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DESIGN OF TRANSVERSE FEEDBACK KICKERS FOR THE HEPS STORAGE RING

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Abstract

The High Energy Photon Source is a 6 GeV synchrotron radiation light source being built in Beijing, China. The electron beam inside the storage ring is designed to run with ultra-low emittance. To ensure high beam quality, the coupled bunch instabilities must be carefully investigated and controlled, therefore an effective feedback system is essential. Stripline kickers are designed for transverse feedback in the HEPS storage ring. The basic structure and main simulation results of these kickers are introduced, including the reflection parameter, transverse shunt impedance, and wake effects.

INTRODUCTION

High Energy Photon Source (HEPS) is the first new-generation synchrotron light source in China. The HEPS accelerator consists of a linear accelerator, transport lines, a booster, and a storage ring. The HEPS storage ring with a beam energy of 6 GeV and a natural emittance of lower than 60 pm·rad is designed for generating X-rays with a brightness higher than 1×10^{22}photons/s/mm^2/mrad^2/0.1% BW [1]. To achieve this, high beam quality should be ensured, which makes an effective and reliable feedback system essential to damp beam instabilities.

In modern storage rings, the digital bunch by bunch feedback system is widely utilized, it mainly consists of four parts: the front-end electronics, the digital processing electronics, the power amplifier, and the feedback kicker. The front-end electronics deals with the oscillation information of each bunch from the beam position monitor (BPM) and send the digitized signal into the processing electronics to calculate the correction signal, which is then amplified by the power amplifier and sent through the feedback kicker to act on the bunch.

In the transverse feedback system of the HEPS storage ring, the commonly used stripline kicker is chosen. In the following, we will introduce the design target, the basic structure, and the main design parameters of kickers.

SYSTEM REQUIREMENTS

Based on the theory of coupled bunch mode instabilities (CBMIs), any $f_{RF}/2$ portion of the beam spectrum contains the information for all potential multi-bunch modes and can be used to detect instabilities and measure their amplitude [2]. For the HEPS storage ring, the main RF frequency f_{RF} is 166.6 MHz, therefore the transverse feedback kicker needs to have a bandwidth from DC to $f_{RF}/2$ (roughly 85 MHz). Considering that the working bandwidth of stripline kicker is mainly decided by the length of stripline electrode, and a too-long electrode is easy to bend and heavy, a length of 450 mm is chosen.

To effectively damp beam instability, the damping time τ of the feedback system must be obviously shorter than the fastest rising time of transverse coupled bunch modes. Besides, the allowed maximum oscillation amplitude in the transverse plane is 0.2 mm for the HEPS storage ring. Therefore, the required kick voltage per turn V can be deduced by the following equation (1),

$$V = 2\frac{T_0}{\tau} \cdot \frac{E}{e} \cdot \frac{\Delta y}{\sqrt{\beta_k \cdot \beta_p}} \tag{1}$$

Where, E is the stored beam energy, T_0 is the revolution period, β_k and β_p are the beat function values at the kicker and BPM. The mentioned parameters of HEPS storage ring are listed in Table 1, based on which, the vertical instability is more severe than the horizontal instability, so we plan to use two vertical feedback kickers and one horizontal kicker. In the next section, the design considerations of these feedback kickers are introduced.

Table 1: Corresponding Parameters of the Transverse Feedback System

	Y direction	X direction
Energy, E	6 GeV	
Revolution Period, T_0	4.54 µs	
β function @ kicker, β_k	5.4 m	8.5 m
β function @ BPM, β_p	6.0 m	5.2 m
Damping time, τ	0.1 ms	0.5 ms
Allowed max. oscillation amplitude, Δy (or Δx)	0.2 mm	
Required kick voltage per turn, V	19.2 kV	3.3 kV

TRANSVERSE FEEDBACK KICKER

Basic Structure

The transverse feedback kicker in the horizontal and vertical directions almost has the same structure. In this section, the vertical feedback kicker (VFB kicker) will be mainly described, also the difference between the horizontal feedback kicker (HFB kicker) and the VFB kicker.

Vertical feedback kicker The transverse feedback kicker in the horizontal and vertical directions almost has the same structure. Using the vertical kicker as an example,

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the stripline kicker mainly consists of two curved electrodes located in the vertical plane inside a round pipe. as basically shown in Fig. 1. In both ends of each electrode, there is a vacuum feedthrough connected to the outside, the two feedthroughs in downstream are used to feed in correction signal, the two upstream are connected to matched loads.

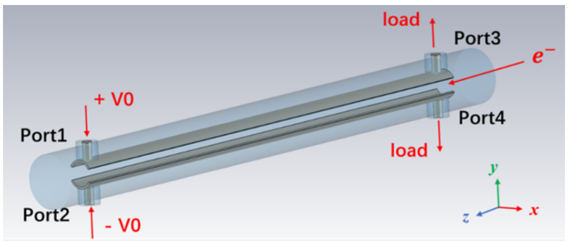

Figure 1: The basic structure of the vertical feedback kicker.

The transmission line including two electrodes and the surrounding beampipe supports two TEM modes: odd and even. Assuming that the characteristic impedance of a single electrode and pipe in these two modes are Z_{even} and Z_{odd} separately, there naturally exists $Z_{odd} < Z_{even}$.

When working for feedback, the stripline kicker is driven by two waves of equal amplitude and opposite phase, therefore we need to match Z_{odd} to roughly 50 Ω to reduce reflection. Besides, the longitudinal beam impedance can be expressed as in Eq. (2) [3, 4],

$$Z_{\|} = \frac{g_{\|} \cdot Z_{even}}{2} [\sin^2(kL) + j\sin(kL)\cos(kL)] \qquad (2)$$

where k is the wave number, L is the longitudinal length of the electrodes and $g_{\|}$ is the longitudinal geometric factor (for a circular electrode with a coverage angle of Φ, $g_{\|}$ analytically equals Φ / π). Based on Eq. (2), the longitudinal beam impedance can be reduced by lower Z_{even}, which can be realized by introducing a ground separation between two electrodes, as schematically shown in Fig. 2.

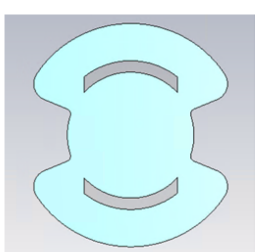

Figure 2: The sectional view of the vertical feedback kicker in the xy plane after introducing the ground separation between electrodes, only the vacuum part is shown.

For our design, the stripline electrode has an inner radius of 11 mm (same as the radius of beam pipe in HEPS storage ring) and a thickness of 2 mm, the surrounding beampipe has a radius of 19.5 mm, the stripline electrode and ground separation has a coverage angle of 95 deg and 45 deg, respectively. The optimized characteristic impedance Z_{odd} is 48 Ω and Z_{even} is 53 Ω.

In order to further reduce the longitudinal beam impedance, the stripline electrode and the ground separation have transition parts at both ends to disturb the fields of longitudinal high order modes (HOMs). The finally optimized model of the vertical feedback kicker is shown in Fig. 3, where the detailed structures of stripline electrodes and the beampipe are shown in parts b) and c). The vacuum feedthrough used is non-magnetic, the inner conductor is screwed to the stripline electrode, and the thinnest part of the inner conductor is designed for stress relief. In all simulation results presented in this paper, the whole structure of the feedthrough is included.

Horizontal Feedback Kicker For the HFB kicker, as the stripline electrodes are located in the horizontal direction and have poor heat exchange with the outside, we need to consider the synchrotron radiation. Therefore, the inner radius of electrode is set as 16 mm to avoid being directly hit. In this case, there must be two transition parts in the longitudinal ends of the HFB kicker to smoothly connect to the beampipe of the storage ring (radius of 11 mm). The structures of electrodes and ground separation are similar to the design of the VFB kicker. The 3D model of the HFB kicker is shown in Fig. 4.

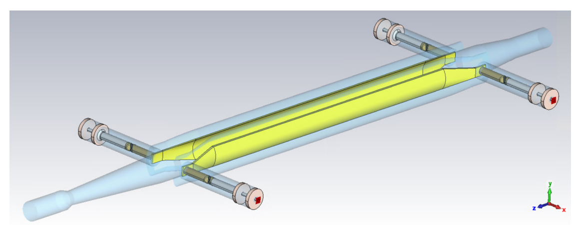

Figure 4: The 3D model of the HFB kicker.

Reflection Parameter

When the transverse feedback kicker is driven, the reflection parameter versus frequency for both the HFB kicker and the VFB kicker is shown in Fig. 5, which indicates the |S11| in the working bandwidth 0 85 MHz is lower than -20 dB, that is, the reflection power is lower than 1%.

Transverse Shunt Impedance

The transverse shunt impedance R_t is another important parameter to measure the efficiency of the kicker. R_t is defined as the ratio between the square of the transverse voltage $V_\perp$ and twice the total input power P_{in}, that is, $R_t = |V_\perp|^2/2P_{in}$. The transverse voltage $V_\perp$ can be calculated based on the electromagnetic fields inside the kicker:

$$V_\perp = \int [(E(z) + v \times B(z))e^{j(kz+\phi)}]dz \qquad (3)$$

By feeding in CW pulse and sweeping the input frequency, the transverse shunt impedance versus frequency of the transverse kickers are shown in Fig. 6. Within the bandwidth of 0 to 85 MHz, the shunt impedance of the HFB kicker is better than 121.5 kΩ, while the shunt impedance of the VFB kicker

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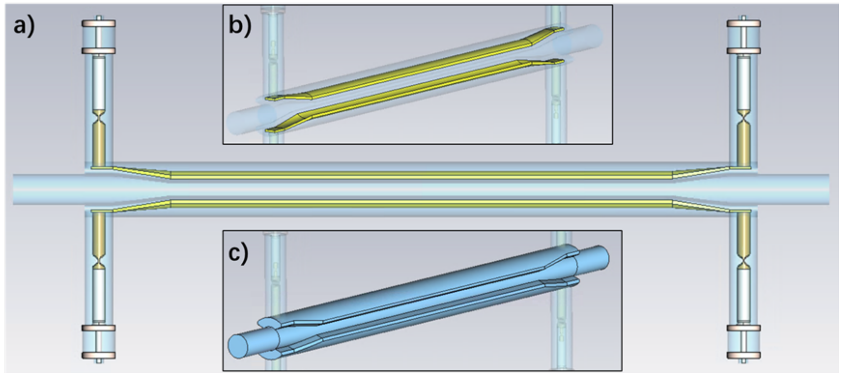

Figure 3: The 3D model of the vertical feedback kicker: a) the whole model; b) and c) show the detailed structures of stripline electrodes and the beampipe.

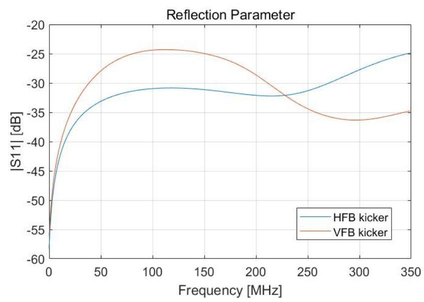

Figure 5: The reflection parameters of the HFB kicker and the VFB kicker.

has a minimal value of 54.4 kΩ. Combining the required kick voltage listed in Table 1, the HFB kicker needs an input power of 99 W and each VFB kicker (two in total) needs an input power of 379 W.

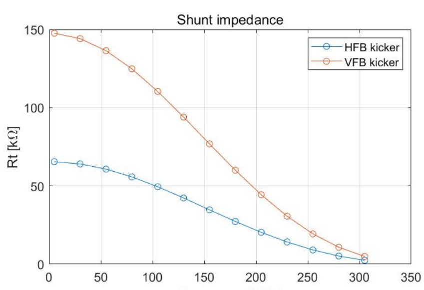

Figure 6: The transverse shunt impedance of the HFB kicker and the VFB kicker.

Wake Effects

The beam coupling impedance of both kickers in the longitudinal and transverse directions are all calculated and proved as lower than the impedance thresholds of the storage ring. For a bunch length (RMS) of 3 mm and a simulated wavelength of 25 m, wake loss factors are listed below. Besides, we calculate every longitudinal HOM to get the field distribution and the power dissipation of each part. Combining with the beam information, we can derive the possible dissipated power on the stripline electrode and then the thermal and structural effects, which could be a judgment criterion of a good or bad design.

Table 2: Wake Loss Factors of the Transverse Feedback Kickers

	VFB kicker	HFB kicker
kz [V/pC]	0.29	0.4955
kx [V/pC/mm]	0.0214	0.0434
ky [V/pC/mm]	0.0442	0.0324

CONCLUSION

This paper introduced the design of transverse feedback kickers for the HEPS storage ring. The transverse feedback system includes two VFB kickers and one HFB kicker, the required input power for each VFB kicker and the HFB kicker is 379 W and 99 W respectively. For these kickers, the basic structure is shown, also the main simulated results including reflection parameter, shunt impedance, and beam-induced wake effects are presented. These kickers are under fabrication and will be tested and installed this year.

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