

USING NOVEL INJECTION SCHEMES FOR ENHANCED STORAGE RING PERFORMANCE*

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Abstract

Injection into an electron stored storage ring using pulsed, higher order multipole elements has recently been demonstrated at KEK's Photon Factory. The advantage of using higher order multipole magnets is that it is less disruptive to the stored beam and thus advantageous for Top-off operation. In addition to Top-off, such novel injector might open the door to operating storage rings with more desirable lattice settings. In this paper we will explore some possibilities for taking advantage of high order multipole pulsed kick injection.

INTRODUCTION

In a conventional injection scheme for electron storage rings such as synchrotron light sources or electron-positron colliders, several pulsed dipole magnets, which are called kicker magnets, are employed to reduce the effective amplitude of the injected beam and facilitate beam injection while preserving an already stored beam [1]. Such a scheme enables us to accumulate the electron beam in the storage ring by utilizing the radiation damping characteristics of the electron beam. The beam injected into the ring is instantaneously perturbed by the kickers located downstream from an injection point. Simultaneously, the kickers are turned off and the beam executes betatron oscillations. It is essential that the kickers are operated at a speed of the order of several microseconds. Subsequently, the beam is captured in the acceptance of the ring and it is damped down to the equilibrium emittance by radiation damping.

At the same time the stored beam with the equilibrium emittance passes a pulsed local bump, which is formed by typically four kickers around the injection point; the beam preserves its central orbit in other parts of the ring. This is repeated at a rate of several Hertz. The injection point location is in the center of straight where a septum magnet is placed. The septum is surrounded by four bump magnets. The conventional injection scheme is illustrated in Fig. 1.

This conventional injection scheme is usually very reliable and can deliver high capture efficiency. As a result the scheme is widely used in electron storage rings. Despite its success there are several constraints of the scheme that limit the performance of the storage ring. One limitation is that the injection scheme requires a lot of space – usually one full straight section. A second limitation is that it requires a fast orbit bump of the stored beam which is not perfectly compensated. Even with the state of the art injection elements and beam feedback systems there is a residual oscillation in the orbit that can last for some 10s of microseconds. A third limitation is

that the acceptance of the beam at the location of the injection point has to be large in order that there is enough room to capture the injection beam. This translates into a required acceptance on the order of 1 cm. The large acceptance in turn requires that the betatron function needs to be relatively large (several meters) at the location of the septum. This final requirement on the beta constrains the lattice and which in turn may constrain the ultimate performance of the machine.

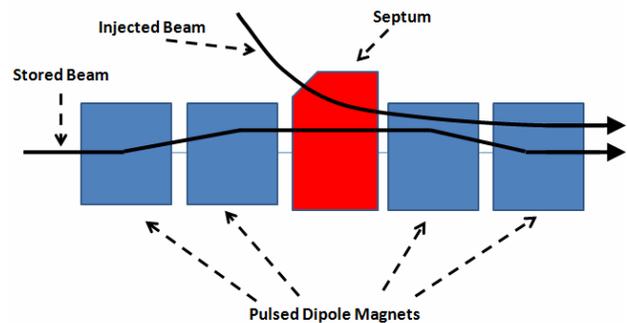


Figure 1: Schematic drawing of a conventional injection scheme.

Recently there has been a very exciting development using first a pulsed quadrupole magnet (PQM) and more recently a pulsed sextupole magnet (PSM) for injection at the Photon Factory in Japan [2-5]. These pulsed magnets replace the four pulsed dipole magnets in the conventional injection scheme. Pulsed multipole magnet injection has the promise to alleviate the constraints mentioned above. It requires (1) less room (one magnet versus four); (2) should perturb the stored beam less due to the low field in the center of the magnet; and (3) because it requires less space can allow the possibility of putting the injection point away from the center of the straight section (see Fig. 2). This is advantageous because shifting the kicker and septum to one side of the straight section allows for small betas in the center of the straight while having a large beta at the location of the septum.

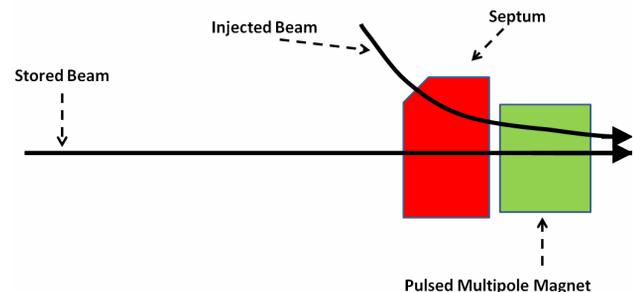


Figure 2: Schematic drawing of an injection scheme where the four pulsed dipole magnets have been replaced with a pulsed multipole magnet and the septum has been shifted to the end of the straight section.

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In previous papers [2-5] the first two advantages have been discussed. In this paper we would like to also discuss the importance of the third point. We will use the Advanced Light Source (ALS) as an illustration.

The Advanced Light Source is a third generation synchrotron light source located at Lawrence Berkeley National Laboratory (LBNL). The lattice of the ALS consists of twelve sectors and each sector consists of a triple bend achromat. In three of the sectors, the normal conducting central bend is replaced with a superconducting bend and two quadrupoles. Fig. 3 shows one sector of the lattice of the ALS in the present operation mode.

ADVANCED LIGHT SOURCE

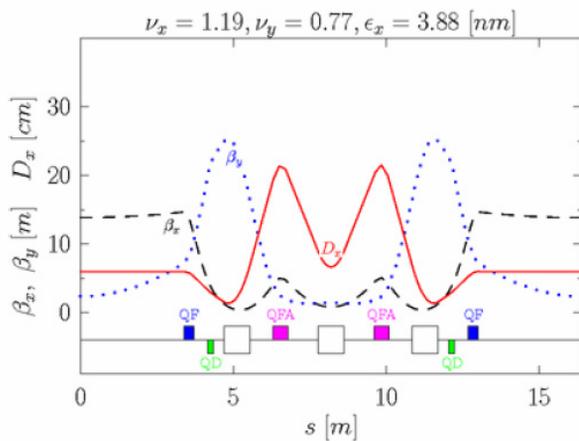


Figure 3: Present lattice: ALS sector with $\nu_x = 14.25, \nu_y = 9.2$ for the whole ring. (emittance calculated for a 12 sector lattice without superconducting bends). Lattice is plotted from the center of one straight to the center of the next.

For light sources, the ultimate quality defining parameter is the photon brightness available at its beamlines. At the ALS two main beamline categories exist: the ones with sources in the accelerator bending magnets and those with sources in the insertion devices (undulators and wigglers) situated in the accelerator straight sections.

Studies have shown that it is possible to improve the brightness of both the bend and insertion device sources by retuning the lattice [6, 7]. These studies were performed using multi-objective evolutionary algorithms (MOGA) to find the globally optimal tradeoffs in brightness in the bend and insertion device beamlines. The results of MOGA revealed that the optimal trade-curve had two distinct regions (see Fig. 4); one that optimized dipole brightness with some penalty for insertion device brightness and one that optimized insertion device brightness with some penalty for dipole brightness. But the brightnesses for both regions are superior to the dipole and insertion device brightness of

the present ALS lattice. One lattice that optimizes the dipole brightness (labeled “A” in Fig. 4) is plotted in Fig. 5 and one lattice that optimizes insertion device brightness (labeled “B” in Fig. 4) is plotted in Fig 6.

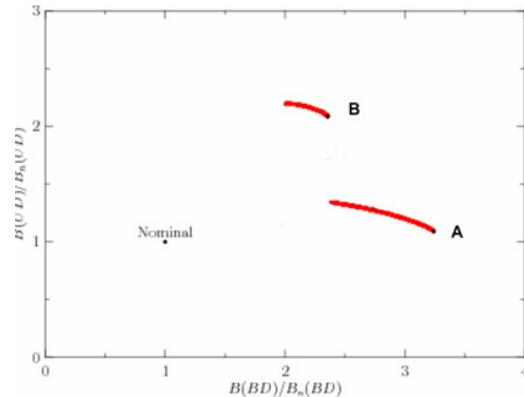


Figure 4: The brightness of sources in bending magnets and in an undulator in the straight. The vertical scale is undulator brightness relative to the nominal sector and the horizontal axis is dipole brightness relative to the nominal sector. The red curves show the optimal front.

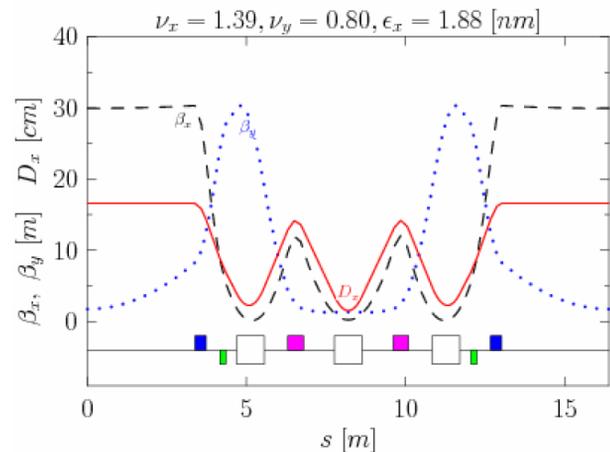


Figure 5: Twiss parameters in region “A” in Fig. 2. It favors brightness at bending magnets.

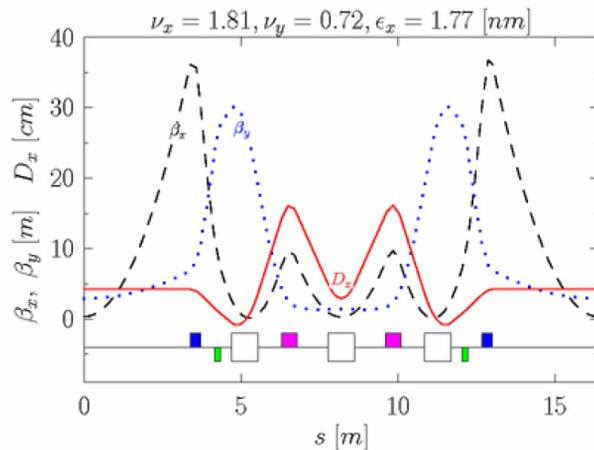


Figure 6: Twiss parameters in region “B” of Fig. 2, with low beta function it favors brightness at undulators.

We see that in comparing the present ALS lattices (Fig. 3, 5, and 6) there are qualitative differences in the three lattices. In particular for the optimal insertion device lattice (Fig. 6) there is a much lower horizontal beta function in the center of the straight section. The horizontal beta function is 0.5 meters as compared with 13 and 18 meters in the other two lattices. This lower beta function provides a better match between the electron beam emittance and the photon beam emittance thus improving the brightness.

In Fig. 7 we compare the insertion device brightness for the three lattices. We see that there are large gains in brightness to be had – particularly for the lattice that optimizes the insertion device brightness. There are additional benefits the lower beta function in the straight in that effects of insertion devices such as changes in beam size and beam motion due to insertion device motion are minimized as well as impact of nonlinear fields on the beam dynamics. So this lattice is very attractive.

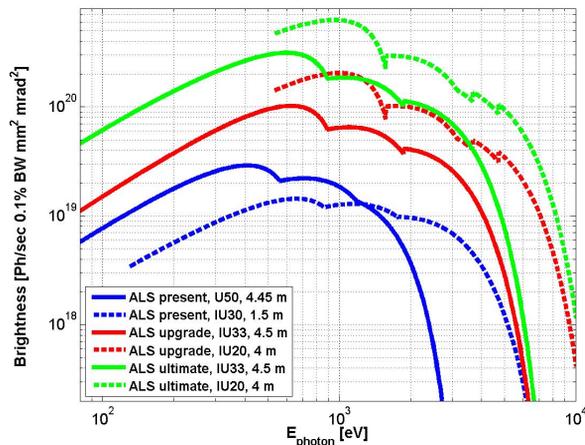


Figure 7: Comparison of ALS insertion device brightness. Blue—Existing lattice (Fig.3) with existing insertion devices. Red—Lattice (Fig.5) with conventional long insertion devices. Green—Lattice (Fig.6) with conventional long insertion devices.

The issue with the small beta lattice as compared with the other two lattices is that the small beta is not compatible with the present conventional injection scheme. There is not sufficient dynamic aperture at the injection point at the center of the straight. Even if there were the resulting betatron oscillations at other high beta points in the ring would exceed the limits of our vacuum chamber.

One can think of modifying the global lattice of the ALS to have a large beta function in the injection straight section with small beta functions in the insertion device straight sections. What makes this high low beta straight challenging is that this involves breaking the natural 12-fold periodicity of the storage ring. Symmetry is important in preserving a large dynamic aperture which in

turn is important for good injection efficiency and long lifetimes. It may be possible to preserve some symmetry (six, four, three, or two fold) by mixing high and low beta straights. One issue with this is that even if it is possible to do not all insertion device straight sections will benefit from the higher brightness. Having high and low beta is something that is currently under investigation. Nevertheless it is ideal if one could inject into a 12-fold low beta lattice. This is where pulsed multipole injection helps.

ENABLING HIGHER BRIGHTNESS USING PULSED MULTIPOLE INJECTION

Looking at the beta functions for the small beta lattice (see Fig. 6) we see that the horizontal beta function peaks near the end of the straight section in the focusing quadrupole (marked blue in the figure). By using a pulsed mode injection scheme located close to the end of the straight section as is illustrated in Fig. 2 we can provide a large beta at the injection point.

We have begun dynamics studies with the small beta lattice injecting near this displaced septum. The early dynamic aperture studies indicate that there is a reasonably large dynamic aperture. However these studies are preliminary and need to include lattices with realistic errors as well as a more realistic model a pulsed magnet. If these results prove to be successful this opens the doors to large increase in performance of the ALS. In addition there may be similar benefits to other electron storage rings.

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