

# A NOVEL NON-LINEAR STRIP-LINE KICKER DRIVEN BY FAST PULSER IN COMMON MODE\*

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## Abstract

The next generation storage ring-based light sources adopt multi-bend achromat lattices to achieve a low emittance. The dynamic apertures of these machines are usually less than 10 mm so that the traditional pulsed local bump injection is difficult to achieve. Off-axis injection with a pulsed multipole or a non-linear kicker could be a viable solution which requires a moderate dynamic aperture of a few mm. In this paper, a novel non-linear kicker design is presented. Unlike pulsed sextupole or nonlinear kicker magnet, the nonlinear kicker we proposed is a traveling wave kicker with 2 strip-line electrodes driven by a nanosecond-level fast pulser in common mode. The disturbance to the stored beam is minimal since the perturbation is limited to the target bunch alone.

## INTRODUCTION

The next generation storage ring-based light sources adopt multi-bend achromat (MBA) lattice to achieve ultra-low beam emittances and a much higher brightness compared to third generation light sources. These lattice utilize very strong focusing to reach an ultra-low emittance, and thus it becomes very challenging to realize a reasonable beam lifetime in addition to a large enough dynamic aperture for conventional pulsed bump injection schemes.

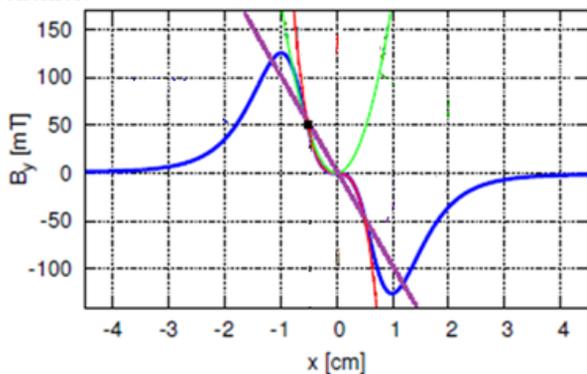


Figure 1: Field distribute of pulsed multipole and NLK (purple: quadrupole, green: sextupole, red: octupole, blue: non-linear).

Originally proposed to reduce the injection transient oscillations, off-axis injection using pulsed multipole kicker magnets(or nonlinear kicker magnet)[1,2,3] is now regarded as a promising injection scheme which could somehow reduce the requirements on the dynamic

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aperture. As shown in Fig.1, in these pulsed multipole kickers, the injected beam is deflected in the strong field region, and the stored beam pass through the no field region (the center of magnet), and both beams are located at one side of the septum plate at the injection point. Actually, these devices can be seen as special pulsed septum without a plate, while have both the features of septum and kicker.

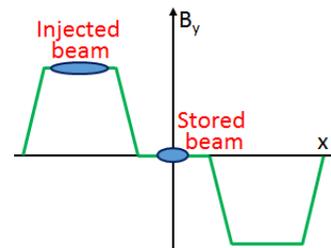


Figure 2: Perfect separating field.

General speaking, a perfect separating field is a step field with a flat top region and a flat bottom region, as shown in Fig.2. However, the practical field inevitably has a smooth field gradient and will disturb both the injected beam and stored beam. Note that more concern is on the stored beam since the users prefer more transparent injection. However, the perfect zero field with zero gradient at the center of magnet is hard to achieve since a high field is desired to deflect the injected beam. Typical distance of peak field from magnet center is 10mm so far [3,4], then it is very different to place the injected beam onto the plateau for a small dynamic aperture lattice design, a very small emittance injected beam is thus favoured if it has to be put on the slope of the field distribution.

## A TRANSMISSION-LINE NLK

In theory, a separating field can be built by field vector cancellation. One solution is to apply symmetrical exciting current, as shown in Fig.3. The Nonlinear Kicker (NLK) proposed by BESSY is an 8-rod magnet with 4 positive current rods in inner area and another 4 negative current rods in outer area, which is shown in Fig.3-(f). Actually, it can be abstracted into coaxial structure, seen in Fig.3-(g). A coaxial transmission line kicker can be driven by a single fast pulser. Obviously, in the inner conductor of coaxial structure, field is zero.

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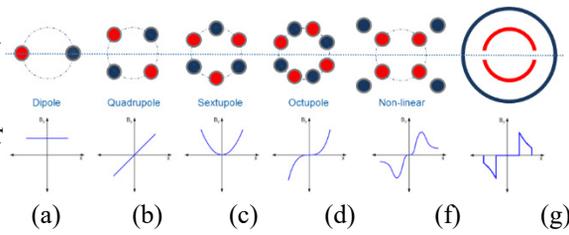


Figure 3: Separating field built by rod coils (red: +direction, blue: -direction).

The other solution is to apply the eddy current shielding. In Fig.4-(b), 2 plate coils driven in common mode can also form a quadrupole field. If introducing an eddy current shielding plate in the middle of the coil, the field at the magnet center can be suppressed as shown in Fig.4-(c). In fact, it is a dual-strip transmission line structure, which can also be driven by a single fast pulser.

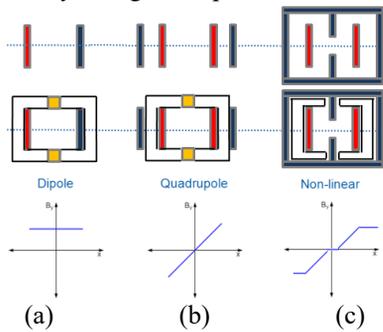


Figure 4: Separating field built by plate coils (red:+direction, blue: -direction).

Both the proposed coaxial and dual-stripline transmission line NLKs can be driven by a super-fast high voltage pulser of several nanoseconds pulse length. There are a couple of advantages using a fast pulser. First, if the pulse length is less than twice of the stored bunch spacing, the residual field in the center of NLK only disturbs the target bunch and make the injection transparent to the users. Second, the faster pulse leads to a better eddy current shielding and a thinner conductor. It is good for a smaller structure.

### EVOLUTION OF STRIPLINE NLK

The dipole dual strip-line kickers used in the scheme of on axis injection are developed in many projects all over the world, such as APSU[5], ALSU[6] and HEPS[7]. A dipole strip-line kicker is driven in difference mode by a bipolar pulser. If the dual strip-line kicker is driven in common mode, a quadrupole like field could be produced, as shown in Fig.5.

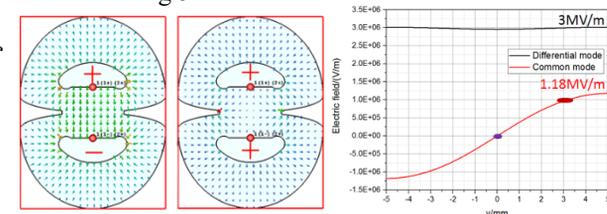


Figure 5: HEPS dual strip-line kicker driven in differential and common modes.

In the strip-line kicker design at HEPS, the gap between the blades is 10mm, a ridge like structure between the blades is introduced to decouple the field excited by two blades for better even mode impedance matching. If the ridge is further extend, the gradient of field is enlarged as shown in Fig.6.

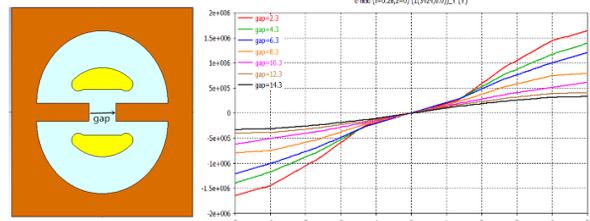


Figure 6: HEPS dual strip-line kicker driven in different modes.

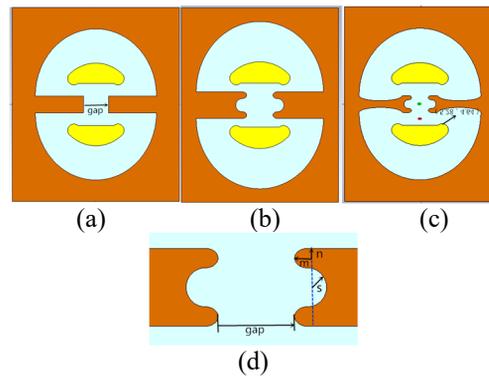


Figure 7: Evolution process of model (gap=6mm, s=1.5mm, m=1mm, n=0.75mm).

Fig.7 shows the further evolution process of nonlinear strip-line kicker. Assuming the injected bunch size( $5\sigma$ ) is  $x=1$  mm,  $y=0.5$ mm and stored bunch size( $5\sigma$ ) is  $x=50\mu\text{m}$ ,  $y=40\mu\text{m}$ . We make gap=6mm, which is larger than the injected bunch size. The injected beam can pass through the channel and merge together with the stored beam with the help of synchrotron radiation damping. In order to supply a larger beam clearance for stored beam, the end of ridges are trimmed like Fig.7-(b). From the simulation result, shown in Fig.8-(a), the local maximum E field is 22.4MV/m (15kV pulser) near the blades edge. It is much larger than the safe value of 13MV/m. The shape of ridges is modified to Fig.7-(d). The local E field distribution look as Fig.8-(b) and the maximum local E field is limited to 6.18MV/m.

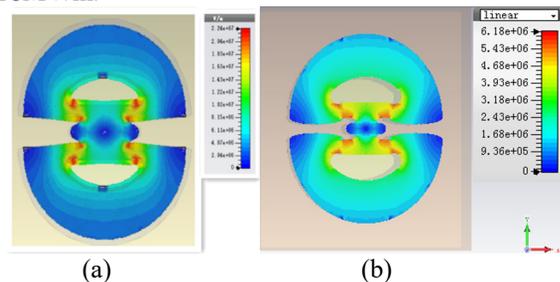


Figure 8: Local E field distribution.

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### FIELD DISTRIBUTION

In the final model, the field distribution between 2 blades of NLK is shown in Fig. 9. At  $y=0$ , and  $y=4$  there are flat plate ( $k_y=0=0.14\text{MV/m}^2$ ,  $k_y=4=0.71\text{MV/m}^2$ ) where the stored beam and injected beam pass. The field distribution along  $y=4\text{mm}$  is shown in Fig.10, the good field region within 1% field nonuniformity is  $\pm 0.4\text{mm}$ .

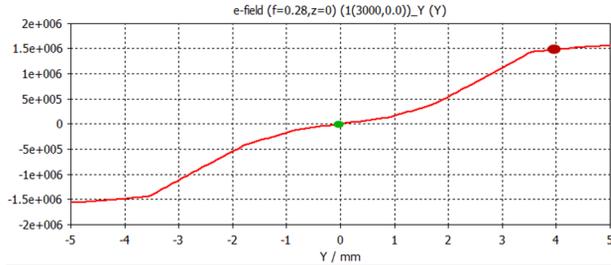


Figure 9: E-field distribution along the  $x=0$  axis.

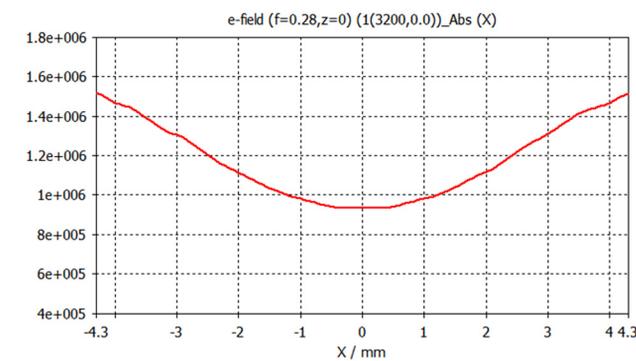


Figure 10: E-field distribution along the  $y=4$  axis.

### EVEN MODE IMPEDANCE

Compared to dipole strip-line kicker, the strip-line NLK must be driven in common mode. So the even mode impedance of the strip-lines are optimized to  $50\Omega$  for matching to fast pulser and feedthrough. The 3D model of the NLK is shown in Fig.11, there are taper parts at the both end of blades and outer body. The main body is  $650\text{mm}$  long and the taper part is  $50\text{mm}$  long. Fig.12 is the TDR simulation result, the even mode impedance is around  $50\Omega$ .

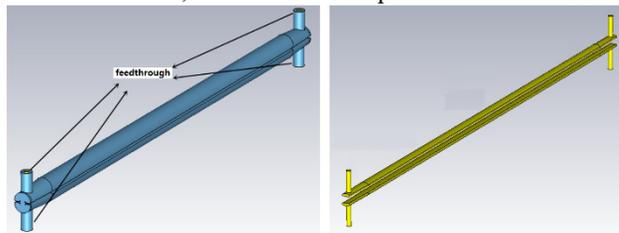


Figure 11: 3D model in the CST.

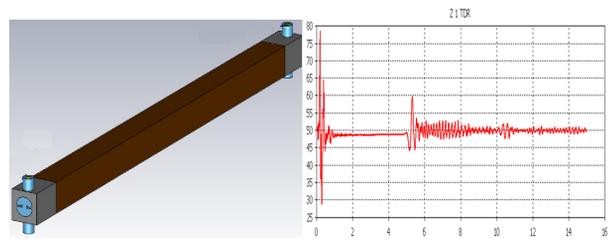


Figure 12: 3D model in the CST.

### BEAM IMPEDANCE

Since the structure is close to the stored beam, the beam impedance evaluation is essential. The short-range longitudinal wake field simulation is shown in Fig.13, here the length of gaussian beam  $\sigma_z=30\text{mm}$ , the loss factor is  $k_l=0.595\text{V/pC}$ . The power loss is  $P_{\text{loss}}=k_l I_b^2 n_b / f_{\text{rev}}=28.1\text{W}$  for the HEPS case, where the beam current is  $I_b=200\text{mA}$ , the revolution frequency  $f_{\text{rev}}=0.23148\text{MHz}$ ,  $n_b=648$ . Fig.14 is the long-range longitudinal wake field.

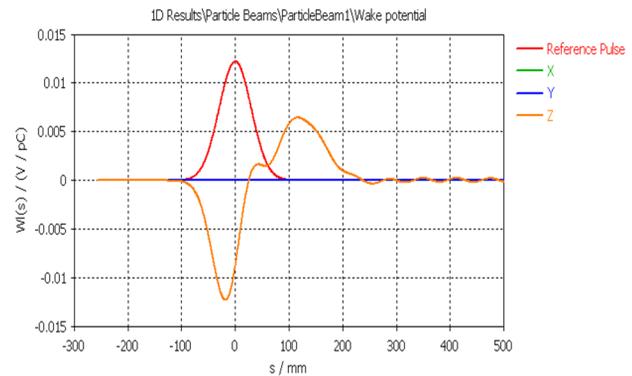


Figure 13: short-range longitudinal wake field.

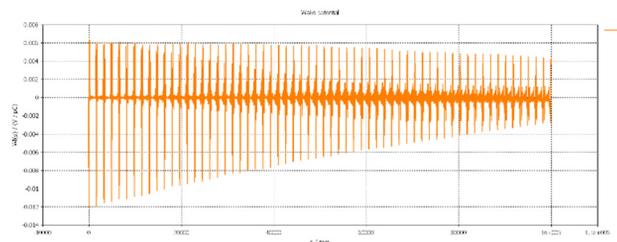


Figure 14: long-range longitudinal wake field.

### CONCLUSION

The proposed novel stripline nonlinear kicker is driven by a fast pulser in common mode. Thanks to the short pulse length, the stored beam disturbance can be suppressed to minimum. The smaller structure helps to build an extremely nonlinear field which may fit for a machine with a small  $DA=5\text{mm}$ .

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