STRIPLINE KICKER DESIGN FOR NSLS2 STORAGE RING*

W. Cheng[#], A. Blednykh, S. Krinsky, O. Singh
NSLS-II, Brookhaven National Laboratory, Upton, NY 11973

Abstract

In the NSLS2 storage ring, there are four stripline kickers/pickups. Two long striplines with electrode length of 30cm will be used as bunch-by-bunch transverse feedback actuators. Two short stripline kickers/pickups with 15cm length will mainly used for tune measurement excitation or signal pickup for the beam stability monitor. High shunt impedance of the long stripline kickers is demanded to produce 200μs damping time. Meanwhile the beam impedance should be minimized. The design work for these two types of stripline is discussed in this paper.

INTRODUCTION

NSLS2 is a third-generation light source under construction at Brookhaven National Laboratory. The machine will have < 1nm.rad horizontal emittance by using weak dipoles together with damping wigglers. For the storage ring of 792m circumference, geometric impedance, resistive wall impedance and ion effects are expected to be significant. A transverse bunch-by-bunch feedback system has been designed to suppress the coupled bunch instabilities. More information can be found in previous paper [1].

High power amplifiers and stripline kickers are the feedback actuators. They are the most expensive parts of the system. Design of the kickers should provide sufficient shunt impedance while minimizing the beam impedance. Striplines have been proved effective as transverse kickers. They have high shunt impedance at low frequency, which is suitable if the main instability contribution is from resistive wall and ions. Required power can be calculated if the stripline shunt impedance, damping time and initial oscillation amplitude are known.

$$\Delta\theta = -\frac{2\alpha}{f_{rev}} \cdot \frac{\Delta x}{\sqrt{\beta_m \cdot \beta_k}} = -2 \cdot \frac{1}{\tau} \cdot T_{rev} \cdot \frac{\Delta x}{\sqrt{\beta_m \cdot \beta_k}}$$
$$V_\perp = \Delta\theta \cdot \frac{E}{e} = -2 \cdot \frac{1}{\tau} \cdot T_{rev} \cdot \frac{E}{e} \cdot \frac{\Delta x}{\sqrt{\beta_m \cdot \beta_k}} \quad (1)$$

in which, $\Delta\theta$ is deflecting angle due to kicker; $V_\perp$ is transverse deflecting voltage; E is the beam energy; α/τ are feedback damping rate/time; Δx is initial beam oscillation amplitude; β_m / β_k – beta function at BPM and kicker.

From Panofsky-Wenzel theorem, electric field and magnetic field have the same kick effect when the power is fed to the stripline kicker from the downstream port:

$$\Delta\theta \approx \frac{\Delta p_\perp}{p_{//}} = \frac{V_\perp}{E/e} = \frac{2\int_{stripline} E_\perp dt}{Energy/e}$$

Kicker shunt impedance is defined as:

$$R_\perp = \frac{V_\perp^2}{2P} \quad (2)$$

where P is the input power.

Based on estimate of growth time of wakefield induced instabilities and fast-ion effects, we require 200μs damping time. For shunt impedance 10 kOhm, which is not hard to get with 30-cm stripline. β_m=12/10m and β_k = 7/21 m (vertical/horizontal), to damp an oscillation with initial amplitude of up to +/- 0.5mm in the vertical plane, we need 1000W power (2*500W) which is commercially available.

At wave number k, transverse shunt impedance of stripline with opposite electrode distance d and length l can be written as:

$$R_\perp = 2Z_c \left(\frac{2g_\perp l}{d}\right)^2 \left(\frac{\sin kl}{kl}\right)^2 \quad (3)$$

where $g_\perp$ is the geometric factor and Zc is the characteristic impedance of the stripline, which is matched to 50 Ohm.

With longer stripline kicker, the shunt impedance is bigger at low frequency but the bandwidth decreases. To separate between bunches in case the instability mode around 250 MHz happens. Stripline electrodes typically select less than half of the bunch space, which is 30cm with 500 MHz RF frequency.

In reality, Eq (3) may not easy to apply since it's hard to get the geometric factor for complicated structure. We use the HFSS simulation code [2] to calculate the electric and magnetic field along the beam path. Integration of kick force determines the vertical deflecting voltage and angle. A two plate 30cm stripline in round chamber has been designed with sufficient shunt impedance.

CHARACTERISTIC IMPEDANCE

Stripline with round chamber and plate type electrode is actually a transmission line. Its characteristic impedance can be approximated by [3]:

$$Z_c \approx \frac{377}{\Phi_0} \ln\frac{a}{b} \quad (4)$$

where a is the chamber inner radius, b is the plate-type electrode radius, and Φ_o is the plate open angle in rad unit.

Eq. (4) turns to the famous coaxial cable characteristic impedance formula while $\Phi_o=2\pi$. Even for round chamber stripline, Eq. (4) doesn't always give the good estimation. For the complex chamber structure, HFSS code is the best to do characteristic impedance match to external cables and instruments (50Ohm).

Stripline can be used as a pickup or kicker. The geometry in Figure 1 shows a typical four electrodes stripline. The geometry has four independent modes, namely sum, horizontal dipole, vertical dipole and quadrupole mode.
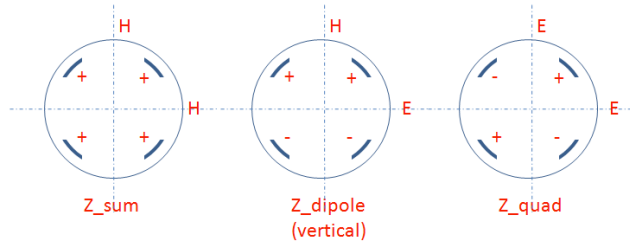

Figure 1: Different operation modes of stripline, H and E are boundary conditions in ¼ models.

For a round chamber, by symmetry, vertical and horizontal Z_dipole should be same. This is not true for other shaped chambers. In the case of two electrode stripline, there are two modes instead of four: Z_even and Z_odd, where Z_even is both electrodes fed in-phase while Z_odd is electrodes fed in opposite phase. Since the stripline will be used mainly as a dipole kicker, we match the Z_dipole (Z_odd for two electrode case) close to 50Ohm from HFSS result. The beam induced signals see the characteristic impedances of Z_sum or Z_even.

The optimized stripline geometry size is listed in Table 1. The dipole characteristic impedance was tuned to 50 Ohm.

Table 1: Geometrical Size of the Striplines

	30cm type	15cm type	note
Name	FB stripline	tune stripline	
L	30 cm	15 cm	electrode length
R	38mm	38mm	chamber radius
d	11.9mm	8.3mm	distance from plate to chamber
t	2mm	2mm	plate thickness
θ	90 deg	60 deg	plate opening
N	2	4	number of electrode
Z_dipole	50.0 Ohm	50.2 Ohm	or Z_odd
Z_sum	60.7 Ohm	65.2 Ohm	or Z_even
$R_\perp$	18.5 kOhm	8.3 kOhm	shunt impedance at low frequency

SHUNT IMPEDANCE

As shown in Eq (3), shunt impedance can be estimated once the geometry is determined. By integrating the electric and magnetic field along the beam trajectory, shunt impedance can be calculated from numerical simulation. Figure 2 shows an example of electric and magnetic field along the beam axis for different exciting frequency, with 1W of power added on the port.

To include the transient effect, the shunt impedance was numerically calculated using the following equations. Result at low frequency is listed in Table 1, which is close to the value from Eq. (3).
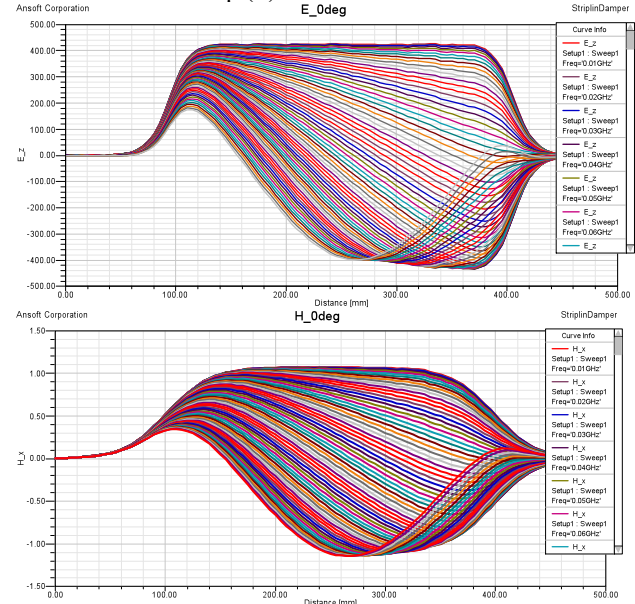

Figure 2: Electric and magnetic field along the beam path (1W, 0-deg, 10MHz to 700MHz).

$$V_E = \sqrt{\left[\int E(0\deg)\right] + \left[\int E(90\deg)\right]}$$
$$V_B = c\sqrt{\left[\int B(0\deg)\right] + \left[\int B(90\deg)\right]}$$
$$V_{EB} = V_E + V_B$$
$$R_\perp = \frac{V_{EB}^2}{2P}$$

(5)

S-parameters have been checked. S11-parameter of the feeding port is below -40dB till 200MHz, which will guarantee minimum reflection back to the high power amplifier. However, the simulation doesn't include the impedance mis-match of the feedthrough. Beam induced high frequency signal may damage the power amplifier. A high power low-pass filter will be added to protect it.

Transverse field uniformity is a concern in case the beam has large oscillation. We shifted the integration line and determined the transverse field uniformity. The variation is <5% with offset as large as 10mm.

BEAM IMPEDANCE

Normal chamber profile of the NSLS2 storage ring is elliptical-like with semi-major and minor axes of 38mm *

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Tech 05: Beam Feedback Systems (hardware)

12.5mm (H*V). Different geometries have been evaluated and it has been found it's difficult to design the horizontal kicker with required shunt impedance. The current design has all the striplines built in a round chamber of radius 38mm. This approach is convenient and cost efficient. However, two tapers are needed on the end of stripline to match to the regular chamber profile. Beam impedance from the taper and stripline body itself is an important design issue.

Several methods have been used to evaluate the beam impedance of the designed structure. Based on impedance wire measurement method [4], a thin wire was added in the HFSS model, see Figure 3. By calculating the S-parameters between ports, longitudinal beam impedance and transfer impedance can be derived from Equation (6).
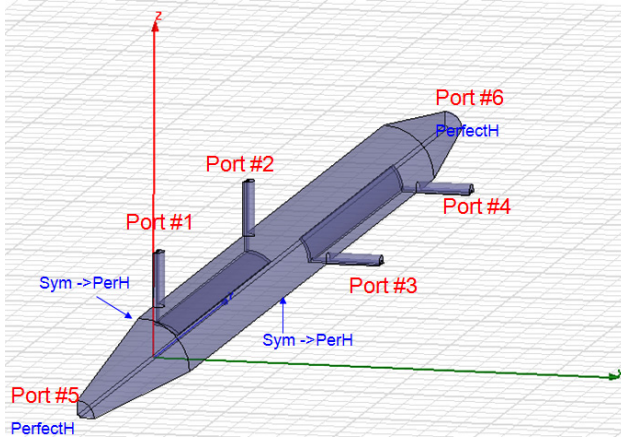

Figure 3: Wire method beam impedance model

$$Z\_beam = 2Z_{c\_port5}(\frac{1}{S_{56}} - 1)$$

$$Z\_trans, i = \frac{S_{5,i}}{S_{5,6}}\sqrt{Z_{c,i}Z_{c\_port5}}$$

(6)

where *i= 1,2,3,4* are the stripline input/output ports.

The wire method results matched well with the Gdfidl calculation up to 3GHz. At higher frequency, the wire method cannot be trusted since more than TEM modes exist. Gdfidl simulation shows no resonant peaks for longitudinal impedance below 20GHz. Figure 4 shows the HFSS simulated results of transfer impedance and longitudinal beam impedance.

Transverse beam impedance was simulated using double wire in the structure. The maximum value is around 12 kOhm/m, which is close to the Gdfidl result and acceptable. Investigation still going on to check the resonant modes which might contribute from the tapers.

SUMMARY

Four stripline kickers have been designed for NSLS2 storage ring. Two long striplines will be used for transverse bunch-by-bunch feedback system. Two short striplines will be used as tune excitation or signal pickups. Sufficient shunt impedance has been achieved, which is

essential to get the damping rate of 200 μs. Beam impedance of the striplines and tapers has been investigated. The results from wire method and Gdfidl match well at low frequency. Longitudinal beam impedance is within acceptable range. Transverse resonant modes need more simulations. The author thanks Dr. Makoto Tobiyama from KEK for his help, thanks NSLS2 RF group for the use of HFSS.
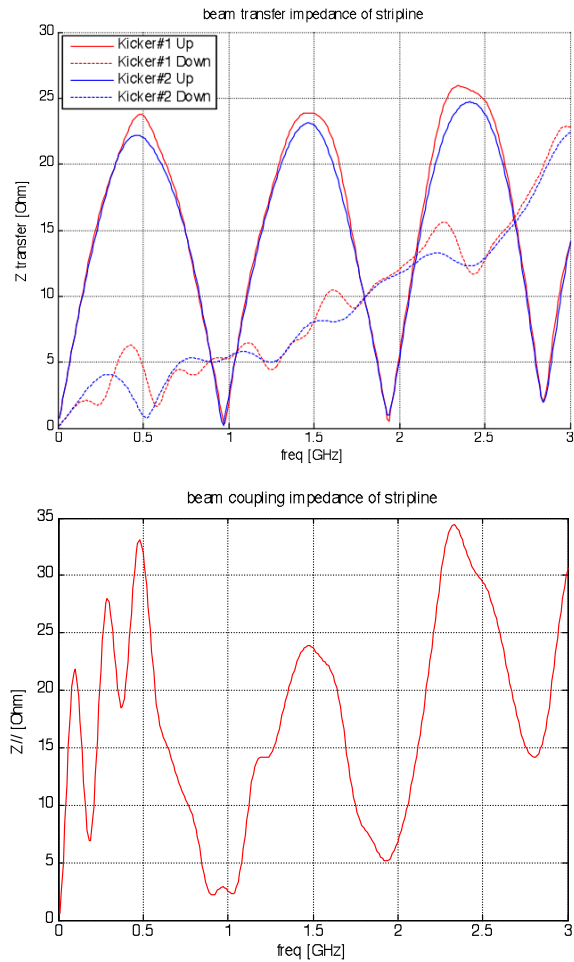

Figure 4, Result of short stripline kicker with tapers: transfer impedance (upper) and longitudinal impedance (bottom).

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