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Injection with a single dipole kicker into the MAX IV storage rings

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ABSTRACT

Injection into the two MAX IV storage rings will not make use of a 4-kicker local injection bump. Instead, pulsed multipole injection will be used for initial filling as well as top-up injection. Since commissioning a pulsed multipole magnet for injection into a storage ring is non-trivial, it has been decided to install a single dipole kicker magnet into the storage rings to provide a simple method for injection during early commissioning. Design studies have revealed that injection with a single dipole kicker into the MAX IV storage rings is not only efficient, but also allows for accumulation of beam. Although this accumulation cannot be made transparent to users (i.e. it is not compatible with user top-up operation), it does provide a simple and robust injection method during commissioning. In addition, the dipole kicker can be used as a pinger magnet during machine studies with a single-bunch filling. This paper reports on the design studies performed for dipole kicker injection into the MAX IV storage rings and presents a summary of the expected performance of such an injection scheme.

1. Introduction

The MAX IV facility [1] which is currently under construction comprises two storage rings and a short-pulse facility driven by a 3.5 GeV linac. Both the 3 GeV storage ring [2,3] and the 1.5 GeV storage ring [4,5] will be operated in top-up mode with 500 mA stored current. Injection into these two rings is performed by the underground full-energy linac [6] via two vertical transfer lines. An overview of the facility layout is shown in Fig. 1. Originally, it was foreseen to inject into the storage rings using a closed four-kicker injection bump [7]; however, subsequent design studies showed that injection with a single pulsed multipole magnet offers significant advantages over the conventional local bump scheme [8]. Not only does pulsed multipole injection involve fewer magnets and relax synchronization and alignment requirements, it also has the potential to make top-up injection transparent to users despite the very hard stability tolerances of an ultra-low emittance light source like the MAX IV 3 GeV storage ring. The MAX IV storage rings will be the first light sources to be designed and operated from the beginning with pulsed multipole injection.

Despite the clear advantages of pulsed multipole injection, commissioning a new storage ring with this type of injection scheme is non-trivial. The pulsed multipole magnet kick shows a strong dependance on the injection amplitude. This amplitude in turn is heavily influenced by both the linear and nonlinear optics as well as the exact position and angle of the beam at the injection point. Additionally, injected bunches have to be transported from the injection septum through a fairly long magnet section successfully before reaching the pulsed multipole where they can be captured within the storage ring acceptance. Since storage ring optics as well as injection positions and angles are initially not exactly known and are prone to errors due to misalignments, faulty cabling, or power supply malfunction in a just assembled storage ring, commissioning a new storage ring with only a pulsed multipole for injection is very demanding and entails significant risks. Optics and alignment errors can be diagnosed and corrected once small amounts of beam can be injected and followed around the storage ring. However, if beam cannot be injected into the storage ring at all or if the injected charge is so low that diagnostics do not deliver data at the required accuracy, discovery and removal of errors can become very complicated and time-consuming.

In order to reduce the risk of commissioning two new storage rings with only pulsed multipole injection, it was decided to install a single dipole kicker in each storage ring. Such a dipole kicker can be used to inject charge from the linac into the storage ring without large dependence on optics or alignment. In this way it becomes a robust injection method during early commissioning when neither the optics nor the injection orbit is well known and/or corrected. This paper will describe how a scheme using only a single dipole kicker for injection into an ultra-low emittance storage ring can be designed including estimates of the injection efficiency and specifications for the required magnet and pulser. Details of the linac and transfer lines as well as top-up injection requirements have been reported in Ref. [8] and will not be

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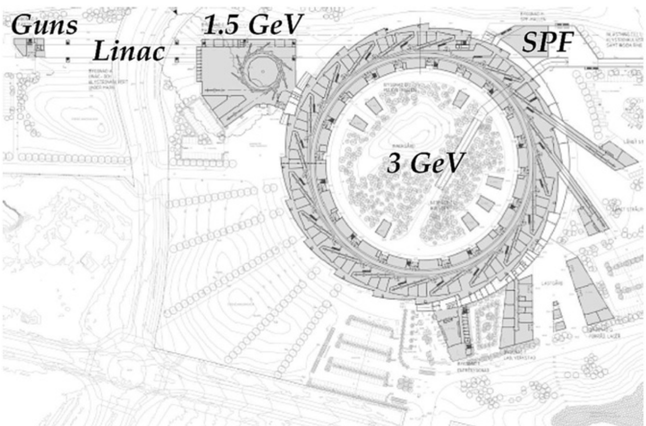

Fig. 1. Layout of the MAX IV facility as seen from above. The guns, linac, and short-pulse facility (SPF) are underground. The 1.5 GeV and 3 GeV storage rings are above ground. Two vertical transfer lines connect the linac extraction points with the storage ring injection points.

repeated here. The next section describes how an injection scheme with only a single dipole kicker is designed. The two following sections present the actual solutions and the expected performance for the two storage rings of the MAX IV facility. The final section discusses technical issues and gives specifications for the dipole kicker magnets, chambers, and pulsers. A description of the use of these kickers as horizontal pinger magnets concludes the paper.

2. Injection with a single dipole kicker

Bunches are injected from the linac through an achromatic vertical transfer line into the storage rings where they reach the injection point (IP), i.e. the magnetic end of the vertical injection septum, with an injection amplitude and angle ($x_{\rm inj}$,$x'_{\rm inj}$) in the horizontal plane defined by the stored beam. The injection invariant $A_{\rm inj}$ of these bunches is then given by [9,10]

$$A^2_{\rm inj} = \gamma_{\rm inj} x^2_{\rm inj} + 2\alpha_{\rm inj} x_{\rm inj} x'_{\rm inj} + \beta_{\rm inj} x'^2_{\rm inj} \tag{1}$$

where the Twiss parameters α, β, and γ have been evaluated at the IP. These bunches are transported to the dipole injection kicker (KI) where their position and angle are given by ($x_{\rm ki}$,$x'_{\rm ki}$). At this point the dipole kicker kicks the particles by $\theta_{\rm ki}$ thus reducing the angle

$$x'_{\rm ki} \longrightarrow x'_{\rm red} = x'_{\rm ki} + \theta_{\rm ki} \tag{2}$$

and the invariant to $A_{\rm red}$. In order for injection with a single dipole kicker to be successful, the reduced invariant must obviously lie within the storage ring's horizontal acceptance, i.e.

$$A_{\rm red} < A_x. \tag{3}$$

A reduced invariant of zero can be achieved if a cross-over location (i.e. $x_{\rm ki} = 0$) is chosen and a sufficiently strong dipole kicker is available (i.e. $\theta_{\rm ki} = -x'_{\rm ki}$). Such a cross-over occurs at a phase advance

$$\Psi = (n - \tfrac{1}{2})\pi - \phi_{\rm inj}, \quad n = 1,2,3,\ldots \tag{4}$$

from the dipole kicker, where $\phi_{\rm inj}$ is the phase advance between the symmetry point (e.g. center of the injection straight) and the IP. At such a cross-over a dipole kick of

$$\theta_{\rm ki} = \frac{A_{\rm inj}}{\sqrt{\beta_{\rm ki}}} \tag{5}$$

then leads to zero reduced invariant. It is important to note, however, that although applying such a dipole kick will lead to zero reduced invariant of the injected bunch, any beam already stored in the machine will be kicked out, i.e., such a kick does not allow for accumulation of beam.

Since it is not always possible to install the dipole kicker in a cross-over location, a non-zero reduced invariant will remain; however, it can be minimized by adjusting the dipole kick properly. For a dipole kicker installed at an arbitrary phase $\phi_{\rm ki}$ from the symmetry point, the minimum reduced invariant is achieved with the dipole kick

$$\theta_{\rm ki} = \frac{A_{\rm inj}}{\sqrt{\beta_{\rm ki}}} |\sin \phi_{\rm ki}|. \tag{6}$$

Of course the above reasoning and analytical solutions are only valid under the assumption of linear betatron motion. In real storage rings betatron motion is nonlinear, especially in ultra-low emittance storage ring such as the MAX IV 3 GeV storage ring with its strong sextupoles and octupoles [11]. In such storage rings the single-dipole kicker injection scheme has to be derived from tracking. Tracking studies reveal the actual trajectory of the injected bunch and indicate candidate locations for the dipole kicker, i.e., locations with low amplitudes and angles sufficiently low so that the dipole kicker can kick bunches into the storage ring acceptance. In addition to the desired optics, these locations need to offer sufficient space for the kicker magnet and should ideally be as close to the IP as possible. In this way the likelihood that the injected bunches can initially be transported from the IP to the dipole kicker increases. The choice of location for the dipole kicker in the MAX IV storage rings will be described on the two following sections.

Once a location for the dipole kicker has been determined, an ideal kick strength $\theta_{\rm ki}$ to minimize the resulting invariant $A_{\rm red}$ can be calculated. Two other strengths are also revealed by tracking studies: the maximum kick $\theta_{\rm max}$ a centered beam (e.g. the stored beam) can receive before it is ejected from the storage ring's acceptance A_x, and the minimum kick $\theta_{\rm min}$ required to kick the injected beam into the storage ring acceptance, i.e., the kick that leads to the reduced invariant $A_{\rm red} = A_x$. If these two kick strengths open up a window, i.e., $\theta_{\rm min} < \theta_{\rm max}$, there exists a dipole kicker setting where injected bunches can be captured, while already captured particles are not ejected from the storage ring. With such a dipole kicker setting, this single dipole kicker can be used to accumulate charge in the storage ring as long as there is sufficient time between two injections for the injected particles to damp down to the stored beam.

For a given location of the dipole kicker it is sometimes possible to create a cross-over at the dipole by slightly modifying the beam position and/or angle at the IP. While this can require increasing the injection invariant, if a cross-over is created at the dipole kicker and enough dipole kick strength is available (this can be more than the nominally required strength, especially in cases where the injection invariant is increased by the offset at the IP), the injected beam's position and angle can both be reduced to zero immediately after the injection dipole, hence minimizing the reduced invariant. During early commissioning when more sever misalignments may be present and/or optics are not set to their design values, this is an interesting injection option because it reduces requirements for available physical aperture to a minimum and increases tolerance to erroneous optics. If an injected beam can be created so that the reduced invariant becomes zero or near-zero after the dipole kicker, chances are increased that the beam can be threaded around the machine to find the closed orbit which is necessary in order to start reducing misalignments and finding optics errors.

The following two sections will present solutions for injection with a single dipole kicker into the MAX IV storage rings where the above-mentioned tracking campaign has been followed to