SIMULATION STUDIES OF A PROTOTYPE STRIPLINE KICKER FOR THE APS-MBA UPGRADE*

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Abstract

A prototype dual-blade stripline kicker for the APS multi-bend achromat (MBA) upgrade has been designed and developed. It was optimized with 3D CST Microwave Studio. The high voltage (HV) feedthrough and air-side connector were designed and optimized. The electromagnetic fields along the beam path, deflecting angle and high electric fields with their locations were calculated with 15 kV differential pulse voltage applied to the kicker blades through the feedthroughs. The beam impedance and power dissipation on different parts of the kicker and external loads were studied for a 48-bunch fill pattern. Our simulation results show that the prototype kicker with its HV feedthroughs meets the specified requirements. The results of TDR (time-domain reflectometer) test, high voltage pulse test and beam test of the prototype kicker assembly agreed with the simulations.

INTRODUCTION

A fast kicker is needed for swap-out injection in APS-MBA Upgrade [1-2]. The kicker assembly consists of the stripline kicker and high voltage feedthrough, as shown in Fig. 1.

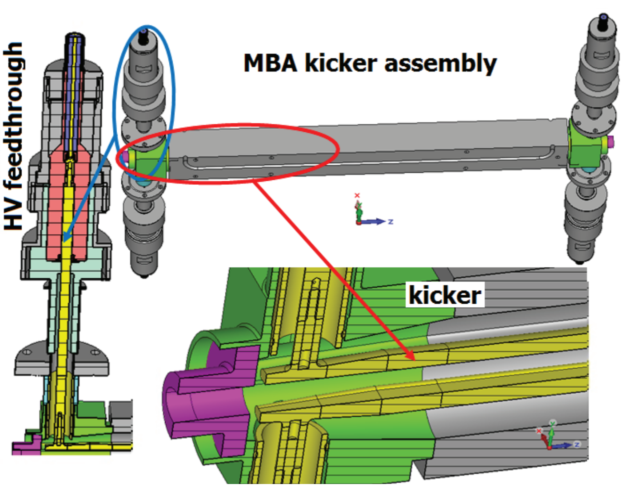

Figure 1: The MBA kicker assembly.

The stripline kicker and high voltage feedthrough with air-side connector need to be designed for impedance matching throughout the structure to achieve the maximum kicker strength, reduce local high voltage concentration, which can lead to breakdown, and minimize the beam impedance. The kicker and feedthrough with air-side connector were designed and optimized to match 50 Ω impedance. Then the electromagnetic fields, wake impedance, beam power loss and power dissipation on the metals and external loads were analysed.

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2D STRIPLINE KICKER MODEL

The main part geometry of the kicker was designed with a 2D modelling program [3]. It was optimized to match the differential impedance as close as possible to 50 Ω while allowing some mismatch in the common-mode impedance. "D" shaped blades were adopted to improve field uniformity in the good field region. The tapered sections were added to both ends of the kicker to improve impedance matching to the feedthroughs.

The optimized geometry is shown in Fig. 2.

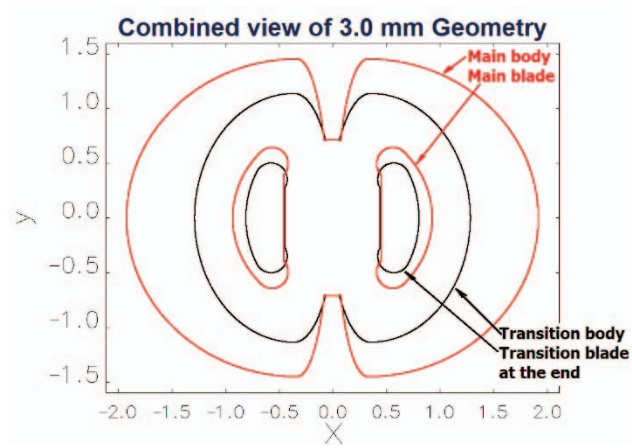

Figure 2: 2D modelling result geometry.

3D SIMUALATION OF THE KICKER

A 3D kicker model was developed based on 2D simulation results, as shown in Fig. 3, and CST Microwave (MWS) [4] was applied.

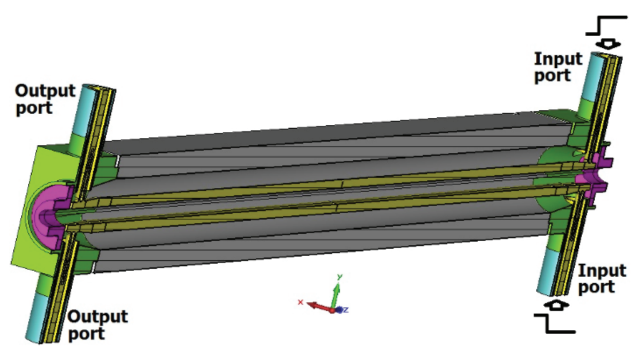

Figure 3: 3D prototype kicker model.

The 3D simulation verified the 2D results and further optimized the tapered part of the stripline kicker. The optimization of the tapered blades and body minimized the reflecting and improved the interface to the feedthrough.

The kicker differential and common-mode impedances were calculated and shown in Fig. 4. The optimized geometry gives a differential-mode impedance of 50 Ω with a common-mode impedance of 67 Ω in the main part of the kicker.

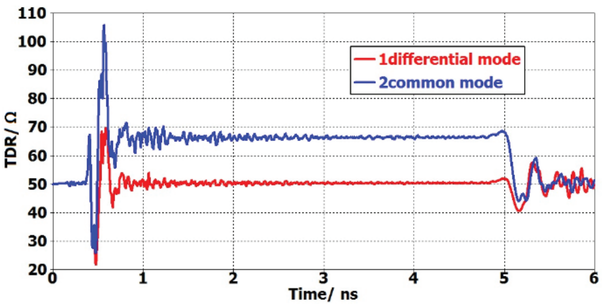

Figure 4: The differential and common-mode TDR simulation in the prototype kicker.

The longitudinal wake impedance is shown in Fig. 5. There is a resonance at 4.1 GHz. We may optimize the kicker further to remove or reduce this resonance in the future.

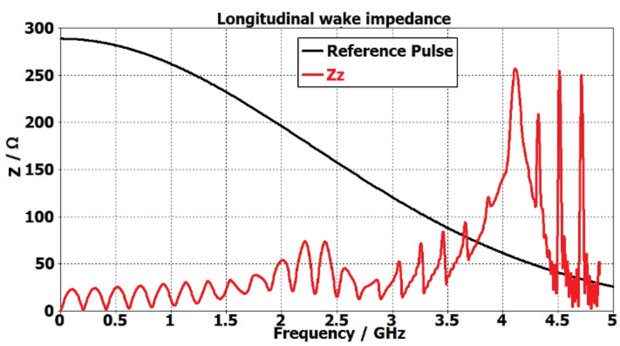

Figure 5: Longitudinal wake impedance of the prototype kicker.

THE DESIGN AND MEASUREMENT OF THE HIGH VOLTAGE FEEDTHROUGH WITH AIR-SIDE CONNECTOR

The feedthrough connecting the fast high voltage pulser and kicker requires ultrahigh vacuum, radiation resistance and voltage. A close to 50 Ω impedance is necessary for the pulser rise and fall time requirement. Due to lack of a suitable off-the-shelf feedthrough, we developed and optimized a high voltage feedthrough in collaborating with COSMOTEC. The TDR test and simulation results of the high voltage feedtrough with air-side connector agreed well, as shown in Fig. 6.

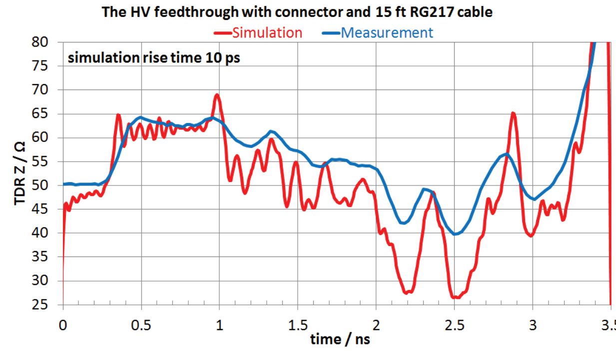

Figure 6: TDR comparison between the measurement and simulation of the HV feedthrough with air-side connector and RG217 cable.

THE END-TO-END SIMULATION THROUGH THE PROTOTYPE KICKER ASSEMBLY

The prototype kicker assembly, including of the kicker and HV feedthrough, was simulated for the impedances and electromagnetic fields.

The TDR simulation was performed for the prototype kicker assembly as shown in Fig. 1. The calculated differential and common-mode TDR are shown in Fig. 7.

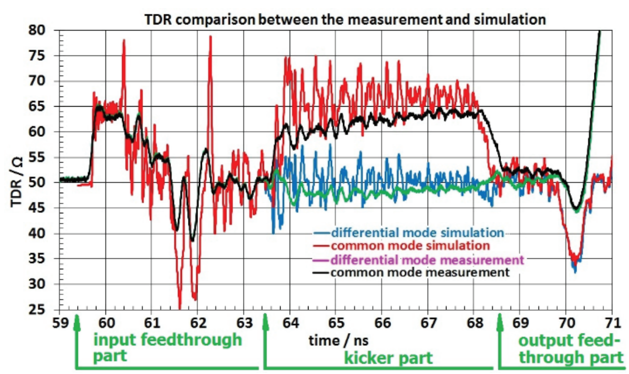

Figure 7: TDR comparison between the measurement and simulation of the prototype kicker assembly.

The electromagnetic fields were calculated along the beam path when a bunch passed the kicker, as shown in Fig. 8. The resulting deflecting angle is 0.79 mrad when the applied voltage is ±15 kV. The kicker strength is 1.10 mrad/m at beam energy of 6 GeV, which meets the 1 mrad/m kicker strength requirement.

In order to assess breakdown risk, we simulated electric field in the entire structure. The electric fields are highest at two areas, a 16.0 MV/m at the edge of the blade ends and a 15.4 MV/m at the center conductor of the feedthrough, as shown in Fig. 9. They are above our target value of 13 MV/m, which is based on DC or low frequency studies. Considering the actual pulse width of 20 ns or less, we think they are acceptable.

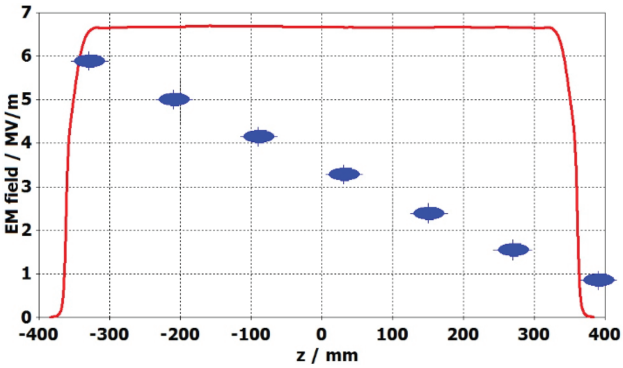

Figure 8: The calculated electromagnetic fields along the beam path and the bunch trace. Red: EM field amplitude. Blue: Gaussian bunch trace.

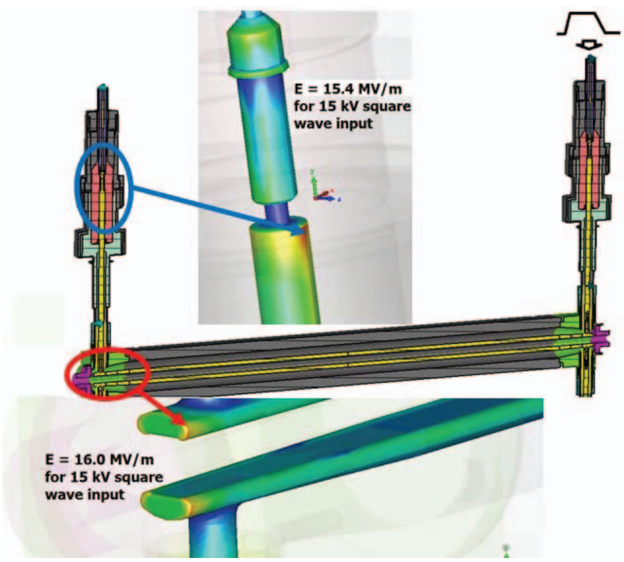

Figure 9: The simulated highest electric fields and their locations in the prototype kicker assembly.

THE BEAM POWER LOSS AND POWER DISSIPATION OF THE PROTOTYPE KICKER ASSEMBLY

We also simulated the beam power loss and power dissipation of the prototype kicker assembly, as shown in Fig. 10. When a Gaussian bunch, with a bunch length of 70 ps rms and charge of 15nC, passes the kicker assembly, the beam power loss is 211.7 W. The power dissipation on the metals is 43.4 W, which includes 5.9 W on the copper blades. The power coupled to the upstream and downstream ports are 60.6 W and 17.5 W, respectively. In an ideal stripline kicker, the beam induced power only goes to the upstream port. This 17.5 W represents the effect of impedance mismatch, which can be reduced by further optimization. Lower beam induced power at the downstream port protects the pulser.

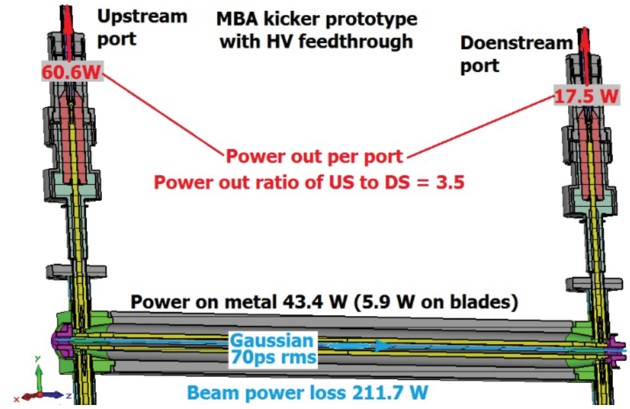

Figure 10: Simulated beam power loss and power dissipation on MBA prototype kicker assembly.

TDR TEST, HIGH VOLTAGE PULSE TEST AND BEAM TEST

The prototype kicker assembly was fabricated and tested recently [5]. Its differential and common-mode TDR was tested. The test and simulation results are compared and shown in Fig. 7. The differential and common-mode impedances of the kicker were measured 47 Ω and 63 Ω respectively in main kicker part.

There was no issue with high voltage breakdown at 15 kV pulse amplitude.

The kicker was installed in the beam dump transport line (BTX) and the beam test showed the deflecting angle 0.64 mrad for 7 GeV, or 0.75 mrad, scaled to 6 GeV, close to the simulated deflecting angle of 0.79 mrad for 6 GeV.

CONCLUSION

The stripline kicker, high voltage feedthroughs and air-side connector were optimized with 3D simulation. They were fabricated and tested. The TDR test, high voltage test, and beam test showed a good agreement with the simulations.

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