SEPTUM AND KICKER MAGNETS FOR THE ALBA BOOSTER AND STORAGE RING

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Abstract

Six kickers and three septa magnets are installed at the ALBA Booster and Storage Ring for injection and extraction of the electron beam. A 100 MeV beam from a linac is injected on axis into the ALBA Booster. The full energy (3 GeV) beam is extracted out of the Booster and injected into the Storage Ring, where four kicker magnets bring the stored beam close to the septum. All septa are direct driven, out-of-vacuum magnets with C iron laminated yoke, and soft iron screen for the stored beam. The Booster kicker magnets are in-vacuum magnets with C-ferrite yoke. The Storage Ring kickers have a C-ferrite yoke and a Ti coated ceramic vacuum chamber. The thickness of the Ti coating is 400 nm and it had been done by magnetron sputtering.

INTRODUCTION

ALBA is a 3 GeV synchrotron light source with a full energy Booster operated at 3 Hz and a 100 MeV Linac as pre-injector [1]. Three groups of pulsed magnets are used for the transfer between the different accelerators: Direct driven septa with the magnet outside the vacuum and full sine excitation. The Booster injection and extraction kickers have the magnet inside the vacuum and are excited by a flat top pulse. The Storage Ring kickers have the magnets outside a ceramic vacuum chamber and are excited by a half sine current. The mechanical design and construction of all the magnets was done by DANFYSIK (Denmark), while the power supply design and construction was done by PPT (Germany).

MAGNET SPECIFICATIONS

The design specifications for the different groups of magnets are given in tables 1 and 2. The values given for the voltage are values measured at the nominal current. The inductance is for magnet, leads and power supply.

SEPTA MAGNET DESIGN

The basic design of all septa magnets is identical. The incoming/outgoing beam is passing through a 0.3 mm thin square stainless steel tube with an internal height of 11 mm and width of 14 mm. The stored beam is passing through a nickel coated mild steel tube. The soft iron gives an excellent shielding of the stray field. For Booster injection and extraction the tube is round with 26.5 mm diameter, while for the Storage Ring the tube has a race track cross section with 80 mm width and 24 mm height.

Table 1: Septa Magnets Parameters

Parameter	Booster Injection	Booster Extraction	Storage Ring	Units
Deflection angle	12.78	4.95	9	deg
Nominal Field	0.13	0.84	0.90	T
Nominal current	1300	9013	9533	A
Maximum field	0.19	1.03	1.11	T
Magnetic aperture	12	12	12	mm
Length	634	1023	1751	mm
Inductance	1.1	2.0	2.75	µH
Nominal voltage	84	450	630	V
Sine pulse length	210	300	390	µs

Table 2: Kicker Magnets Parameters

Parameter	Booster Injection	Booster Extraction	Storage Ring	Units
Deflection angle	33	3.35	7	mrad
Nominal Field	0.03	0.037	0.129	T
Nominal current	415	620	3100	A
Magnetic aperture	20	20	40	mm
Length	400	900	680	mm
Inductance	1.4	2.8	2.6	µH
Voltage	12.9	26.3	6	kV
Max. Voltage	25	35	10	kV
Pulse Form	Flat Top	Flat Top	Half Sine	
Pulse width	.1 / .4 / .2	.1 / .4 / .2	5.5	µs

The magnetic yoke is built from laminated steel, 0.35 mm thick, M270-35 from Thyssen-Krupp as a C magnet. Fig.1 shows the cross section of the Storage Ring injection septum at the location of the joining. The incoming vacuum tube and the conductor with their isolation are glued into the magnet. This design of having the magnet outside the vacuum gives better vacuum performance at the cost of a slightly smaller aperture for the incoming/outgoing beam and a slightly larger septum sheet of 3 mm. The BO injection septum does not require any forced cooling while the septa for BO extraction and SR injection are equipped with water cooling

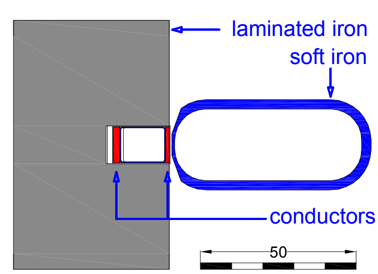

Figure 1: Cross section of SR injection septum.

KICKERS MAGNET DESIGN

The basic design of both Booster kickers is identical. The magnet, in-vacuum, is a C shape made from 33 mm thick ferrite plates (CMD5005 from Ceramic Magnetics). The conductor is running on the inner side of the C and a copper plate working as an eddy current shield is placed on the opposite side.

The four Storage Ring kickers are identical in design. The magnet is outside the vacuum. The yoke is C shape made with 22 mm thick ferrite plates. Comparable to the Booster kickers, the conductor is only running on the inner side while a copper plate used as eddy current shield is installed at the outer side. The ceramic chambers have a race track cross section with an aperture H x V= 80 x 24 mm and a length of 780 mm and have provisions to be air cooled. The thickness of the ceramic is 5 mm. A cross section of the magnet is given in figure 2.

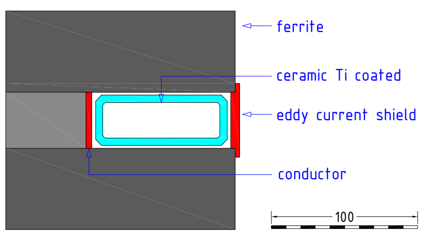

Figure 2: Cross section of Storage Ring injection kicker.

The chamber has been coated by magnetron sputtering with a 400 nm thick Ti layer (overall resistance 4.3 Ohm) done by POLYTEKNIK (Denmark). For this a magnetron sputter source was moved through the ceramic tube. In order to get a homogeneous Ti layer over the whole range the device had to be optimized and the coating was deposited in several strokes.

Ti LAYER THICKNESS

The Ti coating has to be thick enough to induce low thermal losses due to the resistive image current and thin enough not too deform in excess the magnetic field pulse due to the eddy currents. Beam deposited power has been calculated with the expression given by A.Piwinski [2],

$$P = I_{tot}^2 \frac{\rho L}{d} \frac{1}{n_b} \frac{1}{2\pi r} \frac{C}{2\sigma_l \sqrt{\pi}}$$

where,

I	stored total current	0.4 A
ρ	Ti resistivity	$5 \cdot 10^{-7}$ Ωm
d	coating thickness	$0.4 \cdot 10^{-6}$ m
r	half chamber height	0.012 m
w	half chamber width	0.040 m
L	ceramic length	0.780 m
σ_l	bunch length	0.005 m
n_b	number of bunches	448
C	machine circumference	268.8 m

The field reduction has been calculated following the expression given by S.H.Kim [3] using a rectangular geometry as simplified model for the ALBA racetrack ceramic chambers,

$$\frac{B_i(t)}{B_0} = \frac{1}{\sqrt{1+(\omega\tau)^2}} \sin(\omega\tau - \phi) + \frac{\omega\tau}{1+(\omega\tau)^2} e^{-t/\tau}$$

for $t<t_p$

$$\frac{B_i(t)}{B_0} = \frac{\omega\tau}{1+(\omega\tau)^2} (1+e^{-t_p/\tau}) e^{-(t-t_p)/\tau}$$

for $t>t_p$, with,

$$\tau = \frac{4\,\mu_0 w\, d}{\rho\,\pi}$$

and ω the pulse frequency ($57.12 \cdot 10^3$ rad/s) and t_p half the pulse width (5.5 µs). The other symbols have been defined before.

The calculated power deposition due to the image current is 65 W for a 400 nm Ti layer. Both the field amplitude reduction (0.1%) and the delay (75 ns) should be negligible according to the calculations.

The effect of the coating has been further investigated by FEM with the QuickField software in AC mode [4]. Instead of modelling a thin Ti layer, the 5 mm thick ceramic has been modelled as having the same resistance as the Ti layer. The 4.3 Ohm total resistance gives a 130 $(\Omega m)^{-1}$ conductivity. The FEM calculations, using a conductivity of 200 $(\Omega m)^{-1}$, gives a reduction of the field amplitude by 3%, and a phase delay of 300 ns. These results are larger than the values calculated above. The modelling also indicates a transverse field reduction of 0.4% along the chamber width which is due to the C shape of the ferrites.

When the first chamber was coated, it turned out that the measured overall resistance was by a factor of 5 larger compared to what had been expected from a 400 nm thick Ti layer. This is due to the contribution of the surface roughness of the ceramic with grain sizes about 5-10 µm thus increasing the effective resistance of the coating and to a possible reduced density of the sputtered material compared to bulk material. Then the coating thickness was increased in order to get the nominal resistance of 4.3 Ohm. With this value of resistance a field reduction of 3% and a delay of 200 ns were measured on a coated chamber with respect to an uncoated chamber. The results show a better agreement with the simulations than with the initial calculations performed.

The variation in the coating thickness of the four chambers has been estimated from the change in the overall resistance measured flange to flange. All chambers exhibit the same resistance within ± 6 % of the average. The coating homogeneity in a chamber has been estimated using a potential measurement. A voltage of 1V was put over the two flanges and the voltage drop between two electrodes was measured along the chamber. The homogeneity is better than ± 7.5 %.

PULSED POWER SUPPLIES DESIGN

The electronics for all devices consists of 3 units: the charging power supply and the control unit which are installed outside the tunnel and the switching unit, which is installed under the magnet in the tunnel. The control unit essentially contains a PLC (S7 from Siemens) for personal and equipment protection and the 'state-machine' for operating the device. The charging power supplies for all devices are coming from FUG (HCK series) and have a reproducibility better than 0.1%.

For the BO kickers a thyratron (CX2610 from E2V, 55 kV peak voltage, 10 kA peak current) is used as switch. The PFN for producing the flat top is not made by a long cable but by a series of lumped coils and capacitors. For the SR kickers four thyristors in series (SPY 15F4502 from ABB, 4.5 kV peak voltage, 24 kA pulse current) are used as switch. For the BO extraction and SR injection septa the same thyristors are used. In general the switches, diodes and capacitors are overrated by a factor of 2.

MAGNETIC MEASUREMENTS

The septa magnetic field was characterised with a short coil 100 mm long and with 50 windings. The kickers were all measured with a full integral coil. Induced voltages had been measured with a digital scope and the signal integrated. For the current measurement the internal current probes coming from STANGENES were used

Magnetic Measurements on septa magnets

The measurements on all three septa indicated magnets within specifications, with stray integrated fields as low as 10 µT·m at nominal currents.

Magnetic Measurements on BO kicker magnets

The BO kickers have been tested up to maximum voltage and a typical pulse waveform is shown in figure 3 for the BO extraction kicker at nominal current. The measured jitter is 250 ps rms, and the peak stability is 0.1%. Flat top ripple is 1%. Similar results have been obtained for the BO injection kicker.

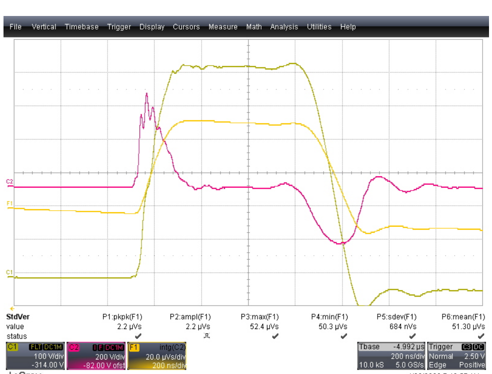

Figure 3: Current pulse for the BO extraction kicker (green), induced voltage on the coil (pink) and integrated field (yellow).

Magnetic Measurements on SR kicker magnets

The maximum measured kick is 10 mrad at V_{max}=8.5 kV while for the nominal bump of 10 mm a kick of 7 mrad is required. The transverse field homogeneity, which is within 0.4% when the kicker is grounded only at one flange, worsens if the kicker is grounded at both exit flanges due to a shorted ground loop that decreases the signal amplitude and introduces a larger transverse dependency. Figure 4 shows the transverse dependency for one of the four kickers.

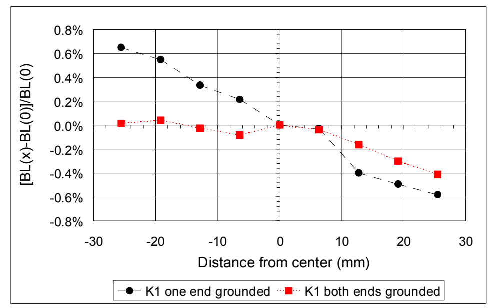

Figure 4: Transverse field homogeneity of integrated field.

FIRST RESULTS WITH BEAM

BO injection elements have been in use routinely since January 2010 performing well within specs. BO extraction and SR injection elements have been used during the first phase of SR commissioning in 2011. All elements have performed well but additional effort is needed specially to improve the identity of the four SR kickers. The identity between the 4 kickers was specified to be better than 0.1% of the peak field and adjustments in the laboratory have shown that it can be achieved. Nevertheless first results have shown a significant residual bump on the stored beam, of about 2 mm p-p in the horizontal plane when the kickers are adjusted for 100% injection efficiency. The 16 bits on the HV power supply allows sufficiently resolution on the setting of the amplitude but the resolution on the delay between kickers is presently limited to 8 ns, although a new board with a resolution of 10 ps is already under test with which we expect to reduce the residual bump. Also the pulse width and pulse shape should be carefully matched.

CONCLUSIONS

The pulsed elements for the ALBA light source have been characterised in detail and already used during the commissioning of the SR. Further investigations are required in order to reduce the residual bump seen by the stored beam created by the four SR kickers.

REFERENCES

[1] G.Beneddetti, D.Einfeld, E.Huttel, M.Munoz, M.Pont, EPAC'08, page 2151

[2] A.Piwinski, PAC 1977, page 1364

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[4] http://www.quickfield.com/