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STUDIES FOR INJECTION WITH A PULSED MULTIPOLE KICKER AT ALBA

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Abstract

Injection into the ALBA storage ring presently uses a conventional local injection bump with four dipole kickers. However, following the promising results of the first tests with single multipole kicker injection at other light sources, studies to implement this new injection scheme have been started for ALBA. Two possible designs for the kicker have been considered: a pure octupole and a non-linear magnet similar to the BESSY type. A comparison between the expected performances of the two kicker designs has been carried out in terms of injection efficiency and transparency for the users. This paper summarises the beam dynamics results from multi-particle tracking simulations and the proposed kicker magnet design.

INTRODUCTION

In a synchrotron light source, top-up injection must guarantee high capture efficiency and transparency to users. ALBA employs a conventional injection scheme with four dipole kickers [1], common for all the third generation light sources. The limitation of this solution is the difficulty and the continuos work to balance (both in the construction phase and during operation) the four kicker magnets and pulsers to produce a local closed bump over long periods of time. Instead, injection with a pulsed multipole kicker (PMK) is now being studied and introduced at other machines [2, 3] as a means to perform fully transparent top-up injection having to align and adjust only one kicker to suppress any displacement of the stored beam. Following the experience gained at other machines in the design of fast and high field PMK, we initiated a design for the magnet. In order to define the specifications for the kicker, its possible location in the ALBA lattice has been identified. Subsequent studies have been carried out to assess the expected injection efficiency as a function of different sources of errors in the PMK, in the transfer line elements and in the machine lattice.

PULSED MULTIPOLE INJECTION IN THE ALBA LATTICE

In pulsed multipole injection, the injected beam is first introduced into the storage ring by a septum magnet and then captured by kicking it into the ring acceptance with a PMK. Since the stored beam passes the PMK at the magnetic centre, there is no field which can perturb it.

Starting with the coordinates of the injected beam with the present septum magnet and taking into account the horizontal invariant of the captured beam with the four-kicker scheme (which presently provides an injection efficiency better than 90%), a suitable location for the PMK can be derived. As shown in [4], the phase advance between the injection point (IP) and the PMK is given by the injection Courant-Snyder invariant W_i and the reduced invariant W_1. The normalised kick needed to put the injected beam into the wanted reduced invariant (Fig. 1) is

$$\Delta P_{PMK} = \sqrt{W_i}\left(-\sin\varphi_{PMK} \pm \sqrt{r - \cos^2\varphi_{PMK}}\right) \quad , \quad (1)$$

where r is the reduction ratio $r = W_1/W_i$, and the normalised kick at the PMK location is defined as

$$\Delta P_{PMK} = \frac{\alpha_{x,PMK}\, x_{PMK} + \beta_{x,PMK}\left(x'_{PMK} - x'_0\right)}{\sqrt{\beta_{x,PMK}}} \quad . \quad (2)$$

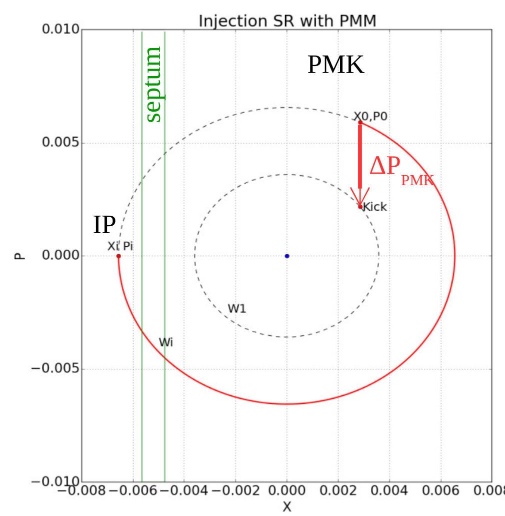

Figure 1: Injection with PMK: the beam describes a circle in the normalised phase space every phase advance of 2π rad. The beam is injected at the IP (septum exit) with a large invariant W_i and travels through the storage ring lattice until the point with $\varphi_{PMK} = 1.68 \cdot 2\pi$ rad where it is kicked into the reduced invariant W_1 by the PMK.

Optimum locations for a PMK are drift spaces with high horizontal beta functions, in order to keep low required kick strengths, and with a real solution for Eq. 1. The normalised kick in Eq. 1 is a double-valued function of φ_{PMK}: the sign that gives the smaller kick strength is taken as the desired solution. In the present injection scheme using a four-kicker local bump, at the IP the injected beam is at x_i = -22.0 mm which gives an injected invariant of W_i = 43.0 mm·mrad. The separation between the injected beam and the bumped stored beam is 10.0 mm which corresponds to a reduced invariant of W_1 = 12.8 mm·mrad. As a result, r = 0.3 has been taken as a target value for the reduction ratio with the PMK.

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Four of the eight short straight sections of the ALBA lattice fulfil this condition, but only one is still free (in sector 2), while the other three are already housing the RF cavities (in sectors 6, 10 and 14). Moreover, the available short straight section in sector 2 has the important advantage of being in the first sectors after the IP, which reduces losses of injected electrons at large amplitudes before being kicked by PMK.

At the chosen PMK location, the coordinates of the injected beam are x_0 = +8.7 mm and x'_0 = -2.0 mrad and taking into account the optics functions (Table 1) and a reduction ratio target of r = 0.3 , the PMK kick given by Eqs. 1 and 2 is θ_{PMK} = +1.3 mrad which at 3 GeV corresponds to an integrated field $B_{PMK}L$ = 13 mT·m.

Table 1: Injected Beam Parameters at the IP and at the PMK Location based on Linear Model

	at IP	at PMK
beta function, β_x (m)	11.26	9.18
alpha, α_x	0.0	0.0
beam position, x (mm)	-22.0	+8.7
beam divergence, x' (mrad)	0.0	-2.0
Invariant, W (mm mrad)	43.0	12.8
position, s (m)	0.0	25.0
phase advance, φ_x (rad/2π)	0.0	1.68

TECHNICAL DESIGN OF PMK

The PMK magnet should have a magnetic field profile optimised to have a high field (13 mT·m) at the injected beam position while keeping the field at the stored beam position close to zero (< 0.03 mT·m) in a wide plateau.

A reference design for a 300 mm long stripline-like geometry has been developed. The full physical aperture required at the PMK position not to limit the storage ring physical acceptance is H x V = 29 x 9 mm^2. To avoid the detrimental effects of eddy currents, the magnet will be surrounded by a ceramic chamber with typical thicknesses in the order of 5 mm and a tolerance of at least 1 mm. Therefore, the PMK requires a free area of 40 x 20 mm^2.

The reference design of the magnet has been performed with OPERA-2D. Two possible designs are presented, both are based on the use of eight wires to generate the required magnetic field at the injected beam position (x_0 = +8.7 mm) and have a central plateau of ±1.1 mm with field smaller than 0.1 mT to ensure stored beam orbit stability within 10% of the beam size. The first design is based on an octupole, while the second one is a non-linear kicker (NLK) based on the wire distribution developed by BESSY-II [5]. The selected wires have a cross section of 4 mm^2, although at this moment this is not relevant for the presented results. Figures 2 and 3 depict the OPERA-2D schematics and the magnetic field in the midplane for the design based on a pure octupole magnet and for the design of a NLK.

The pulser unit will be a conventional capacitive resonant discharge circuit generating a half sinusoidal. With a revolution time of 896 ns at ALBA, the pulse length to have a single turn injection has to be shorter

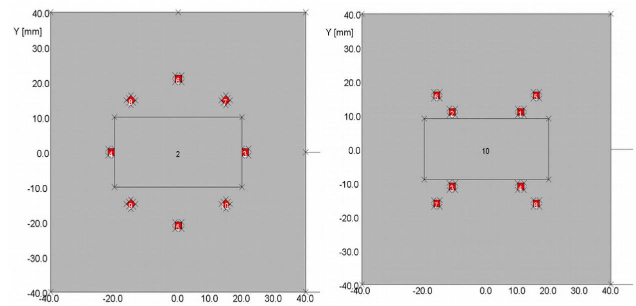

Figure 2: Geometry of the octupole kicker wires (left) and of NLK (right) for ALBA designed with OPERA-2D.

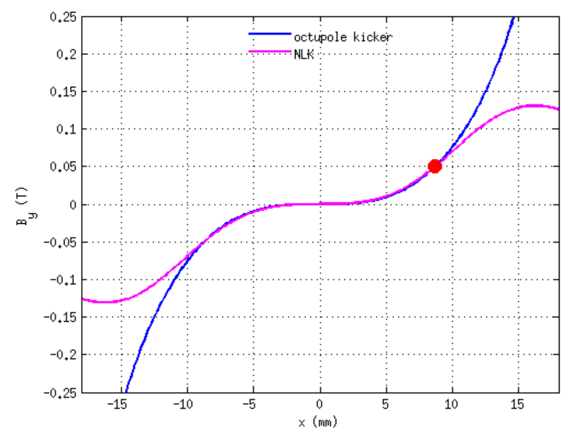

Figure 3: Magnetic field in the midplane of octupole kicker (blue line) and of NLK design (magenta line) for ALBA. The injected beam is at +8.7 mm (red circle).

Table 2: Main Parameters of the Pulser Unit for the Octupole Kicker and the NLK Design

	Octupole	NLK
Pulse length (μs)	1.7	1.7
Current (kA)	9.5	8.0
Inductance (mH)	1.10	1.07
Voltage (V)	19.0	16.0

than 1.79 μs. The main parameters for the pulser unit are summarised in Table 2.

In principle, an advantage of the NLK would be the flat area around the field maximum and ideally the injected beam could pass the kicker at this location thus enabling good capture efficiency even in presence of fluctuations of the injected trajectory. However, at ALBA this NLK feature cannot be exploited as there is a trade-off between the vertical position of the inner rods not to limit the physical acceptance and the horizontal position of the field maximum (in Fig. 3 at 16 mm from the centre). As a consequence, the injected beam will sample a field gradient with both kicker designs and tracking simulations had to be run to confirm that capture does not suffer from the gradient seen in the PMK.

CAPTURE EFFICIENCY WITH A PMK

Tracking simulations have been performed with ELEGANT in order to model a realistic injection process

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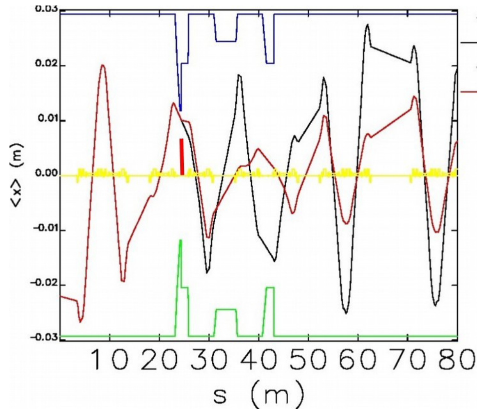

Figure 4: ELEGANT tracking for the injection with PMK placed at s = 25 m in ALBA. The amplitude of the injection trajectory and the vacuum chamber aperture from the IP are shown with the kicker off (black line) and on (red line) through the first quarter of the ring.

which takes into account the effect of non-linearities of the lattice and all other error sources.

As first result (Fig. 4), tracking reveals that a small injection angle of x'_i = -0.25 mrad minimises the resulting reduced invariant at W_1 = 11.5 mm·mrad, which lies below what is achieved with the present four-kicker bump and should improve the injection efficiency.

In order to assess the injection efficiency, an ensamble of 1000 particles with a Gausssian distribution (cutoff at 3σ) was tracked for 100 turns. Transfer line optics mismatching was taken into account assuming an injected emittance of ε_x = 20 nm·rad, twice the booster one.

In this ideal condition, capture efficiencies of 97.0% for the octupole kicker and 99.5% for the NLK were obtained. In addition, the simulations showed that the effect of a pulse ripple is negligible and even much larger field variations up to 15% still keep the capture efficiency above 75%. The effect of kicker timing errors was also studied by simulating a half sine pulse 1.7 µs long: no efficiency degradation was found for errors smaller than 200 ns (Fig. 5), that is a great advantage with respect to the four-kicker scheme.

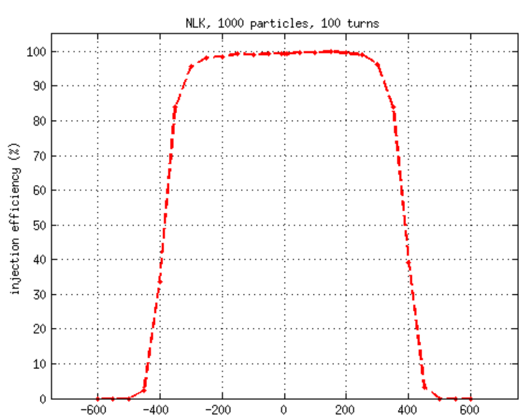

Figure 5: Capture efficiency as a function of time delay in the kicker pulse for the NLK case (lattice without errors and injection angle x'_i = -0.25 mrad).

Finally, tracking simulations, run with 40 different seeds of errors, including misalignment in all storage ring magnets, orbit correction and residual beta-beating of 1.2% RMS, still give efficiencies of 96.5%. On the other hand, as shown in Fig. 6, the tracking studies revealed that the injection angle is the parameter with most significant impact on the efficiency, since the injection angle precision must be smaller than ±0.07 mrad to keep the efficiency always above 75%. This condition requires an injection septum relative stability smaller than $4 \cdot 10^{-4}$ which is comparable to the performances of the existing magnet.

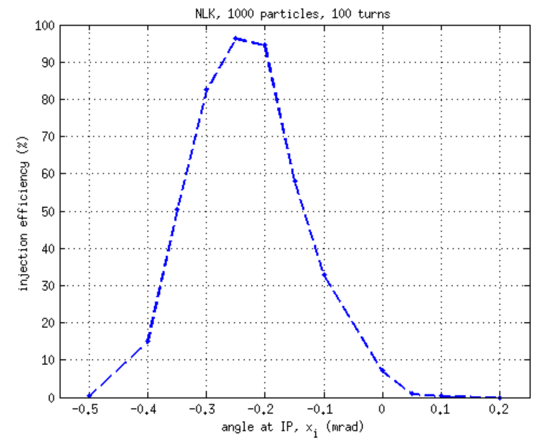

Figure 6: Capture efficiency for NLK case calculated as percentage of survived particles after 100 turns in a lattice including misalignment, orbit correction and beta-beating (average efficiency for 40 seeds). The peak of 96.5% is at x'_i = -0.25 mrad and the maximum change in the angle at IP to keep the efficiency above 75% is ±0.07 mrad.

CONCLUSIONS

The study of PMK injection in the ALBA storage ring demonstrates the feasibility of such scheme to obtain capture efficiency as good as the four-kicker scheme but with much less stored beam disturbance. In addition, tracking simulations show that PMK injection is less affected by timing and field errors of the pulsed unit.

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