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SUPPRESSION OF TRANSVERSE BEAM INSTABILITIES BY STRIPLINE KICKERS AT TPS

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Abstract

Collective beam instabilities could limit the accelerator performance if proper countermeasures are not in place. Active beam feedback systems are commonly used to suppress beam instabilities. The resistive wall impedance including phase-II insertion devices at TPS are calculated with analytic formulas. The growth rate of transverse coupled bunch instabilities due to wall impedance is estimated by theory. The RF properties of existing stripline kickers in TPS are analysed with a 3-D electromagnetic simulation code GdfidL. Based on the above analysis, the requirements for a beam feedback system are calculated and the results are reported.

INTRODUCTION

The original designs of stripline kickers of transverse feedbacks used in Taiwan Photon Source (TPS) were adapted from the SLS/ALBA design [1, 2]. There are one horizontal kicker and two identical vertical kickers installed in TPS storage ring at present. The horizontal kicker was found damaged when the beam current was pushed over 500 mA in April 2016. The horizontal kicker was replaced by an improved design in Jan. 2017. The geometries of both transverse kickers presently in use at TPS are shown in Fig. 1.

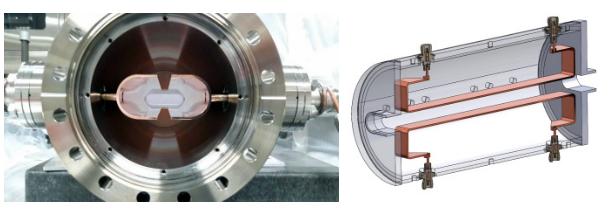

Figure 1: Transverse stripline kickers presently in use at TPS. The horizontal kicker of improved design (left) and the vertical kicker (right), respectively.

For the phase-II insertion devices (IDs) at TPS, it is planned to install six IDs in the next three years [3]. The transverse resistive wall impedance including phase-II IDs is estimated by analytical formulas [4, 5]. The growth rate of transverse coupled bunch instabilities driven by wall impedance is calculated by theory [5]. The RF properties of both transverse kickers are characterized by a 3-D electromagnetic simulation code GdfidL [6]. The power requirements for transverse feedbacks to damp the coupled bunch instabilities are estimated for a stored beam current 500 mA and the results are reported.

PROPERTIES OF STRIPLINE KICKERS

A stripline kicker is a system of coupled transmission lines. When a particle beam is traversing the kicker and the kicker is driven by amplifiers of feedback system, two characteristic TEM modes are excited, namely the even and odd modes [7]. In the original designs of transverse kickers, the emphasis was only placed on matching the characteristic impedance of odd mode to 50 Ω. This design scheme results in a large reflection of input driving voltage and beam induced voltage. The loss factors of both kicker modules are also large giving excessive beam induced RF heating in user operation. When we replaced the damaged horizontal kicker, the new design scheme includes the reduction of loss factor and the optimum matching of mode impedances as given by:

$$Z_{even} = Z_0 \text{ and } Z_{even} Z_{odd} = Z_0^2 \qquad (1),$$

where Z_0 is the terminating line impedance (typically 50 Ω). The improved design of horizontal kicker results in a better impedance matching and a significant reduction of beam induced RF heating. The detailed design of the improved horizontal kicker has been reported [8].

Impedance Matching of Vertical Kicker

The results of impedance matching for two TEM modes in the existing vertical kicker are given by Table 1. The comparison of measured data and simulation for time domain reflectometry (TDR) is show in Fig. 2.

Table 1: The Summary of Mode Impedance for the Vertical Kicker Presently in Use at TPS

	Existing kicker
Z_{even} [Ω]	150.55
Z_{odd} [Ω]	49.92
Z_{even}* Z_{odd}	7515

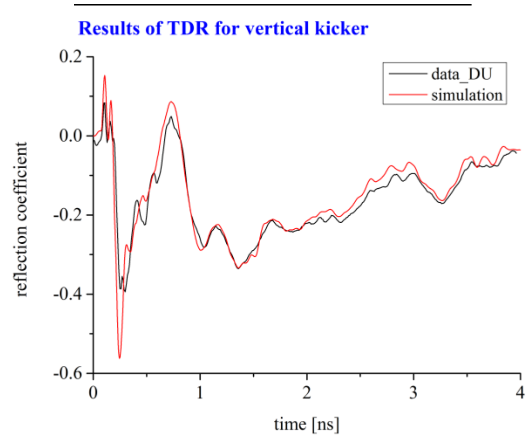

Figure 2: The comparison of measured data and simulation of TDR for the vertical kicker presently in use at TPS.

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Transverse Shunt Impedance and Loss Factor

The longitudinal beam impedance and the loss factor are calculated by the simulation code GdfidL using the time domain and eigenmode solver with absorbing boundary conditions. There are several prominent resonant modes in the longitudinal impedance of vertical kicker as shown in Fig. 3.

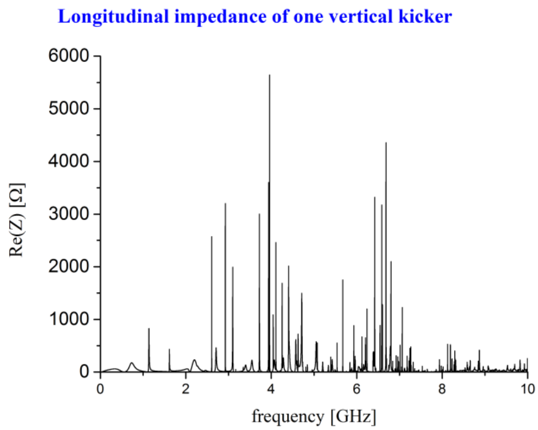

Figure 3: The real part of longitudinal beam impedance of one vertical kicker simulated by GdfidL.

A list of some prominent resonant modes of longitudinal impedance for one vertical kicker and the growth times of longitudinal coupled bunch instabilities driven by those modes at 500 mA are given in Table 2. The longitudinal damping time of TPS storage ring is 6.1 ms. If we consider the worst scenario that the modes of two vertical kickers add up in phase, the strength of radiation damping is still adequate to suppress the longitudinal coupled bunch instabilities. As long as we avoid adding any cavity-like vacuum component to the storage ring, a longitudinal feedback system is not necessary at TPS. The loss factor is calculated at rms bunch length 15 ps and the estimated average heating power are given in Table 3 for a stored beam current 500 mA in 700 bunches. The analyses for transverse resonant modes of both kickers are still in progress.

Table 2: The Prominent Resonator Modes of Longitudinal Impedance and Growth Times of Coupled Bunch Instabilities for One Vertical Kicker

f **[GHz]**	**Q_{total}**	**R/Q [Ω]**	**τ [ms]**
3.7210	1060	2.832	27.96
3.9593	2699	2.091	14.89
6.6835	2415	1.804	13.94

Table 3: The Calculated Loss Factor and Average Power Dissipated by Particle Beams in Each Transverse Kicker

Kicker	**Loss factor [V/pC]**	**Dissipated Power [W]**
Horizontal	0.31	236.0
Vertical	1.07	814.5

The transverse shunt impedances of both horizontal and vertical kickers are calculated by exciting a kicker with a given input power P_{in}. The transverse wakepotential (transverse beam voltage, $V_\perp$) is then calculated with a very small drive charge in GdfidL simulations. The transverse shunt impedance is derived from the definition $R_\perp = V_\perp{}^2/2P_{in}$ and the transverse beam voltage [9]. The transverse shunt impedances of each transverse kicker as calculated by GdfidL simulations are shown in Fig. 4.

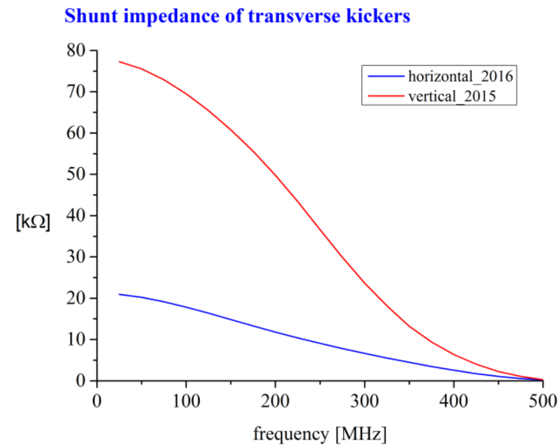

Figure 4: The transverse shunt impedance of each transverse kicker is calculated by GdfidL simulations.

DAMPING RATE OF BEAM FEEDBACK

The schematic layout of a transverse beam feedback system at TPS is depicted in Fig. 5. Each downstream port of stripline kicker is individually driven by a wideband RF amplifier with a maximum output power 500 W.

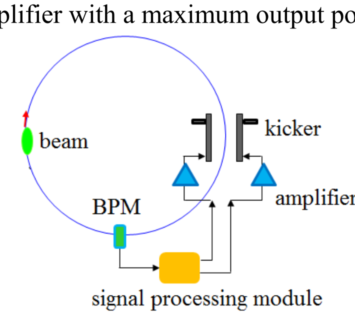

Figure 5: The schematic layout of a transverse beam feedback system at TPS.

At time t= 0, the beam displacement is detected by the beam position monitor (BPM) of feedback system. Then, the measured beam signal is processed through the signal processing module and fed to each downstream port of the stripline kicker. The earliest possible time for the kicker to apply an angular kick to the particle beam is after a delay time of one revolution period T_0, i.e. at time t= T_0. After the particle beam receives an angular kick from the kicker, the change of beam displacement is detected by the BPM in the next turn, i.e. at time t= $2T_0$ approximately. The damping rate α of the oscillation amplitude can be approximated by $\frac{dy}{dt} = -\alpha y \approx \Delta y/2T_0$. After applying an angular kick θ_k to the particle beam, the change of beam displacement as measured by the BPM of feedback system in the next turn is given by

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$$\begin{pmatrix}\Delta y \\ \Delta y'\end{pmatrix} = \begin{pmatrix} m_{11} & \sqrt{\beta_p \beta_k}\sin\phi \\ m_{21} & m_{22}\end{pmatrix}\begin{pmatrix}0 \\ \theta_k\end{pmatrix} \quad (2)$$

$$\Delta y = \theta_k \sqrt{\beta_p \beta_k}\sin\phi = -2\alpha T_0 y_0 \quad (3),$$

where β_p is the beta function at the location of BPM, β_k is the beta function at the location of kicker, ϕ is the betatron phase advance from the kicker to the BPM, and y_0 is the initial beam oscillation amplitude (injection disturbance). Therefore, the damping rate α_d of a beam feedback system is approximately given by

$$\alpha_d = \frac{\theta_k \sqrt{\beta_p \beta_k}\sin(-\phi)}{2T_0 y_0} \quad (4)$$

To operate a beam feedback system at its maximum efficiency, the betatron phase advance from the BPM to the kicker should be adjusted to $\pi/2$ such that the phase factor $sin(-\phi)$= 1. After the phase delay of feedback system is properly adjusted, the maximum damping rate α_d of a beam feedback system is given by [10]

$$\alpha_d = \frac{\theta_k \sqrt{\beta_p \beta_k}}{2T_0 y_0} \quad (5)$$

The angular kick applied to the particle beam by a stripline kicker is given by [7]

$$\theta_k = \frac{eV_\perp}{cp} = \frac{V_\perp}{cB_0\rho} \quad (6),$$

where $B_0\rho$ is the magnetic rigidity. The maximum damping rate given by Eq. (5) can be rewritten as

$$\alpha_d = \frac{\sqrt{2P_{in}R_\perp}}{cB_0\rho}\frac{\sqrt{\beta_p\beta_k}}{2T_0 y_0} \quad (7)$$

POWER REQUIREMENTS FOR TRANSVERSE FEEDBACK SYSTEMS

There are 10 phase-I IDs already installed for user operation at TPS. Six more IDs are planned to be installed in the next three years for the phase-II. The transverse resistive wall impedances are calculated by analytical formulas [4, 5], including 16 ID chambers, 5 titanium coated ceramic chambers, and standard beam pipes. The calculated vertical wall impedance is shown in Fig. 6.

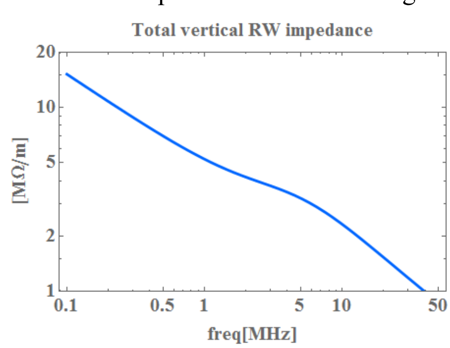

Figure 6: The calculated vertical resistive wall impedance at TPS. Total of 16 ID chambers are included.

If we specify a net damping rate α_{net} for a beam feedback system, the required input power is given by

$$P_{in} = \frac{2(\alpha_d cB_0\rho T_0 y_0)^2}{R_\perp \beta_p \beta_k} \quad (8)$$

$$\alpha_d = \alpha_{net} + \alpha_{BI} - \alpha_{rad} \quad (9),$$

where α_{BI} is the growth rate of coupled bunch instabilities, and α_{rad} is the radiation damping rate. In routine operation, the transverse beam feedbacks are used to suppress the coupled bunch oscillation of stored beam excited by the injection disturbance [11]. The parameters used to estimate the power requirements of transverse feedbacks are given in Table 4. If we specify a net damping time as 0.5 ms, the input power needed by transverse feedbacks to suppress the beam oscillation excited by the injection disturbance are given in Table 5 for the horizontal plane and in Table 6 for the vertical plane, respectively. Note that the radiation damping time for the horizontal plane is 12.20 ms and 12.17 ms for the vertical one.

Table 4: Parameters Used to Estimate the Power Requirements of Transverse Feedbacks

	Horizontal	Vertical
Injection disturbance [mm]	1.0	0.5
Beta function [m]	7	5
Shunt impedance [kΩ]	20.9	77

Table 5: The Input Power Needed by the Horizontal Feedback to Suppress the Beam Instabilities

Chromaticity	α_{BI} [s^{-1}]	α_d [s^{-1}]	P_{in} [W]
0.5	512.7	2430.8	312.6
3.1	220.1	2138.1	241.9
4	114.7	2032.7	218.6

Table 6: The Input Power Needed by the Vertical Feedback to Suppress the Beam Instabilities

Chromaticity	α_{BI} [s^{-1}]	α_d [s^{-1}]	P_{in} [W]
0.5	1967.8	3885.6	106.2
2.5	1151.9	3069.7	66.3
4	459.3	2377.1	39.8

SUMMARY

The RF properties of both transverse stripline kickers are analysed by the simulation code GdfidL. There will be no longitudinal beam instabilities driven by the resonant modes of beam impedance in stripline kickers. The analyses for transverse resonant modes in stripline kickers are still in progress. Based on the present accelerator parameters, the input power needed by transverse feedbacks to suppress the beam oscillation excited by the injection disturbance is estimated. It is concluded that the capacities of both transverse feedbacks are adequate to maintain a stable operation at a beam current 500 mA with phase-II IDs installed in TPS storage ring.

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