BUCKET-BY-BUCKET ON /OFF-AXIS INJECTION WITH VARIABE FIELD FAST KICKER

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Abstract

The bucket-by-bucket on-axis/off-axis injection system and the fast TEM mode kicker with variable kick field distribution for the system are proposed. The kicker can produce the kick field from dipolar to quadrupolar by adjusting the input strength and polarity. With this system, the injection to ultra-low emittance rings like the planned SPring-8 II ultimate storage ring should be achieved with the on-axis scheme with sufficient current for user operation even with narrow aperture at early stage of the commissioning, and the off-axis scheme for the variety bunch current filling.

INTRODUCTION

The SPring-8 II [1,2], the upgrade plan of the SPring-8 storage ring, is the ultra-low emittance storage ring with the six-bend cells for the reduction of the emittance by two order magnitude lower than that of the SPring-8 ring with double bend lattice.

The six-bend cell has very strong focusing to suppress the dispersion function to small value to get low emittance, therefore, high field sextupoles magnets are required to correct the high natural chromaticity at low dispersion functions. Such high nonlinearity reduces the dynamic aperture as low as a few mm even at the injection point of the beta function of 25m. The injection to such narrow aperture is challenging issue for the injection system for the SPring-8 II. Also the following excellent performances of the current ring should be kept in the new ring;

1) Freedom of the filling with variety of bunch current,
2) High purity of isolated high current bunches,
3) Small perturbation on the stored beam at injection.

Also for the new ring,

4) On-axis injection for narrower aperture expected at the early stage of the tuning of the ring, with top-up operation with high average current,

is requested.

It is not easy to fulfil above requirements with the current injection scheme: a bump formation and a septum magnet, because of such narrow dynamic aperture.

We propose a bunch-by-bunch on-axis and off-axis injection system, with proposed variable field fast kicker, to fulfil above requirements.

VARIABLE FIELD FAST KICKER

Recently, a TEM mode fast kicker is being developed for the extraction of a bunch from the damping ring of a linear collider [3]. The structure of such kicker is basically a parallel plate type and produces a dipole kick.

Here, we propose a kicker of which field distribution can be varied from dipole to quadrupole field by the control of the input field strength and its polarity. The dipole field is for on-axis injection and the quadrupole field is for off-axis injection.

The shape of the kicker is shown in Fig. 1. The kicker electrodes are driven by TEM-mode with high power pulsers (max. 50kV) [3] connected to each electrode. The impedance of the electrodes is 50 Ω.

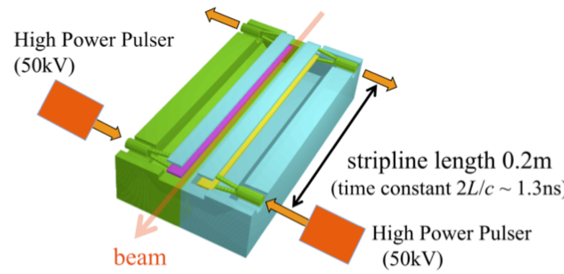

Figure 1: Shape of variable field fast kicker. Upper outer conductor is removed to show the structure.

FIELD CALCULATION

In TEM-mode, the field propagates with the speed of light and the kick by the magnetic field for a counter propagating charged particle is the same amount and the same direction as the kick by the electric field, therefore, the total kick is the twice of the kick by the electric field. The TEM mode has the same electric field as the two-dimensional static field in the plane normal to its propagation direction, therefore, the electric field in this plane is calculated with electrostatic code: MAFIA-S.

The structure of the electrodes and calculated electric field distribution in the kicker is shown in Fig. 2 in the plane normal to the direction of the field and the beam. One 50 Ω input drives the left two 100 Ω electrodes and another drives the right two. The calculated electric field for several sets of the left and right input field voltages is shown in Fig. 3 and 4, in which the vertical half gap of the kicker is set to 5mm.

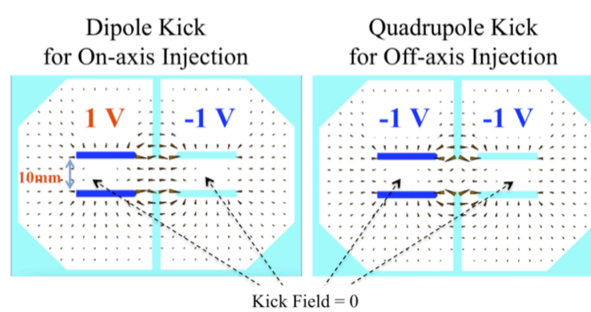

Figure 2: The electrode shape and the electric field of the kicker in the plane normal to the field propagation. [Left] the left and right electrodes are driven by 1V and -1V, respectively, for dipole field. [Right] all electrodes are driven by -1V for quadrupole field.

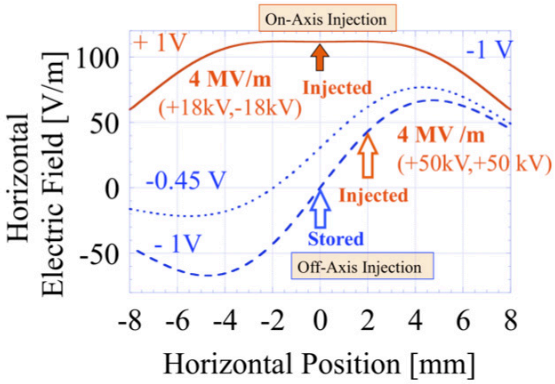

Figure 3: Horizontal electric field for the set of drive voltage of (left, right) electrodes. [Solid line] (+1V, -1V) for dipole kick. [Dotted line] (-0.45 V, -1V) for the mixture of the dipole and quadrupole kick. [Dashed line] (-1V, -1V) for quadrupole kick. The arrows show the position of the injected and stored beams. The kick field strength including magnetic field contribution for the input voltage of 18kV or 50kV are also shown.

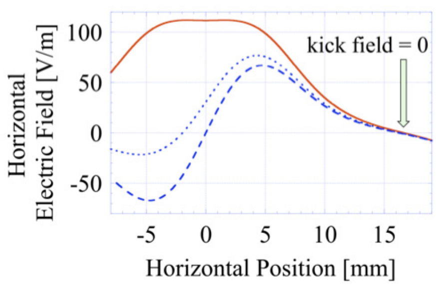

Figure 4: Horizontal electric field in wider region than Fig. 4. The field is zero at ~17 mm, which is intentionally created by the opening in the outer end of the electrodes.

The allowable maximum electric field strength in the kicker limits the available kick voltage. The calculated maximum field strength is 500V/m for the input voltage ~1V as shown in Fig. 5 (left). The time structure of the electric field of the kicker is 2ns, which corresponding to ~250MHz in frequency. From the Kilpatrick limit in Fig. 5 (right), the allowable maximum field strength is 15 MV/m which corresponding to the drive voltage 30kV (= 15MV/m/(500V/m)) and the planned voltage 50kV exceeds the limit. However, this limit is known to be rather conservative, thus, we should confirm the maximum drive voltage by the bench test.

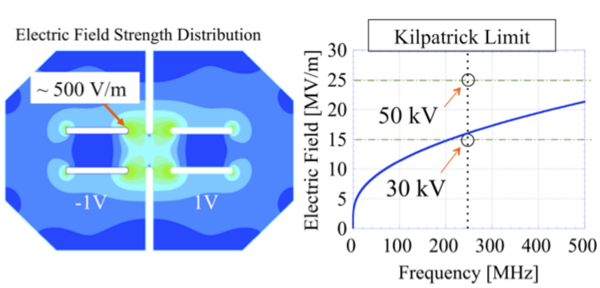

Figure 5: Electric field strength distribution (left) and Kilpatrick limit (right).

The effect of the wake produced by the kicker is estimated by the loss factor for bunch length 5mm (rms) calculated with three-dimensional simulation by MAFIA-T. If the reduction of the transverse wake is requested, we may increase the vertical gap because the transverse wake is proportional to third power of the gap.

However, the kick is also reduced as the gap is increased, as shown in Fig. 6, and the required number of kickers are increased as 5, 7 and 15 for the half gap 5mm, 7mm and 10mm, respectively, to achieve the kick angle 0.6 mrad for the 6 GeV beam (=3.6MV kick) as shown in next section. The calculated total loss factors with the kickers including the number of kickers are shown in Fig. 7.

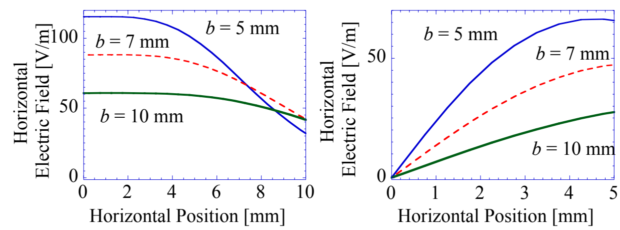

Figure 6: The dependence of the horizontal electric field on the vertical half gap (b) of the kicker. The dipole field strength (left) is proportional to the gap, while the quadrupole field strength (right) has stronger dependence on gap as expected in the analogy magnets.

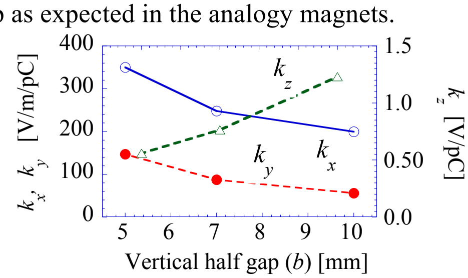

Figure 7: The loss factor of the kicker for horizontal (k_x), vertical (k_y) and longitudinal (k_z). The values are the sum of the all the required number of kickers; 5, 7, 15 for the vertical half gap 5mm, 7mm, 10mm, respectively.

The time structure of the kick is the running average of the input to the kicker in the time period of $2L/c$, where L is the kicker length and c is the speed of light. Therefore, the kicker length is set to 0.2m for $2L/c$ to be 1.3 ns for 2ns spacing RF buckets. The kick calculated by the three-dimensional simulation with MAFIA-T for the expected input filed is shown in Fig. 9.

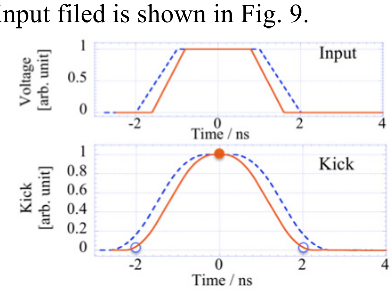

Figure 8: Time structure of the kick (lower) for the input field (top) to the kicker. The rise/duration/fall time of the input field is 0.8ns/1.6ns/0.8ns (solid line), and 1ns/2ns/1ns (dashed line).

The characteristics of the kicker, as compared with the kicker for the damping ring in [3], can be summarized as

1) strong horizontal kick field is obtained by narrowing vertical gap, not narrowing horizontal gap, thus wider horizontal physical aperture is obtained,
2) the grounded electrodes are placed at the top and bottom of the horizontal center of the kicker. With these electrodes, Field distribution can be continuously controllable from dipole to quadrupole field by changing the input field strength and polarity,
3) also the flat region of the field can be obtained with this grounded electrodes,
4) the opening of the kicker electrodes in outer end produces the point where the kick field is zero.

INJECTION TO SPring-8 II

The injection to the SPring-8 II ring is designed to be in the horizontal direction. The horizontal and vertical beta functions of the normal straight sections are set to 1m to obtain the high brightness of the undulator radiation. With those small beta functions, the dynamic aperture is less than 1mm, whereas the SPring-8 II ring has four ~30m long straight sections where the optics has the freedom to increase the value of the beta functions to ~25m, or the dynamic aperture to 2mm. Therefore, one of the long straight sections is assigned to injection section. The injector to the ring is planned to be SACLA, the X-FEL linac at SPring-8, because of its low emittance: less than 0.1 nm rad, and the beam size at the injection point is less than 0.046 mm for β_x =25m, just the point size in Fig. 3. The possible scheme of the injection with the system is shown in Fig. 9 and 10. The beam energy is 6 GeV. In off-axis injection in Fig. 9, the stored beam suffers no dipole kick, but quadrupole kick, which create quadrupolar oscillation of the beam, however this kick is limited to the injected bucket and no perturbation on the other stored beam.

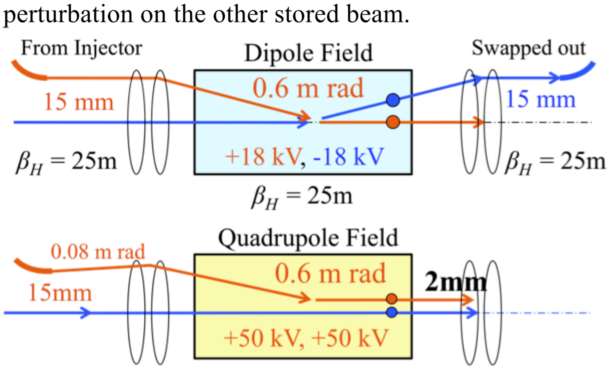

Figure 9: The on-axis swap injection with dipole kick (top) and off-axis injection by quadrupole kick (bottom). The drive voltages of left and right electrodes are also shown.

Several injection schemes for off-axis injection with sharing the amplitude with the stored beam are shown in Fig. 10. The weak dipole kicker is placed before the main kicker. The injected beam passes the point where the dipole kick field is zero in the dipole kicker, like as shown in Fig. 4. For the sharing scheme, only the beam in the injected bucket suffers the share of the oscillation and the most stored beam is stable. However, its betatron oscillation amplitude is as large as few mm, thus the bunch-by-bunch feedback system has to suppress with this large amplitude in case single bunch beam instability occurs, which is not easy task if the instability is strong.

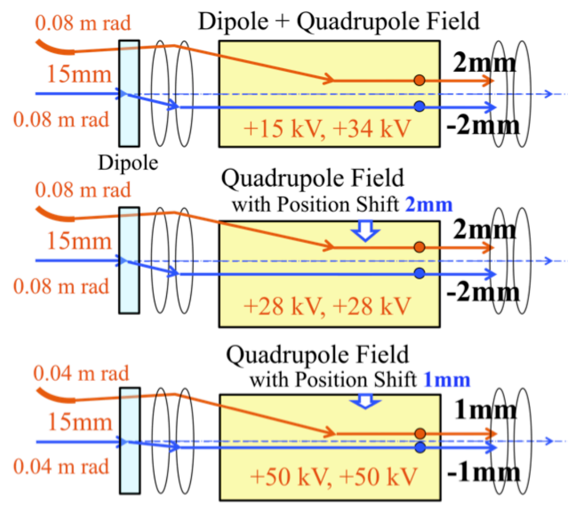

Figure 10: Several injection schemes for off-axis injection with quadrupole field by sharing the amplitude with the stored beam with extra dipole kicker. [Top] With the sum of dipole and quadrupole kick by the lower unbalanced voltages as shown in Fig. 3. [Middle] The position shift of the kicker with lower voltages. [Bottom] For narrower aperture of 1mm with the same voltages as in Fig. 9 with position shift 1mm. In pre dipole kicker, beam passes at zero field point of shown in Fig. 4.

DEDICATED KICKERS

One may consider dedicated kicker for off-axis scheme. The kick on stored beam creates quadrupole oscillation, but if it is allowable if the effect is limited to several buckets, then one may use single long kicker and longer drive pulse instead of many 0.2m kickers.

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