

BENCH MEASUREMENTS AND BEAM TESTS OF A PROTOTYPE STRIPLINE KICKER FOR SWAP-OUT INJECTION IN THE ALS-U*

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Abstract

The ALS upgrade to a diffraction-limited light source (ALS-U Project) relies on a swap-out injection scheme, where the circulating current is maintained constant by injecting on-axis fresh bunch trains replacing old trains, which are simultaneously extracted.

The realization of a stripline kicker to perform such an operation presents several challenges in terms of optimal matching to the pulser, contributions to the beam coupling impedance, and dissipation of the power deposited by the stored beam.

To test our design choices for the ALS-U kicker, we have built and installed on the ALS a test kicker with characteristics similar to the design for the ALS-U, as the more challenging aspects of the project are concerned. In particular, while the small distance between stripline electrodes reduces the required pulser voltage, the extreme proximity of the circulating beam requires a careful evaluation of the interaction between beam and kicker.

In this paper we present the measurement techniques used to improve the alignment of the stripline electrodes during assembly and monitor their status after installation on the ALS.

INTRODUCTION

A fast kicker for swap-out injection is one of the key enabling technologies in the ALS-U Project [1]. The main parameters of this kicker have been discussed in [2]. The tapered stripline solution adopted, powered by an inductive adder fast pulser presents several challenges. The pulse, which extracts a depleted bunch train and simultaneously injects fresh one, is characterized by a voltage close to 6 kV and fast rise and fall times, which allow other trains separated by a 10 ns long gap to continue circulating unperturbed. The kicker electrodes have to be placed in a vacuum chamber of a diameter around 10 mm and, therefore, necessarily in close proximity of the circulating beam. In such a situation it is paramount to minimize the kicker's beam coupling impedance, not only to limit any effects on the circulating beam, but also to reduce as much as possible the beam power coupled into the stripline electrodes, which have limited power dissipation capabilities. Furthermore, excellent impedance matching along the entire structure is required to avoid any reflections that could slow rise or fall time. To validate our design and technological solutions a test kicker has been installed and operated on the current ALS as reported in [3].

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In this paper we focus on the challenges in the fabrication and commissioning of the stripline kicker and on the bench and beam-based RF measurements that helped us in the process.

THE ALS TEST KICKER

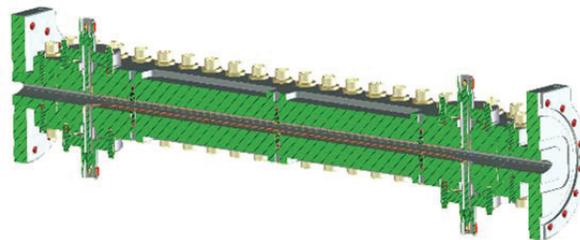


Figure 1: ALS test kicker longitudinal cross-section.

The ALS test kicker (Fig. 1) consists of a pair of 50 cm long tapered striplines. Its most prominent feature is significantly reduced gap between electrodes, as small as 6 mm, and overall extremely compact vertical dimensions with the entire assembly fitting in a 14 mm high vacuum chamber (Fig. 2).

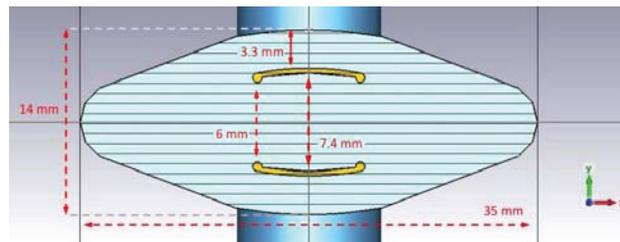


Figure 2: ALS test kicker transverse cross-section.

The striplines have been designed to present a $Z_{odd} = 50 \Omega$ characteristic impedance along their entire length when excited in their differential (odd) mode. The characteristic impedance of each electrode in their common (even) mode is $Z_{even} = 74 \Omega$. The first impedance is the relevant one from the point of view of the deflecting voltage waveform; any deviations from its nominal value generate reflections along the stripline, which may slow down its rise/fall time, or introduce ripples on its flat top, resulting in undesired oscillations of the injected bunches. The second impedance controls the interaction with the circulating beam. Deviations from a 50Ω value, matched to the stripline terminations, may increase the beam power deposited on the electrodes, perturb the bunches trajectory, and direct beam-induced power into the pulser. The presence of three MACOR® [4] supports on each stripline, visible in Fig. 1, locally alters the characteristic impedance generating reflections at their locations, in

addition to any mismatches created by imperfect stripline alignment and frequency performance of the feedthroughs.

STRIPLINE ALIGNMENT BY TDR MEASUREMENTS

More traditional stripline kickers, with their larger transverse dimensions, are less sensitive to the exact positioning of the electrodes inside the vacuum chamber. Our smaller dimensions increase the mechanical precision requirements, as it will be shown next. Single-ended TDR measurements on the open kicker during assembly were essential in achieving the desired precision. During such measurements the vacuum chamber is opened along its horizontal midplane in order to be able to install the electrodes. Under this condition the TDR signal driven into a feedthrough in good approximation excites only the even mode and a direct measurement of Z_{even} is possible.

After the kicker has been fully assembled, instead, it can be demonstrated that the TDR measurement on one stripline, while the other is left unterminated, excites in equal amount the even and the odd modes and the average $(Z_{even} + Z_{odd})/2$ is obtained as the measurement result. This measurement mode is of course the only one possible when monitoring deformations and changes in striplines position after the kicker has been installed on the ALS.

Analytical Model

In order to interpret the results of our measurements we developed a simple analytical model, which relates the characteristic impedances measured to vertical displacements of the striplines from their nominal positions shown in Fig. 2.

As discussed earlier, the striplines support propagation of two different TEM modes designated as *even* and *odd*.

In general, it is well known that the characteristic impedance of a TEM mode can be written as

$$Z_{char} = \sqrt{\frac{L}{C}} \quad (1)$$

where L is the stripline inductance, which can be assumed constant for rigid translations of the electrode inside the vacuum chamber and C is its capacitance. For the even TEM this capacitance is between the stripline and the adjacent vacuum chamber wall and for the odd TEM it is the capacitance between the two striplines. Both capacitance can be approximated by a parallel plate capacitor having a surface S equal to the stripline surface and a distance between plate d with two different design values according to whether we refer to the even or the odd mode given by:

$$\begin{aligned} C_{even} &= \epsilon_0 \frac{S}{d_{even}} \\ C_{odd} &= \epsilon_0 \frac{S}{d_{odd}} \end{aligned} \quad (2)$$

The values of d_{even} and d_{odd} can be extracted from Fig. 2.

From Eqs. (1) and (2) it is easy to convince oneself that a vertical displacement Δy of a stripline modifies the characteristic impedances according to

$$\begin{aligned} Z_{even}(\Delta y) &= Z_{even}(0) \sqrt{1 + \frac{\Delta y}{d_{even}}} \\ Z_{odd}(\Delta y) &= Z_{odd}(0) \sqrt{1 - \frac{\Delta y}{d_{odd}}} \end{aligned} \quad (3)$$

where we consider positive values of Δy to correspond to displacements towards the center of the vacuum chamber.

From Eq. (3) one can readily appreciate that a displacement of about $90 \mu\text{m}$ changes Z_{even} by 1Ω , while it takes about $300 \mu\text{m}$ to cause an analogous change in Z_{odd} .

TDR Measurements

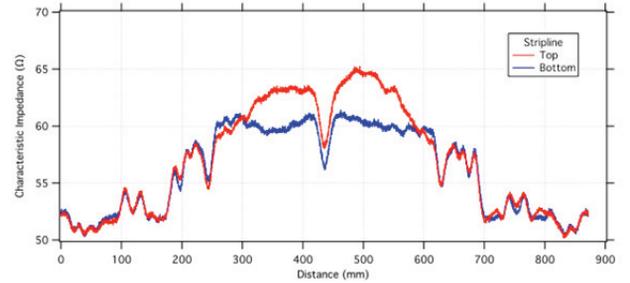


Figure 3: Measured characteristic impedance of top (red) and bottom (blue) stripline in the assembled kicker as a function of the location along the stripline.

Figure 3 shows the result of a TDR measurement after striplines were aligned and the kicker was fully assembled and installed on the ALS.

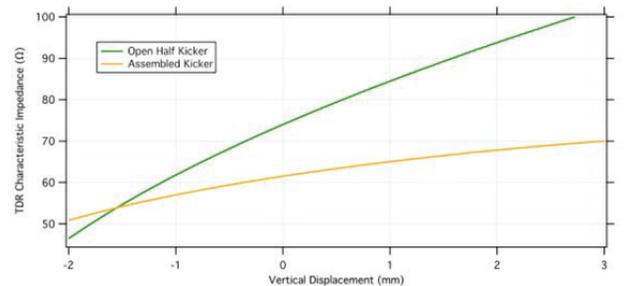


Figure 4: Analytically calculated characteristic impedance as a function of stripline vertical displacement. Kicker fully assembled (orange) and half kicker (green).

The double peaks around $s \approx 100 \text{ mm}$ and $s \approx 750 \text{ mm}$ correspond to the feedthroughs HN connectors. In between those one can notice the three large negative dips corresponding to the MACOR® supports.

The orange curves in Fig. 4 show the characteristic impedance measured by TDR for the assembled kicker analytically calculated according to Eqs. (3). Curves are calculated assuming $Z_{even}(0) = 74 \Omega$ and $Z_{odd}(0) = 49 \Omega$,

as obtained by analyzing the transverse profile in Fig. 2 with the CST [5] electromagnetic simulation code.

By comparing Figs. 3 and 4 it would seem that the bottom stripline is about 500 μm farther away from the kicker center than designed, while the top stripline is about the same quantity closer. Furthermore, the top stripline appears less flat. This behavior could be consistent with gravity's pull acting in opposite direction on the two striplines.

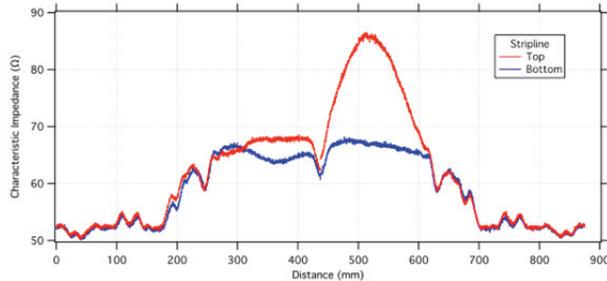


Figure 5: TDR measurements on the open kicker halves after kicker removal.

After almost a month of operations on the ALS, due to a mistake the full 500 mA beam was injected with the bunch lengthening harmonic system detuned. We estimate that the shorter bunches resulted in a fourfold increase in the beam power coupled to the striplines. Following beam based measurements shown in the next Section and observing a lifetime reduction consistent with a smaller aperture near the test kicker location, it was removed during a scheduled shutdown. TDR measurements were performed on the two halves separately, as shown in Fig. 5. It is worth mentioning that these measurements are performed with both striplines facing up, thus consistent with the bottom stripline position in the installed kicker. Comparing to the green curve in Fig. 4, we can see that the striplines now look all to be around 500 μm closer to the vacuum chamber except for one half of the top stripline, which should be bent up to about 2 mm closer to the beam path. Mechanical measurements confirmed this value for the electrode sagging.

BEAM BASED MEASUREMENTS

Due to beam-induced signals on the feedthroughs, it is not possible to use the TDR technique in the presence of circulating beam. On the other hand, it is also necessary to frequently monitor the striplines, especially as beam current is ramped up. Thermocouples installed on the kicker cannot react rapidly to electrodes deformations and, essentially, a fast rise of their reading would only give evidence of damage already incurred.

Measuring the beam induced signals themselves, captured on a 12.5 GHz bandwidth oscilloscope, proved very useful not only for assessing power levels, but also in providing a potentially continuous and fast-reacting monitoring of any changes in the electrode shape and in the conditions of electrical contacts and dielectric supports.

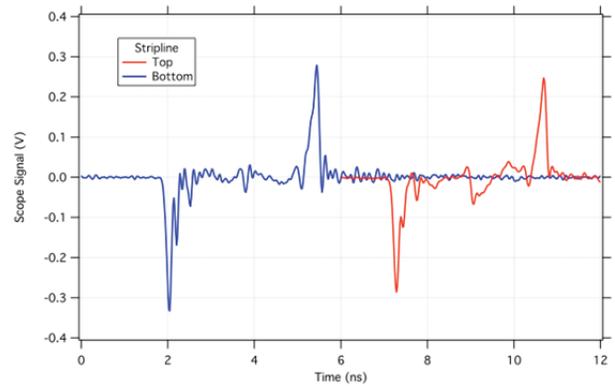


Figure 6: Beam induced signals on the kicker striplines (upstream ports).

Figure 6 shows an example of such signals collected from a single bunch on the upstream ports of the two striplines (artificially offset). Besides the classic inverted peaks separated by twice the stripline length, the reflections caused by the dielectric posts are prominent, at least on the bottom stripline trace. The top stripline, which we have seen was characterized by a worse impedance matching on the downstream half of the stripline, shows a wide hump, which became more prominent after the injection accident. While it is hard to extract quantitative information about stripline deformation from these signals, they are invaluable for real-time monitoring of the electrodes conditions. Especially in the commissioning phase by observing these signals and gradually increasing beam current it is possible to react much faster than with thermocouples and limit damage.

CONCLUSIONS

We have presented electromagnetic techniques used to assemble and monitor the ALS test kicker during operations. These techniques allowed us to improve the mechanical alignment of the electrodes in the stripline kicker with the narrowest gap ever installed in a storage ring and to promptly detect and diagnose a deformation in a portion of one of the striplines incurred due to an oversight during a beam injection.

Overall, our test kicker was successfully tested under ALS normal operating conditions, which are more challenging than what expected in the ALS-U due to shorter bunch lengths.

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