DEVELOPMENT OF A HORIZONTAL DRIVE STRIPLINE FOR THE APS TRANSVERSE FEEDBACK SYSTEM*

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Abstract

The APS bunch-by-bunch feedback system originally used two four-blade striplines, one for pickup and the other for both horizontal and vertical drive. A new two-blade stripline for horizontal driving was designed and installed in order to increase horizontal plane kick strength. `sddsoptimize`, a generic optimizer, was employed to optimize the geometry of the stripline in order to achieve both impedance matching and high shunt impedance. Beam-based measurements showed an increase in kick strength from the original 0.25 μrad to 0.78 μrad. The stripline has been in operation for more than one year. This report describes simulation, optimization, and the performance of the new stripline.

INTRODUCTION

The APS storage ring has four striplines that are designed for tune measurement and feedback applications: two of them are part of the tune measurement system, and the other two are used as a pick-up and kicker for the bunch-by-bunch feedback project [1]. Beam-based drive strength measurements and simulation studies have shown the kick strength in the horizontal plane is insufficient for the desired damping rate. A new 2-blade stripline was designed and installed in a high beta-x location in sector 35 of the storage ring. This report describes the simulation, optimization, and measurement of the new stripline. A description of the mechanical design and fabrication is presented elsewhere [2].

OPTIMIZATION OF GEOMETRY

To simplify the modeling process only 2-D simulations were performed. Field and impedance of the stripline are calculated with the program `estat` [3], and `sddsoptimize` [4], a generic optimizer, is used to search for the best solution for both impedance matching and higher deflecting field. After optimization we used Opera-2d [5] to verify with smaller mesh size.

The stripline body consists of two elliptical arcs and two circular arcs. The elliptical arcs match the walls of the APS vacuum chamber. The inner surface of the blades also conforms with the vacuum chamber inner surface. Figure 1 shows the parametrization for the simulation. A cross section of the stripline is defined by the long and short axes a and b of the ellipse, the center offset x_c of the circular arcs, the radius of the circle r, the half angle span of the circle β, the half angle span of the blades α, and the thickness of the blades d.

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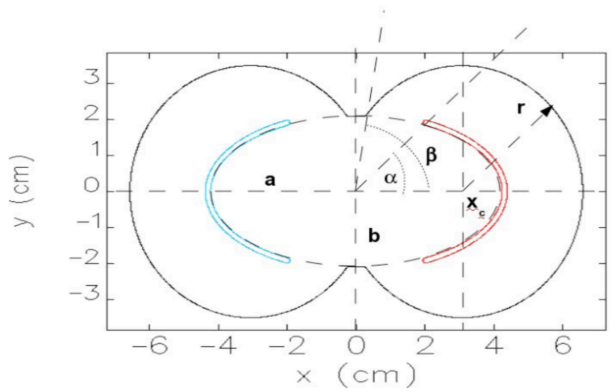

Figure 1: Parametrization of the stripline geometry. The dotted ellipse marks the inner surface of the adjacent vacuum chamber of the storage ring.

Figure 2 is a plot of one simulation run. Optimization involves examination of the parameters, setting boundary conditions, and removing any unnecessary constraints. Because of the conflicting requirement of impedance matching and field strength maximization, optimization process terminates after a certain number of iterations. The final solution was a compromise.

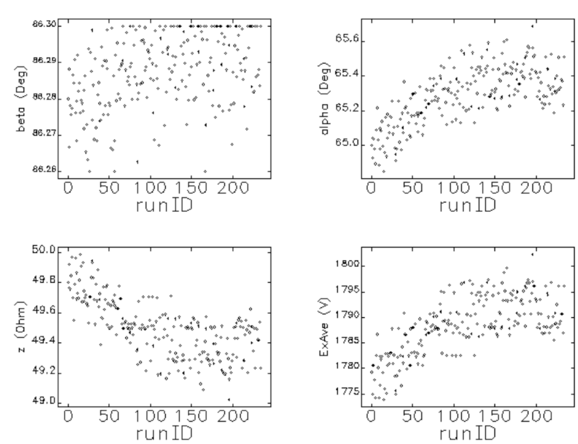

Figure 2: Plots of an optimization run.

The kicking angle produced by a transverse stripline is calculated with the following equation [6]:

$$k_{xy} = \frac{2\,e\,E_{xy}\,L}{E_0} \times sinc\left(2\pi \frac{L}{\lambda}\right) \approx \frac{2\,e\,E_{xy}\,L}{E_0} \quad .$$

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The approximation applies to the low-frequency drive. For the transverse feedback system the wavelength for the drive signal is about three times the length of the stripline. For a drive power of 500-Watt per blade, the kick strength derived from simulated result is 0.78 μrad. The measured kick angle is within measurement accuracy.

MATCHING OF BOTH DIFFERENTIAL AND COMMON-MODE IMPEDANCE

For transverse feedback applications the two blades are driven in differential mode. Therefore the differential impedance must match the 50-Ohm impedance of the amplifiers. However, when considering HOM coupled-bunch modes we must also consider common-mode impedance. When common-mode impedance matches the load impedance, maximum amount of power is coupled to the load and the modes are suppressed. For a 2-blade geometry, due to the unavoidable coupling between the two blades, it is not possible to match both common-mode and differential-mode impedance. However, some mismatch of common-mode impedance can be tolerated as long as a large portion of the mode power is coupled out to the loads. We set a goal of ±0.5 Ohm mismatch on the differential impedance while relaxing the requirement for the common mode to ±5 Ohm. Another concern is the vertical deflecting HOM. It is possible that beam can drive vertical modes. The 2-blade design does not have load coupling of vertical modes. We believe this can be remedied by steering the beam to the vertical center of the stripline.

HOM modes were simulated with GDFIDL. With a stainless steel body and smooth transition surfaces, the couple-bunch impedance is acceptable.

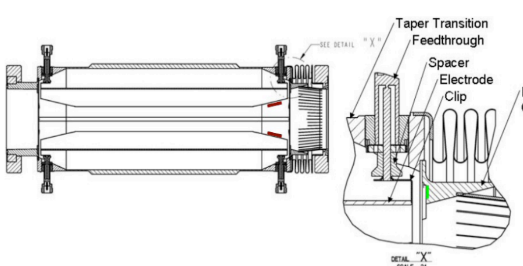

Figure 3: Left: side view of the stripline main body and the transitions. Red marks show the location on the blades where a wire is welded for impedance tuning at the transition. Right: the impedance clip that attaches the blade to feedthrough. A spacer is added between the clip and the feedthrough body to improve the matching there. The green mark shows the impedance trimming area on the end cover.

COMPENSATION FOR 3-D EFFECT

At both ends of the stripline the impedance calculated with the 2-D model no longer holds. This is especially true at the interface between the blades and the feedthroughs. In order to compensate for the 3-D effect, a tapered transition section is designed at both ends, as shown in Figure 3. 2-D model is applied to several cross sections to maintain impedance matching. An impedance matching clip, also shown in Figure 3, is used to attach the blades to the inner conductor of the feedthrough. By trimming the width of the clip and the gap between the clip and the end-wall, the local impedance can be adjusted empirically. Figure 4 shows a photo of the stripline assembly before installation.

Figure 4: The stripline assemby before installation.

STRIPLINE IMPEDANCE MEASUREMENT AND TUNING

Measurement and impedance matching were performed at each stage of assembly process. We used an Agilent 86100C time domain reflectometer (TDR) to measure the impedance of each blade. S-parameters were also measured with a network analyzer. Impedance matching is adjusted by adding spacers or trimming off some material.

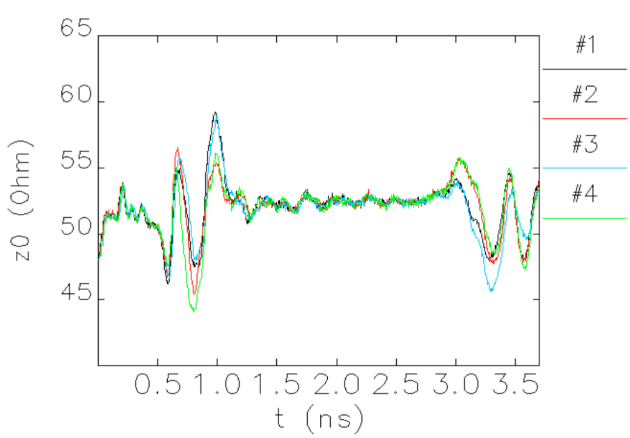

Figure 5: Impedance measurement result after final tuning.

Mismatches were identified at three places: (1) at a gap between the clip attachment point and the feedthrough, (2) at the clip interface to the stripline blade, and (3) at the tapered transition section of the blades. These were corrected by adding a spacer, trimming the clips width

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and inner surface of end-cover, and by welding stainless pieces to the blade edge. After tuning, impedance of both blades are within 50±5 Ohm.

Figure 5 shows the final TDR measurement results. Most of the mismatched areas are within 0.15 cm. In comparison, the wavelength of the operating frequency is longer than 1.2 m. The effect caused by the mismatch is insignificant.

KICK STRENGTH MEASUREMENT WITH BEAM

We performed a beam test of the stripline. Kick strength is measurement with the orbit bump method. Using the feedback processor, a pulse train is generated and applied to the amplifiers. The signal is synchronized with the storage ring revolution and the bunches receive a DC kick proportional to the pulse amplitude. A special orbit correction configuration is set up that uses two horizontal correctors to form a closed bump with the stripline kick. The polarity of the waveform is toggled at 10-second periods. The amplitude of the kick is scanned from zero to its maximum value.

`ExperimentDesigner` [7] is used to control the scan and record data. Figure 6 shows a plot of the data.

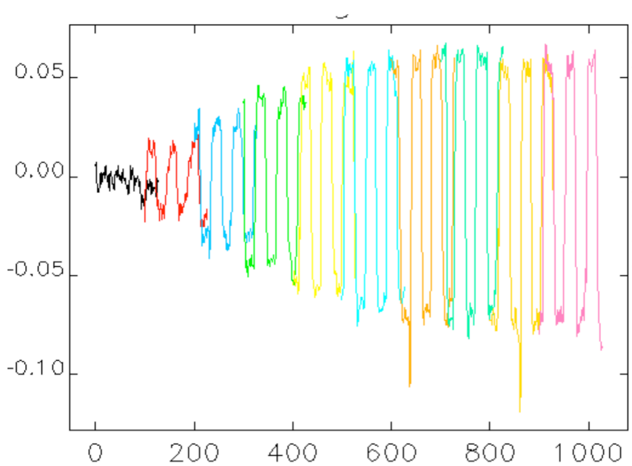

Figure 6: Plot of kick strength measurement. The x-axis is the sample number and the y-axis is the beam position in ADC counts.

The kick angle is calculated with the following:

$$k=-k_1\sqrt{\frac{\beta_1}{\beta_k}}\frac{\sin\psi_{12}}{\sin\psi_{k2}}=k_2\sqrt{\frac{\beta_2}{\beta_k}}\frac{\sin\psi_{12}}{\sin\psi_{k1}} \quad ,$$

where k_1 and k_2 are the kick angles of the upstream and downstream correctors, k is the kick angle of the stripline; β_1, β_2 and β_k are beta functions at the correctors and the stripline; and ψ_{12}, ψ_{k2}, and ψ_{k1} are the betatron phase advances between the correctors and the stripline. We measured 0.78 μrad with a drive power of 500 Watt on each blade.

The stripline has been in operation for close to two years. We did not observe any instabilities due to the stripline. A close-loop test of the bunch-by-bunch feedback system shows a much improved performance of the horizontal loop with a measured damping time of 0.1 to 0.2 ms.

CONCLUSIONS

We successfully developed and installed a horizontal stripline for the transverse feedback system. A beam test shows the agreement of measured kick strength with simulation and improved close-loop performance of the horizontal feedback loop. The 2-D simulation and optimization methods are both efficient and adequate for stripline design. The procedures and methods we employed in impedance measurement and tuning have worked well and insured good quality.

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