALCK
05/12/2007
Matériau <non spécifié>
694.27 Kg
File name:25331-CEL-0001-Assemblage
25331-CEL-0001
D
A2

Parameters of the Bending Magnet

Gap =	22.6	mm
Energy=	3	GeV
Bo =	0.8736	T
Rho=	11.45467	m
Müo=	1.257E-06	
N*I=	1.571E+04	A*Wdg (nominal)
N*I=	1.728E+04	(total)
N =	24	Wdg
I =	7.201E+02	A

Electrical Calculations

Rad = Radius for winding the coils around the poles =	0.059	m
l1 = length of straight 1 =	2	m
l2 = lenght of straight 2 =	0	m
Number of pancakes	2	
Number of turns per pancakes	12	
l = Length of the conductor around the pole	4.370697	m
L = Length of coil conductor in a pancake	52.448364	m
L(ges) = Length of all coil conductors	104.896728	m
Conductor heigth	12	mm
Conductor width	12	mm
Conductor area (width*heigths)	144	mm^2
Cooling diameter	6	mm
Cooling area	2.827E+01	mm^2
Copper area	1.157E+02	mm^2
Specific resistance	0.0179	Ohm*mm^2/m
Current density	6.223E+00	A / mm^2
Resistance per pancake	0.00811	Ohm
Resistance per magnet	0.01623	Ohm
Voltage drop per magnet	11.6840	Volt
Power per magnet (D.C.)	8413.88	Watt
Power per magnet (A.C.)	3170.26	Watt
Length of magnet	2.10	m
Pole width	0.06	m
Inductance	0.00477	H
Time constant	0.29	sec

Cooling Parameters of the Bending Magnet

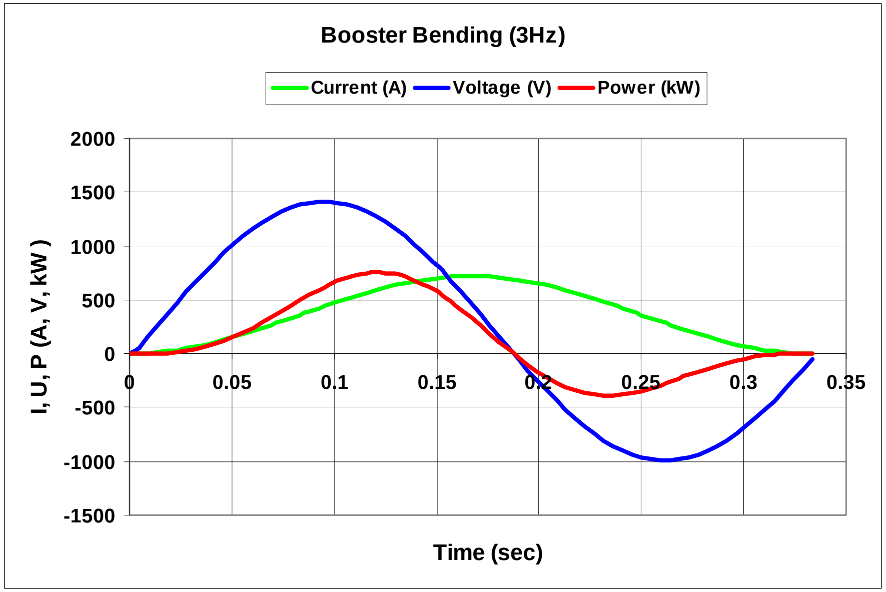
Cooling Calculations

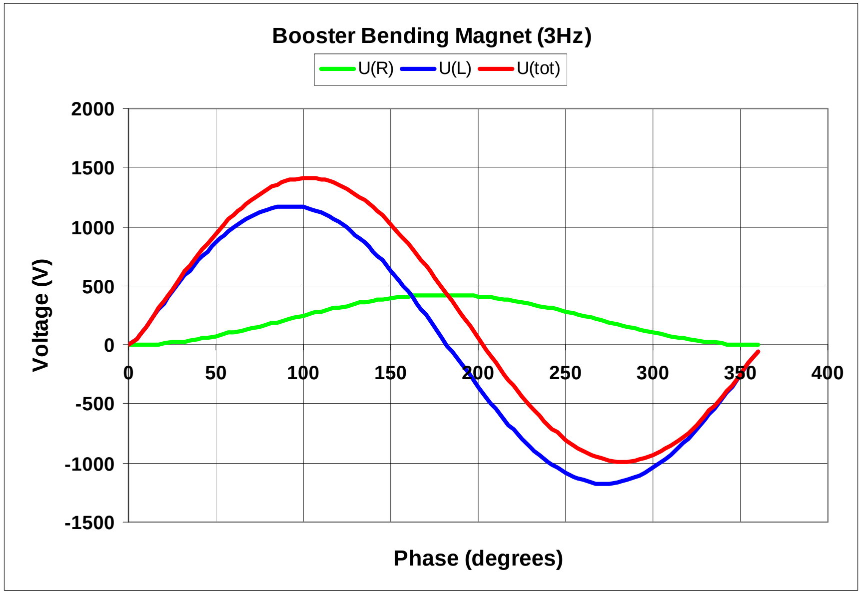
Temperature drop	11	Degree celsius
Number of cooling circuits	2	
Length of cooling circuit	52.448364	m
Power per cooling circuit	1585.132325	W
Cooling water flow per circuit	3.44E-05	(m^3) / sec
Cooling water flow per circuit	1.24E+02	liter / hour
Cooling water speed	1.22E+00	m / s
Pressure drop	2.22E+00	bar
Reynold figure (should be larger as 1160)	3.65E+03	
Critical water speed to reach reynold figure	4.17E-01	m / s

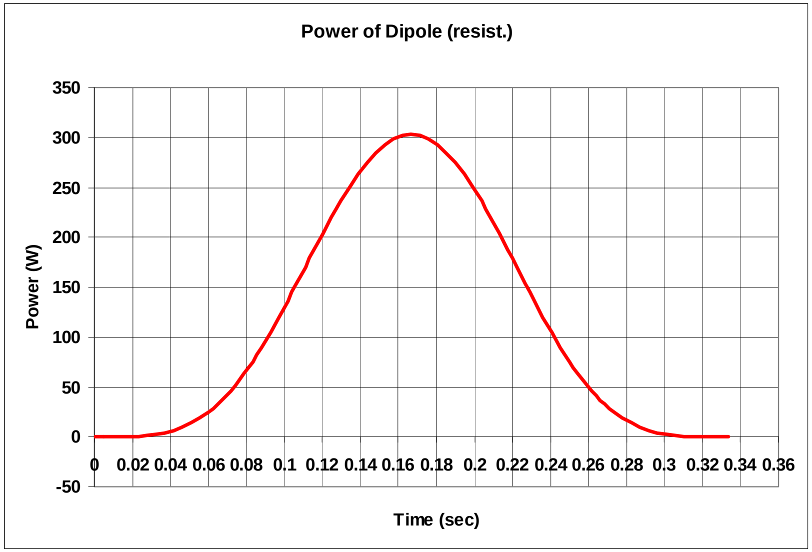
Main Parameters of the Bending Magnet

Combined Magnet		BO-MA-BEND1	BO-MA-BEND2
Number of magnets installed		8	32
Beam Energy, extraction	GeV	3.00	3.00
beam energy, injection	GeV	0.10	0.10
Bending radius	m	11.4592	11.4592
Bending angle	degrees	5.00	10.00
Bending field, extraction	T	0.8733	0.8733
Bending field, injection	T	0.0291	0.0291
quadrupole field strength	m^{-2}	0.229	0.229
quadrupole field	T/m	2.292	2.292
sextupole field strength	m^{-3}		
sextupolar field	T/m^2	9.000	9.000
Effective magnetic length, arc	m	1.0000	2.0000
Effective magnetic length, straight	m	0.9997	1.9975
Gap	mm	22.6	22.6
Length of Fe yoke, straight	m	0.9720	1.9720
Number of turns per coil		12	12
Number of coils		2	2
Conductor cross section/turn	mm^2	12 x 12	12 x 12
Cooling channel diameter	mm	5	5
Number of ampere turns	amp-turn/coil	7906	7906
peak current	A	659.0	659.0
peak current density	A/mm^2	6.08	6.08
Resistance at 20ºC	mΩ	9.2	18.2
Inductance	mH	1.28	2.56
Frequency	Hz	3	3
resistive voltage, max	V	6.1	12.0
inductive voltage, max	V	15.9	31.8
average power dissipated	W	2000.4	3942.3
Cooling agent		demin. water	demin. water
ΔT, maximum	ºC	11	11
Number of cooling circuits		1	2
Max pressure drop	bar	7.0	7.0
Maximum inlet pressure	bar	10.0	10.0
Maximum inlet temperature	ºC	23.0	23.0

Ramping of the Bending Magnet







Thank you very much
and
I wish you a lot of success
in your carrier

D.Einfeld