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A DOUBLE DIPOLE KICKER FOR OFF AND ON-AXIS INJECTION INTO ALBA-II

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Abstract

Injection into the ALBA-II storage ring will be performed off-axis in a 4 meters straight section with a single multipole kicker. We present a novel topology for the coils of the injection kicker, named double dipole kicker (DDK). The resulting magnetic field is the superposition of two opposite dipoles, generated by four inner and four outer conductor rods. When the eight rods are powered, the dipole term cancels and the remaining multipole field is used for off-axis injection. Alternatively, when the four inner rods are switched off, an almost pure dipole is produced, that is useful for on-axis injection during the commissioning. A prototype of DDK is presently under design to be installed and tested in the existing ALBA storage ring. The positioning of the rods is calculated in order to maximize the kick efficiency in mrad/kA and minimise the disturbance to the orbit and the emittance of the stored beam. A metallic coating with optimised thickness along the inner ceramic vacuum chamber should provide compensation for the eddy currents induced field in order to minimize the disturbance to the stored beam while ensuring sufficiently low heat dissipation by the beam image currents.

INTRODUCTION

ALBA started to study a pulsed multipole kicker for single turn off-axis injection in the previous years [1–3]. The proposed design was a so called non-linear kicker (NLK), whose coils topology was first conceived at BESSY-II [4] and then adopted and tested in other machines [5, 6]. The studies initiated in 2020 for the ALBA upgrade to a new low emittance ring have lead to a different design of the kicker which fits better the new needs of the injection into a ring with a smaller physical aperture and a very compact arrangement of the magnets. In the kicker presented in this paper, the coils have a different topology consisting of four inner rods and four outer rods which produce two opposite dipole fields cancelling each other along the longitudinal axis of the magnet and a non-linear field off axis [7]. The novel pulsed magnet, named double dipole kicker (DDK), has two important advantages: first, despite the small vertical aperture, the peak of the non-linear field can be generated at the position of the injected beam, and second, switching on either the inner or the outer coils an almost pure dipole is produced, that is very useful for on-axis injection in the first turn commissioning of the upgrade ring. In this paper the magnetic concept of the DDK and the parameters to design the prototype to be installed and tested in the existing ALBA storage ring are presented.

DOUBLE DIPOLE KICKER TOPOLOGY

We propose a new idea for the topology of the kicker coils. The topology designed in [1, 3] is changed to a different one shown in Fig. 1.

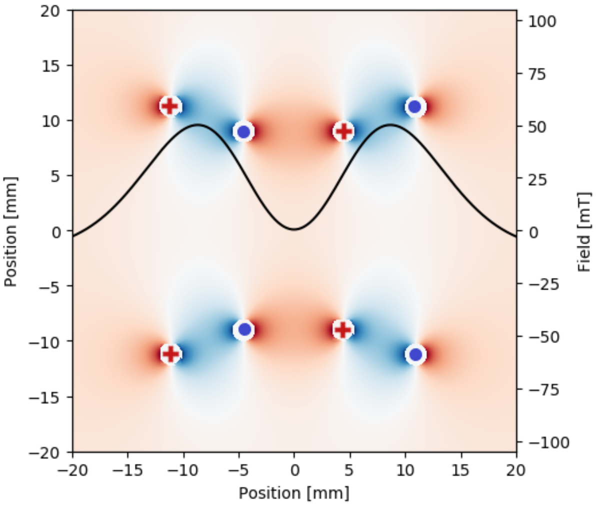

Figure 1: Cross section of the coils topology for the proposed DDK prototype for the ALBA storage ring (the red cross and the blue circle represent the direction of the current carried by the rods) and 2-D magnetic field (colour code) and the field along the horizontal mid plane (black solid line). The coils geometry produces a null field at the center where the stored beam is passing through. The minimum vertical aperture among the rods is ±9 mm and the field reaches its peak value at the injected beam position $x = 8.7$ mm.

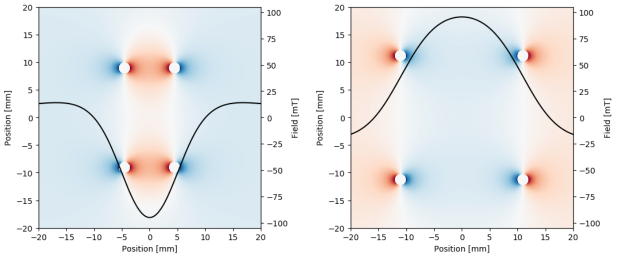

Figure 2: In the DDK, when either the four outer (left plot) or inner (right plot) rods are switched off, a dipole field is produced around the center.

The main difference of this field profile with respect to that of the NLK previously designed is that it results in a narrower plateau and a non zero crossing. On the other hand, the attractive feature of the DDK is that by switching off either inner or outer coils a dipole field is produced around the center as shown in Fig. 2.

The first motivation to chose such kicker design is that a dipole kicker would be very useful for on-axis injection in the first turn commissioning of the upgrade storage ring of ALBA. The upgrade lattice design, ALBA-II [8], has a very compact arrangement of the magnets and an injection straight section of only 4 meters, with no room for a second injection kicker. Hence, combining two magnets, the dipole and the multipole, in one kicker would be very useful for the injection into ALBA-II. The second advantage of the DDK topology is that the horizontal position where the peak of the field is located is not limited any more by the vertical aperture of the vacuum chamber ($h = \pm 6$ mm). This means that the DDK can have a peak at the position of the injected beam trajectory $x = 8.7$ mm, which was not possible with the NLK design for ALBA [3]. That makes the injection scheme more tolerant to injection trajectory errors, which are mainly due to the septum field fluctuations [2].

Finally, in the DDK geometry needed for ALBA the inductance of the coils is almost halved (0.9 μH for inner plus outer coils and even less for the two separated circuits) with respect to the NLK (1.7 μH [3]) and consequently the required voltage for the power supply is significantly reduced.

TOLERANCES FOR TRANSPARENT INJECTION

The standard condition on the orbit stability for transparent injection for the users is that it has to be less than 10% of the beam size: $\Delta x < 10\%\,\sigma_x$ and $\Delta x' < 10\%\,\sigma'_x$. For ALBA this implies that the defect field at the stored beam position must be $\Delta B_x < 13$ μT and $\Delta B_y < 70$ μT and the gradient must be less than $\frac{\partial B_y}{\partial x} < 0.36$ T/m.

In order to guarantee top-up transparency in ALBA, the mechanical tolerance on the rods positions should be ± 1 μm in both directions, which is unrealistic with the available technologies. Realistic mechanical tolerances with the existing technology can be as small as ± 20 μm, which can produce a displacement of the position of the minimum field of the order of $\Delta x \sim \Delta y \sim \pm 200$ μm.

After the kicker assembly, the profile of the magnetic field will be measured (both with magnetic and beam-based measurements) and the stored beam position should be aligned in order to make it pass through the position where the kick on the beam has its minimum (null gradient), where still a field of the order of $\Delta B_{x,y} \sim \pm 200$ μT is expected. The proposed solution in order to make null field at the position of the stored beam and ensure transparent top-up consists of powering the inner and outer coils with two independent power supplies, with very stringent specifications on the matching between the two pulses. The 10% rule for the orbit stability determines that the integral of the difference between the current of the two pulses has to be less than 0.12% of the pulse value.

FIELD ERROR DUE TO FINITE PROPAGATION SPEED

The signal propagation through the magnet coils also plays a role in terms of field error. In the previous discussion the implicit assumption that at any time the current flowing in all the conductors had the same magnitude was made, this indeed is not the case when considering transient effects in conjunction to parasitic capacitance between conductors. An exact analysis of the effect would require a detailed 3-D electromagnetic simulation of the magnet geometry. Nevertheless an approximated solution can be derived by assuming the current pulse to propagate through the magnet conductors at constant speed, which is assumed equal to the speed of an electromagnetic wave in the dielectric material that surrounds the coils. In the proposed design a non negligible part of the field is inside the ceramic vacuum chamber, most likely of alumina, that has a propagation speed three times slower than vacuum. It can be safely assumed that the actual speed lies in between what observed in a conductor immersed entirely in alumina and the case of vacuum only.

The connection order of the rods affects the overall field distortion induced by this delayed propagation effect. Furthermore by employing two independent pulser units to power the inner and outer coils it is possible to partially compensate the field distortion, resulting in a remarkable reduction of the effect [7].

The overall effect on the stored beam can be estimated from the mean of the absolute value of the field error along the pulse. Table 1 shows the mean field error for the single and double power supply configurations, both for vacuum only and alumina only magnet.

Table 1: Average field error along the kicker axis due to finite propagation speed through the coils surrounded by vacuum or ceramic.

	Single power supply		Double power supply	
	Vacuum	Alumina	Vacuum	Alumina
ΔB_x	160 μT	475 μT	50 μT	155 μT
ΔB_y	210 μT	630 μT	0	0

COATING EFFECTS OF THE CERAMIC CHAMBER

A second source of perturbation of the stored beam are the eddy currents in the metallic coating (titanium) of the ceramic chamber of the kicker that are produced by the time dependent field. Typical thickness of the coating to ensure an acceptable power dissipation is of the order of 1 μm [3,5], however the coating thickness can be also optimized in order to minimize the perturbation on the stored beam.

The magnet field is generated by a current pulse that is assumed to be a semi-sinus of time length $t_p = 1.75$ μs, i.e. less than two revolution times. The eddy currents in the coating produce a time dependent induced field that perturbs the profile of the design magnetic field.

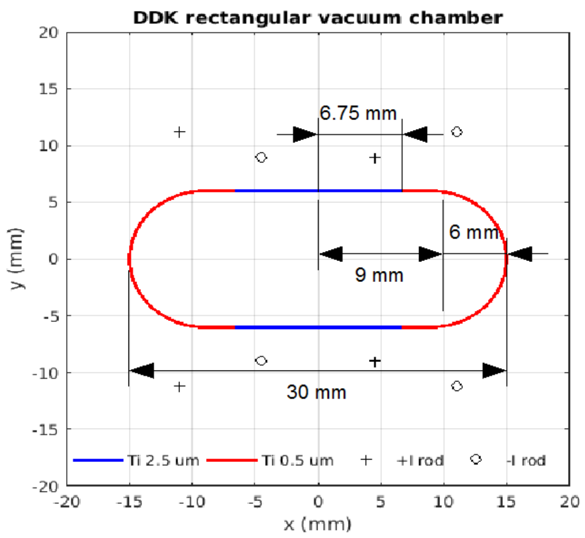

Figure 3: Cross section of the ALBA prototype DDK and the aperture of its ceramic vacuum chamber. The black circles and crosses indicate the positions of the kicker rods. The solid line in blue and red shows the inner aperture of the ceramic chamber where the titanium coating is applied.

With a diameter for the conductor rods of 2 mm, a rectangular-like cross section of the vacuum chamber with full aperture $H \times V = 30$ mm × 12 mm has been chosen (Fig. 3) and the eddy currents have been calculated for a 2-D field (no dependence on the longitudinal coordinate z) by solving Maxwell's induction law and imposing the continuity equation for the induced current density inside the coating, which means that the integral of the eddy currents through a transverse coating cross section has to be zero.

The two distributions of eddy currents on the surface of the top/bottom walls and on the sides walls of the vacuum chamber (regions respectively in blue and red in Figs 3) produce opposite contributions to the induced field at the center $(x, y) = (0, 0)$. Applying a uniform coating thickness of 1 μm on all the surface, the induced field at $(x, y) = (0, 0)$ would have a value $B_y^{eddy} = 0.75$ mT much larger than the tolerance for transparent top-up ($\Delta B_y < 70$ μT).

The induced field at the center can be made zero by employing on the top and bottom surfaces a metallic coating five times thicker than on the sides surfaces. We expect this to be realized by masking the side surfaces after reaching the nominal thickness in that part of the ceramic chamber. Discussions with the manufacturer will take place in due time. In addition we do not expect that a 2 μm step should have any influence on the behavior of the coating neither on the beam dynamics. With this solution, the perturbation on the stored beam due to the eddy currents is minimized and in principle zero (Fig 4), while the attenuation and delay of the field at the position of the injected beam are even smaller than for a uniform coating of 1 μm thickness [7].

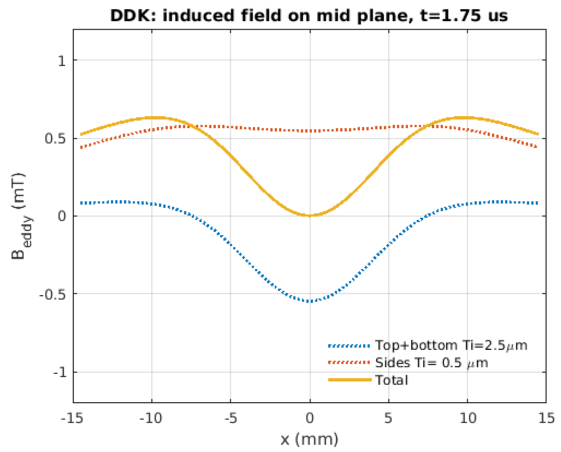

Figure 4: The induced field on the horizontal mid plane (yellow line) and the contributions from the top and bottom coated surface (blue dot line) and from the sides surface (red dot line) of the ceramic chamber. The coating is made of titanium. Applying a thickness of 2.5 μm on the top/bottom surface and 0.5 μm on the sides surface, the field at $(x, y) = (0, 0)$ is zero.

DDK MAGNETIC SPECIFICATIONS

The design parameters chosen for the ALBA DDK prototype are summarized in Tables 2 and 3.

Table 2: Main Parameters of the DDK Prototype for ALBA

Inner rod position	x_i, y_i	4.50, 9.00	mm
Outer rod position	x_e, y_e	11.00, 11.20	mm
Diameter of the rods		2	mm
Field at x = 8.7 mm	B_y	50	mT
Magnetic length	L	300	mm
Total coils inductance	L_{tot}	0.90	μH
Inner coils inductance	L_{in}	0.83	μH
Outer coils inductance	L_{out}	0.55	μH
Mutual inductance	M_{inout}	-0.24	μH

Table 3: Main Parameters of the Half-sinus Current Pulse

Pulse duration	t_p	1.75	μs
Peak current	I_0	2675	A
Nominal repetition rate	f_{rep}	3.125	Hz

CONCLUSIONS

The DDK magnetic design concept for a prototype, to be installed in the existing ALBA storage ring in the next two years, has been completed. The tests and performances with beam of this first kicker should validate this novel design. The experience and results acquired from this prototype will be the basis for the design of a second DDK magnet with specifications for the injection into ALBA-II.

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