THE DESIGN IMPROVEMENT OF HORIZONTAL STRIPLINE KICKER IN TPS STORAGE RING

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Abstract

We plan to replace the existing horizontal stripline kicker of the transverse feedback system with an improved design. Large reflected power was observed at the downstream port of stripline kicker driven by the feedback amplifier. A rapid surge of vacuum pressure was observed when we tested the high current operation in TPS storage ring in April 2016. A burned feedthrough of the horizontal stripline kicker was discovered during a maintenance shutdown. The improved design is targeted to reduce the reflection of driving power from feedback system and to reduce beam induced RF heating. This major modification of the design is described. The results of RF simulation performed with the electromagnetic code GdfidL are reported as well.

INTRODUCTION

The designs of stripline kickers of transverse feedbacks used in Taiwan Photon Source (TPS) were adapted from the SLS/ALBA design [1, 2]. Both the horizontal and vertical stripline kickers were installed and used in the commissioning of TPS phase-I insertion devices (IDs) since the 3rd quarter of 2015. The first hint of a problem for the horizontal stripline kicker was noticed when we operated in decay mode and stored 520 mA beam current in the storage ring on 12 Dec. 2015. An abrupt vacuum burst was recorded by an ion gauge nearby the horizontal kicker, with the peak pressure exceeding 6600 nPa. Similar events of vacuum burst recorded by the same ion gauge occurred several times when we tested the high beam current operation of storage ring in the first half of 2016. A hardware inspection was performed during the summer shutdown in 2016. We found the central connector of a feedthrough had brown spots and dielectric filling material of coaxial adapter was burned due to overheating. We also observed large reflected signals traveling towards the drive amplifier, which is connected to the downstream ports of kicker, at beam currents larger than 180 mA. This large reflected signal could cause damage to the drive amplifier. After reviewing all the data, it was decided to replace the horizontal kicker with an improved design which should achieve a better impedance matching and significant reduction of the beam induced RF heating. The detailed design and analysis of improved horizontal stripline kicker is reported and comparisons to the old design will be discussed.

OBSERVATION OF PROBLEMS

Abrupt vacuum bursts near the horizontal kicker were frequently observed during the high current beam test in TPS storage ring as shown in Fig. 1. The damaged coaxial feedthrough is shown in Fig. 2.

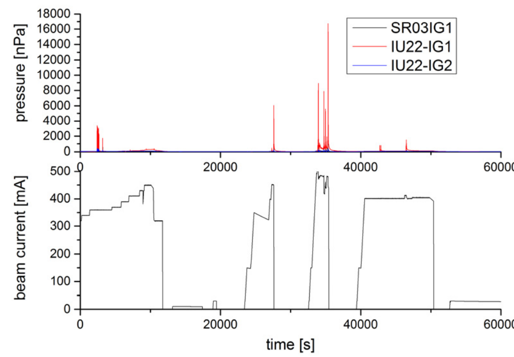

Figure 1: Vacuum pressure recorded by three ion gauges surrounding the horizontal kicker (top), beam current stored in storage ring (bottom).

Figure 2: Burned feedthrough connector (left), damaged coaxial adapter connected to the feedthrough (right).

DESIGN IMPROVEMENT

When a particle beam pass through a stripline kicker, both the even and the odd mode are excited by the beam and the drive amplifier, respectively [3]. The revised kicker design should improve the impedance matching to minimize the beam induced signal going downstream toward the drive amplifier and reduce the reflection of driving power applied by drive amplifier. We also made efforts to design the stripline-to-coaxial transition of the kicker which contributed to a large reduction in the loss factor of kicker module.

Impedance Matching

For an ideal stripline pickup/kicker, with the even mode impedance Z_{even} matched to the terminating line impedance (typically 50Ω), the beam induced signal only prop-

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agates to the upstream port and there is no beam induced signal at the downstream port [3]. From the viewpoint of an equivalent network, the stripline kicker is composed as a pair of coupled transmission lines with even and odd mode excited simultaneously. The necessary condition for the input impedance of a drive port to be matched to the terminating line impedance is given by the theory of coupled transmission lines [4, 5]:

$$Z_{even}Z_{odd} = Z_0^2 \tag{1}$$

where Z_0 is the terminating line impedance. One should make efforts to match both the impedance of even mode and the input impedance of drive port.

The stripline electrode arrangement has a racetrack cross-section profile to follow that of the beam pipe in the straight sections. The stripline electrodes are enclosed by a circular tube made out of stainless steel. The diameter of circular tube was adjusted to match the input impedance of drive port according to Eq. (1). To speed up the fabrication process for the scheduled shutdown in Jan. 2015, we settled with a circular tube of diameter 100 mm which could be readily procured off the shelves. The 7/8 EIA vacuum feedthroughs made by Kyocera were used for this design version. The horizontal stripline kicker after assembly is shown in Fig. 3. The simulated electric field pattern of the odd mode is shown in Fig. 4. The calculated impedance of both TEM modes of the stripline kicker is listed in Table 1.

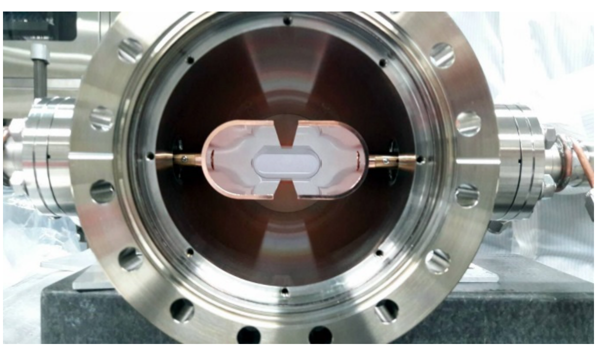

Figure 3: The horizontal stripline kicker after assembly.

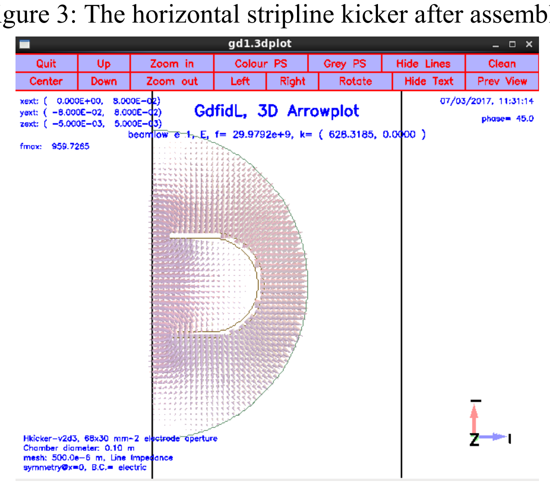

Figure 4: The simulated electric field pattern of the odd mode in the stripline kicker. Only half the structure was depicted.

Table 1: The Impedance of TEM Modes in the Horizontal Stripline Kicker

Mode	[Ω]
Z_{even}	66.58
Z_{odd}	34.70

The time domain reflectometry (TDR) was simulated by the 3-D electromagnetic code GdfidL [6] and compared with TDR measurements, see the result in Fig. 5.

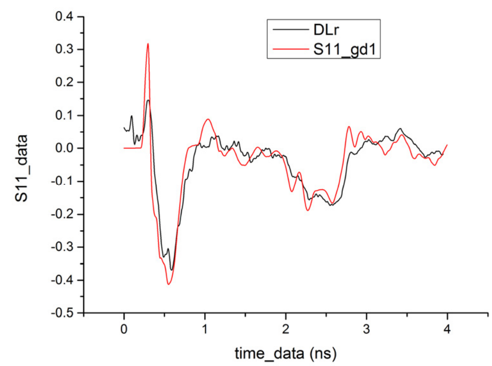

Figure 5: The comparison of simulated TDR (red) and measured data (black). Only one port was excited and the other three ports were terminated with 50 Ω.

Reduction of Loss Factor of the Kicker Module

The beam induced RF heating is related to the loss factor of kicker module. We made additional efforts to design the end plates of kicker chamber to effectively reduce the longitudinal and vertical gap as seen by the particle beam. Besides the special end plate design, we also increased the vertical gap of racetrack electrodes from 68x20 mm^2 to 68x30 mm^2. The combined effect of both approaches results in a significant reduction of loss factor for the kicker module. A zoom-in view of the end plate design is shown in Fig. 6.

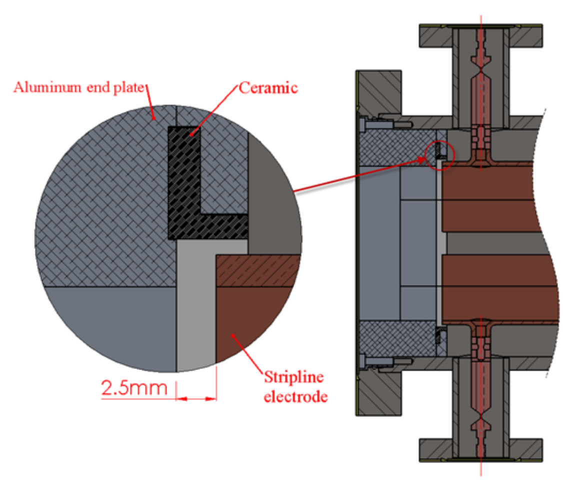

Figure 6: A zoom-in view of end plate with a shallow rectangular indentation used to shield the stripline electrodes.

A shallow rectangular indentation of depth 4.5 mm was machined on both end plates and the stripline electrodes were extended into the shallow indentation by 2 mm. The vertical gap between end plate and electrode is 2.5 mm. A ceramic washer of 1.5 mm was inserted between the electrodes and the end plates to assure electrical insulation.

The calculated loss factors for the old design and this improved design are listed in Table 2. There are 864 RF buckets in TPS storage ring. In routine operation the storage ring is typically filled with 600 bunches. The average RF heating power at 500 mA total current was estimated approximately by the following expression:

$$\langle P \rangle \approx \frac{\Delta E}{T_b} \tag{2}$$

where ΔE is the parasitic energy loss per bunch, and T_b is the RF period.

Table 2: The Calculated Loss Factor and Average Power of Beam Induced RF Heating at 500 mA Total Current (rms bunch length= 4.5 mm)

Mode	Loss factor [V/pC]	RF heating [W]
Old design	1.044	1081.7
Improved design	0.310	321.2

The longitudinal impedance spectrum of the entire kicker module was calculated using a time-domain numerical simulation software (GdfidL), the result is shown in Fig. 7. The beam pipe and all four coaxial ports terminated to 50 Ω were all included in the GdfidL simulation. There appears a dominant resonant mode at 1.233 GHz. The Q-factor and shunt impedance of this resonant mode were calculated by GdfidL using the eigenmode solver with absorbing boundary conditions [6]. The growth time of longitudinal coupled bunch instabilities driven by this resonant mode can be calculated by the formulas of the theory of bunched beam instabilities [7]. The RF parameters of dominant resonant mode calculated with absorbing boundary conditions are list in Table 3. The longitudinal radiation damping time of TPS storage ring is 6.08 ms, a much lower value than the instability growth time driven by this resonant mode at 500 mA total current. Therefore, the trapped resonant modes in horizontal kicker will not cause longitudinal coupled bunch instabilities.

Table 3: RF Parameters of Dominant Resonant Mode Calculated by GdfidL with Absorbing Boundary Conditions

f [GHz]	R/Q [Ω]	Q_{total}	Growth time [ms] at 500 mA total current
1.2327	5.98	412.53	93.1

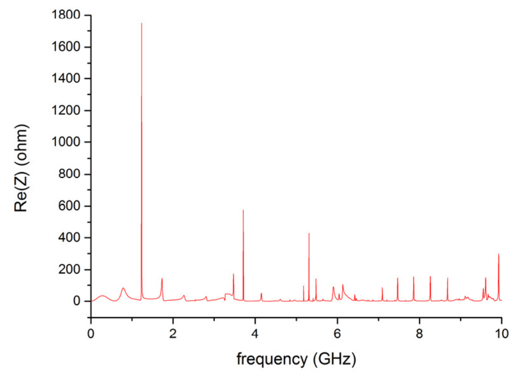

Figure 7: The longitudinal impedance simulated by GdfidL for the entire kicker module. The spectral resolution is 3.12 MHz.

SUMMARY

The improved design has decreased the loss factor of horizontal kicker module by a factor of 3.37. Also the beam induced RF heating is reduced substantially. Abrupt vacuum bursts are no longer observed near the location of horizontal kicker. The trapped resonant modes in the horizontal kicker were analysed, but are of no concern for longitudinal coupled bunch instabilities.

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