ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-WEPOPT028

DESIGN UPDATE ON THE HSR INJECTION KICKER FOR THE EIC*

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Abstract

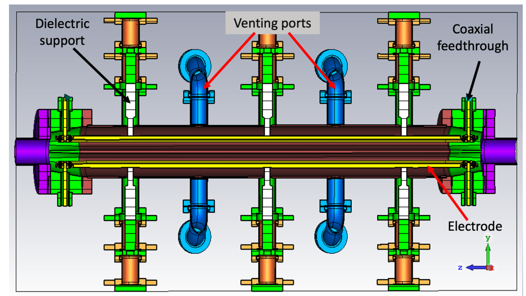
The Electron-Ion Collider (EIC), the next-generation nuclear science facility, is under the design at the Brookhaven National Laboratory. The present RHIC rings will be reconfigured as the Hadron Storage Ring (HSR) for the EIC. Design of a stripline injection kicker for the HSR for beams with the rigidity of ~ 81 T-m poses some technical challenges due to the expected shorter bunch spacing, heating due to higher peak current and the larger number of bunches, and the required higher pulsed voltage. Recently, we updated its mechanical design to optimize the characteristic and beam coupling impedances. In addition, we incorporated the impedance tuning capability by introducing the kicker aperture adjustment mechanism. Finally, we incorporated high voltage FID feedthroughs (FC26) to this kicker. This paper reports the design and optimization updates of the HSR injection kicker including the impedance tuning capability, optimization of both the characteristic and the beam coupling impedances, and finally the incorporation of a high voltage feedthrough design.

INTRODUCTION

The EIC [1–3], a next generation nuclear science facility, is under design and will be built at the Brookhaven National Laboratory. Design of a stripline injection kicker for the EIC Hadron Storage Ring poses some technical challenges due to expected shorter bunch spacing, heating due to higher peak current and larger number of bunches, and higher pulsed voltage required to operate this kicker. The basic information, design parameters, and initial geometry of this injection kicker can be found in [2, 4]. In summary, each kicker module is about a meter long structure having curved electrodes with a 59 mm (updated from 50 mm) gap between them. We may need up to 20 kicker modules to inject ~81 T-m hadron beam from the Alternating Gradient Synchroton (AGS) to the HSR. This article mainly focuses on the recent mechanical design updates and optimization of the kicker.

KICKER GEOMETRY UPDATE

The HSR kicker design is significantly matured, and almost ready for prototyping. Figure 1 compares its original design, [4] with the latest design. In comparison to its original design, we modified its cross-section to incorporate the impedance tuning capability. In addition, we reduced the total number of dielectric supports (from six to four) along with their length and width, and optimized the geometry of the tapered electrode to lower the impedance mismatch. Finally, we replaced the ideal coaxial feedthrough with a real design. We will present these mechanical design updates in the following sections.



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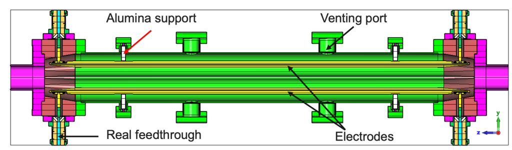

(b)

Figure 1: Top view of the EIC HSR horizontal kicker (a) in its initial geometry, and (b) with updated geometry.

IMPEDANCE TUNING CAPABILITY

The injection kicker is designed for a maximum of 25 ns full bunch length and the length of each stripline is ~3 ns. In order to produce a near constant amplitude kicking voltage along the entire length of a stripline, it is essential to minimize the characteristic impedance mismatch. The mismatch between the kicker and its connecting components such as: feedthroughs and cables introduces amplitude fluctuations due to the multiple power reflections between the feedthroughs and therefore causing beam emittance dilution. In practice, the actual impedance of a commercial 50 Ω cable or a feedthrough could vary from 48 Ω to 52 Ω. Based on this, we incorporated the impedance tuning capability, to properly match kicker's impedance with its connecting components, by adjusting the gap between the electrodes. The adjustment can be done by adding or removing shims on the alumina supports after the kicker is built.

To maintain the design requirement for the minimal gap between the electrodes of 50 mm, we ran CST [5] simulations to finalize the kicker's cross section. First, we increased the diameter of the kicker housing, at the fixed gap of 50 mm between the electrodes, until we get the maximum value of

* Work supported by Brookhaven Science Associates, LLC under Contract No. DE-SC0012704 with the U.S. Department of Energy
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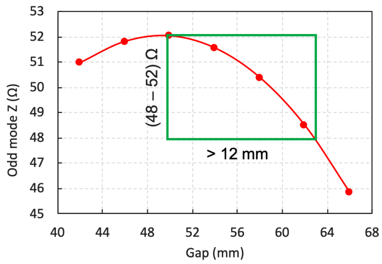


Figure 2: Plot showing the variation of the odd mode impedance with the gap between the electrodes.

the characteristic impedance, 52 Ω. The maximum value was found by increasing the diameter from ~102 mm to 106 mm. Then we varied the gap between the electrodes to find the minimum value of the impedance, 48 Ω, at the constant housing diameter of 106 mm. Figure 2 depicts the variation of this impedance with the electrodes gap, which indicates that we should tune each stripline electrode by up to 6 mm to achieve the desired impedance range of 48 Ω to 52 Ω. Here, we chose the kicker geometry having a standard value of characteristic impedance, 50 Ω, which demands 59 mm gap between the electrodes. All the optimization performed in the following sections are based on the 50 Ω geometry.

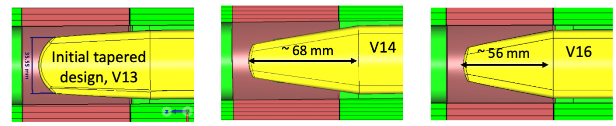
KICKER GEOMETRY OPTIMIZATION

The main goals for the kicker geometry optimization are to reduce both the characteristic impedance and the beam coupling impedance. We discuss both the characteristic and coupling impedances optimization in the subsequent subsections.

Optimization of the Characteristic Impedance

The characteristic impedance was optimized when the variation of impedance along the structure, generated by the Time Domain Reflection (TDR) simulations, was reduced by modifying kicker geometries. To perform the TDR simulations, we excite a Gaussian pulse having the frequency range of 0-2 GHz, as the maximum beam frequency (-20 dB) corresponds to minimum HSR bunch length of 60 mm is ~ 1.7 GHz. We optimized the characteristic impedance of the HSR kicker by introducing tapered electrode and adjusting its appropriate length, and tuning the dimension of dielectric (alumina) supports and kovar screws. We discuss these topics in the following sub-sections.

Tapered Electrodes and its Appropriate Length Incorporation of a tapered electrode lowers the impedance mismatch in the transition region between feedthrough and stripline electrode [4, 6, 7]. We further optimized tapered electrode's geometry by adjusting the tapered strength and tapered length. For this, we investigated three different tapered designs (yellow colored), shown in Fig. 3 (a), where the left one is the initial geometry (shallow tapering), middle one represents modified design with higher tapering strength,



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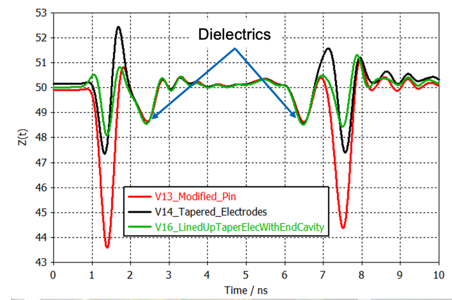


(b)

Figure 3: (a) Three different tapered electrode designs, and (b) TDR comparison corresponds to them.

and the right one is the optimized design. The first two designs have a tapered length of ~ 68 mm, while the optimized design has a tapered length of ~ 56 mm. In the initial design, the tapering strength of the electrode was limited by the contact geometry/button of the feedthrough central conductor to the electrode, which we modified later to enhance the tapering strength.

Figure 3 (b) depicts the corresponding TDR comparison for three geometries shown in the Fig. 3 (a), where the red, black and green curves correspond to the initial, modified and the optimized (Version 16) tapered designs. Simulation showed that increased tapering strength reduced the impedance mismatch by a factor of ~ 2 (black and green curves) in the transition regions between feedthrough and stripline electrode while comparing with the initial design (red curve). In addition, our study showed that the amplitude of overshooting observed in the modified design (black curve) was lowered in the optimized design (green curve) by aligning the start point of tapering for the electrode with the end cavity (reddish color geometry) as shown in the Fig. 3 (a), right.

Alumina Support The purposes of placing dielectric (alumina) supports on each stripline electrode are to minimize the deflection on the strip line due to its own weight, that ultimately helps to reduce impedance mismatch, and to maintain the stripline's alignment when replacing or adjusting the feedthroughs. The beam induced heating may generate stress on the stripline due to thermal expansion, which can be eliminated with a proper sliding support design on it. Stress analysis (using ANSYS), which corresponds to the electrode deformation, showed that eliminating the mid-support has little effect on the straightness of the strip line. Hence, two alumina supports, as shown in the 1 (b), are sufficient. Initially, we planned to use maccor as a di-

13th Int. Particle Acc. Conf. IPAC2022, Bangkok, Thailand JACoW Publishing
ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-WEPOPT028

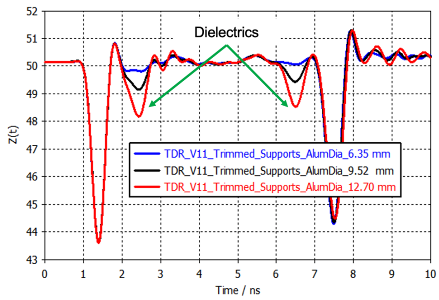


Figure 4: Impedance mismatch comparison with dielectric's dimension, where the red black, and blue curve respectively represent the diameter of 12.70 mm, 9.52 mm, and 6.35 mm.

electric which will be replaced with alumina because of its robustness while brazing with metals.

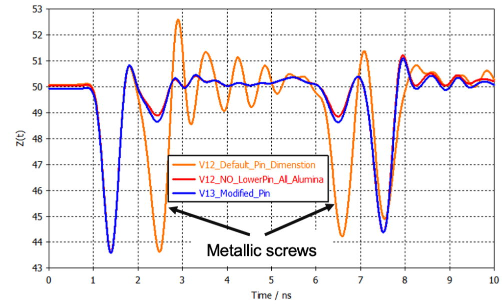
In addition, we reduced the diameter of alumina rod from its initial value of 12.70 mm to 9.52 mm to further lower down the impedance mismatch as shown in Fig. 4. In fact, 6.35 mm showed the lowest impedance mismatch but, this diameter is too small from mechanical perspective. Moreover, we reduce the height of the alumina rod from its initial value of 195 mm to 33 mm as CST simulations showed that height of the alumina has no impact on characteristic impedance.

Kovar Screw Initially, we believed that kovar screw does not introduce any impedance mismatch as long as it stays inside the alumina (to hold it), and hence we had treated the kovar metal as alumina in the simulation. Later, we found that these metallic screws perturb the boundary condition and introduce large impedance mismatch (the orange curve in the Fig. 5 (a)). Therefore, we reduced the length of the bottom screw from its initial value of 14.22 mm to 1.27 mm to minimize the observed impedance mismatch. Fig. 5 (b) compares the CAD models of the kovar screw's initial design (right), and optimized design (left). With the optimized design, the previously observed impedance mismatch is significantly reduced (dark blue curve in the Figure 5 (a)).

Optimization of the Coupling Impedance

For the coupling impedance optimization, we compared the wakefield and impedance produced by an ultra-relativistic beam having the bunch length of 60 mm by varying the kicker geometry slightly. First, we optimized the end-flange design, which was discussed in detail in our earlier paper [4]. Here, we investigated the possibility of lowering the wake-loss factor as stated in the recent injection kicker paper [8] by changing the tapering strength of the end-cavity.

Tapering of the End Cavity We studied the effect of the tapering strength of the end-cavity, the transition region between the beam pipe and electrodes housing on the loss factor. CST simulation showed a slightly lower wake-loss factor for shallow tapering, however we also observed overshootings (more impedance mismatch) in the TDR plot, and hence we adopted the initial design.



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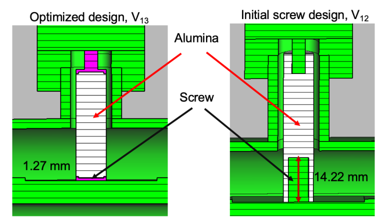

(b)

Figure 5: (a) Plot showing the comparison of the TDR plot for different kovar screw design. (b) CAD model showing the design of the kovar screw to hold the alumina support: initial design (right), and the optimized design (left).

INCORPORATION OF A REAL FEEDTHROUGH

Finally, we updated HSR kicker design by replacing ideal coaxial feedthroughs with real feedthroughs. We prepared a high voltage feedthrough model Fig. 6 (right) based on the commercial FID design Fig. 6 (left). More investigation on this feedthrough design is forthcoming.

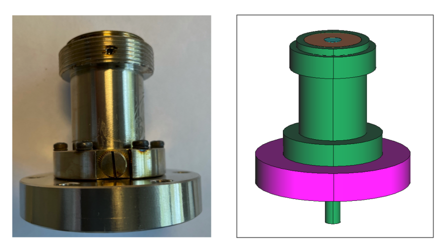

Figure 6: Picture of a FID feedthrough (left), and a reconstructed CST model of a FID feedthrough (right).

SUMMARY AND FUTURE WORK

The EIC HSR injection kicker design has advanced toward maturity. In this paper, we reported recent design updates and the optimization of the kicker design. Simulation of the peak surface electromagnetic field is ongoing. Future work will focus on the thermal simulation and optimization of the feedthrough design.

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