TRANSIENT STUDIES OF THE STRIPLINE KICKER FOR BEAM EXTRACTION FROM CLIC DAMPING RINGS

C. Belver-Aguilar, M.J. Barnes, CERN, Geneva, Switzerland

Abstract

Stripline kickers are generally assumed to have equal contributions from the electric and magnetic field to the total deflection angle, for ultra-relativistic beams. Hence parameters of the striplines, such as the characteristic impedance, the field homogeneity and the deflection angle are typically determined by simulating the striplines from an electrostatic perspective. However recent studies show that, when exciting the striplines with a trapezoidal current pulse, the magnetic field changes during the flat-top of the pulse, and this can have a significant effect upon the striplines performances. The transient solver of Opera2D has been used to study the magnetic field, for the striplines to be used for beam extraction from the CLIC Damping Rings (DRs), when exciting the electrodes with a pulse of 1 μs flat-top and 100 ns rise and fall times. The time dependence of the characteristic impedance, field homogeneity and deflection angle are presented in this paper. In addition, two solutions are proposed to improve the flatness of the magnitude of the magnetic field throughout the flat-top of the pulse, and the predicted results are reported.

STUDIES IN THE TIME DOMAIN

DRs for high energy e^+e^- colliders, such as CLIC, have a significant role for achieving high luminosity at the interaction point. Two RF baselines are considered for the CLIC DR operation: 1 GHz and 2 GHz RF systems. The injection and extraction process from the DRs will be carried out using one injection and one extraction system, respectively, in each ring, with only one pulse stored in the rings per cycle: this pulse contains either one single train of 156 bunches with 1 GHz RF structure, or two trains of 312 bunches with 2 GHz RF structure. For the extraction system, a pulse of 560 ns rise/fall time and 900 ns pulse flat-top is required for the 1 GHz baseline, whereas the 2 GHz RF system demands a pulse of 1 μs rise/fall time and 160 ns flat-top [1].

Inductive adders will be used to generate the pulses for the striplines for the CLIC DRs [2]. In order to limit the electrical and thermal stresses on the system, the goal is to achieve output current pulse rise and fall times of approximately 100 ns.

The deflecting field of the striplines has been previously studied considering only an electrostatic field [3] and an AC magnetic field [4]. Now, transient simulations with Opera2D [5] have been carried out, and a pulse of 100 ns rise and fall time and 1 μs flat-top has been considered (values close to the 1 GHz RF system goals). The prototype electrodes are made of aluminium Al6063, with an electrical conductivity $\sigma = 3.03 \times 10^7$ S/m. The magnetic field at the centre of the striplines aperture has been calculated and the results are shown in Fig. 1. For these simulations terminating resistors of 50 Ω are assumed, which results in a nominal current of ± 250 A with ± 12.5 kV driving voltage.

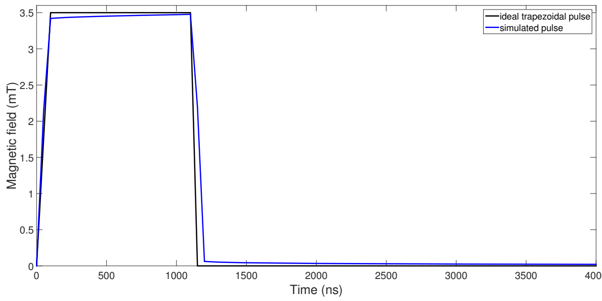

Figure 1: Magnetic field calculated with Opera2D (blue line), compared with an ideal trapezoidal current pulse (black line).

The odd mode characteristic impedance, field inhomogeneity and deflection angle have been studied when considering ideal trapezoidal voltage and current pulses. The characteristic impedance is calculated from inductance and capacitance: these quantities are derived from predicted stored magnetic and electrostatic energy, respectively. The odd mode characteristic impedance increases from 40.57 Ω at the beginning of the flat-top to 41.01 Ω at the end of the flat-top, corresponding to an increase of 1.1%. The field inhomogeneity at 1 mm radius, from the centre of the striplines aperture, increases from ±0.0028% to ±0.0112%, which is close to the maximum limit imposed by beam dynamics requirements (±0.01%). The total deflection angle increases from 1.3597 mrad to 1.3697 mrad, as shown in Fig. 2, which corresponds to an increase of 0.73%.

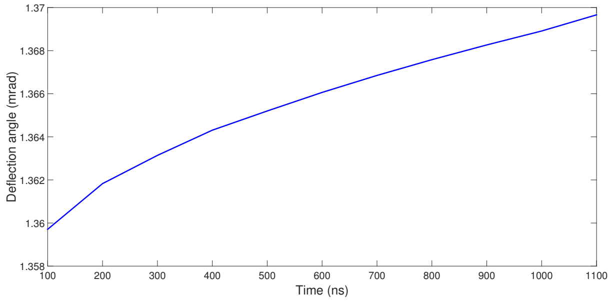

Figure 2: Total (sum of electric and magnetic) deflection angle, during the pulse flat-top.

The increase of the characteristic impedance and hence the increase of the magnetic field and deflection angle, during the pulse flat-top, is greater than specified. In an attempt to flatten the "flat-top" field two proposals are pre-

ISBN 978-3-95450-177-9

sented in the following: (1) using a thin silver coating on the electrodes, and (2) modulate the driving pulses to compensate for the variations in the field flat-top.

SILVER COATING

To improve the flatness of the deflection pulse, the electrodes could be coated by a thin layer of silver in order to increase the electrical conductivity. Opera2D does not presently permit a thin layer of silver to be modelled on top of the aluminium electrodes. Hence, to evaluate the influence of silver, the electrical conductivity of the electrodes has been changed to that of silver ($\sigma = 6.3 \times 10^7$ S/m). A comparison of the magnetic field, during the pulse flat-top, when considering solid aluminium or solid silver electrodes is shown in Fig. 3.

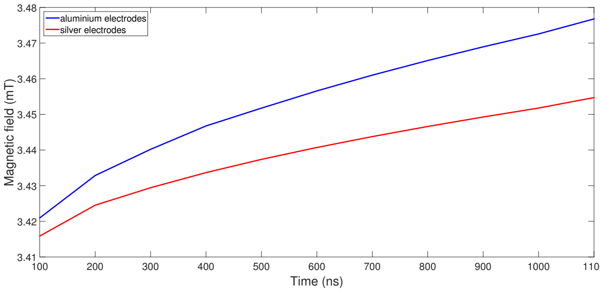

Figure 3: Flat-top magnetic field when considering electrodes made of aluminium (blue line) and silver (red line).

When modelling silver electrodes, the magnetic field at the beginning and at the end of the flat-top is 3.416 mT and 3.455 mT, respectively: hence the increase of the magnetic field during the pulse flat-top is reduced from 1.63% (aluminium electrodes) to 1.14%. Also the field inhomogeneity improves, with a maximum value at the end of the flat-top of ±0.0078%. In addition, the odd mode characteristic impedance ranges from 40.52 Ω to 40.84 Ω during the pulse flat-top: hence the increase of the odd mode characteristic impedance is reduced from 1.1 % (aluminium electrodes) to 0.8%. The total deflection angle, for silver electrodes, changes from 1.359 mrad to 1.366 mrad during the pulse flat-top, as shown in Fig. 4, which corresponds to an increase of 0.5%.

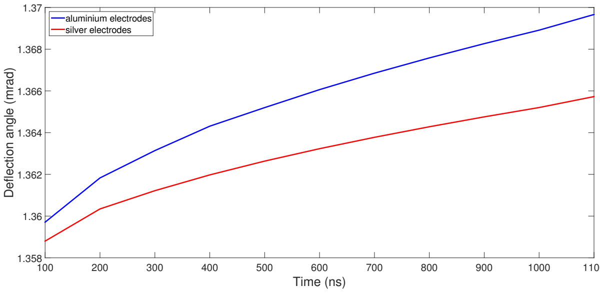

Figure 4: Flat-top deflection angle when considering electrodes made of aluminium (blue line) and silver (red line).

PULSE MODULATION

The variation of the magnetic field, and therefore the total field during the pulse flat-top, can theoretically be compensated, as shown in Fig. 5, by modulating the driving current/voltage, of the electrodes, during the flat-top of the pulse.

The inductive adder has a modulation layer and hence this layer could be used to achieve the required waveforms. The "ideal" current and voltage waveforms have been calculated by considering the total compensation required to achieve a flat deflection angle pulse. To verify the derived waveforms, these are modelled in Opera2D as the driving current and voltage waveforms, assuming ideal terminating resistors on the output of the electrodes.

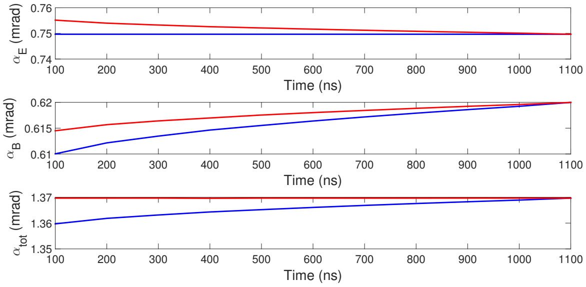

Figure 5: Flat-top electrostatic, magnetic and total deflection angle before modulation (blue line) and after modulation (red line), for aluminium electrodes and considering 50 Ω terminating resistors.

Modelling the derived, modulated, waveform in Opera2D, the increase of the total deflection angle during the flat-top is reduced by more than a factor 100: from 0.73% to 0.006%. The modulation is such as to appropriately increase the magnitude of the start of the flat-top driving voltage/current: the flat-top then decreases in value until it is equal to the original value at the end of the flat-top: Fig. 6 shows a zoom of the required "flat-top" of the voltage/current, for ideal 50 Ω terminating resistors.

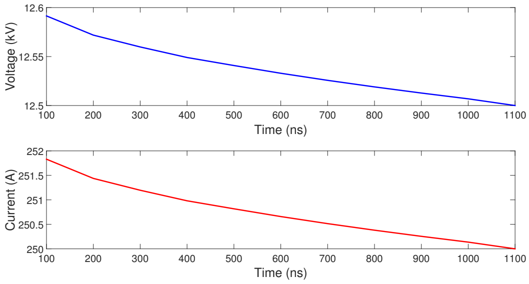

Figure 6: "Flat-top" voltage (blue) and current (red), in order to obtain a “constant” deflecting field (50 Ω terminators).

The voltage and current pulses shown in Fig. 6 have been specified as the flat-top of the driving waveforms in

ISBN 978-3-95450-177-9

Opera2D electrostatic and transient magnetic analyses, respectively, to predict the deflection angle shown in Fig. 5: these waveforms assume ideal 50 Ω terminating resistors. When considering 40.5 Ω terminating resistors, the ideal driving waveforms are shown in Fig. 7.

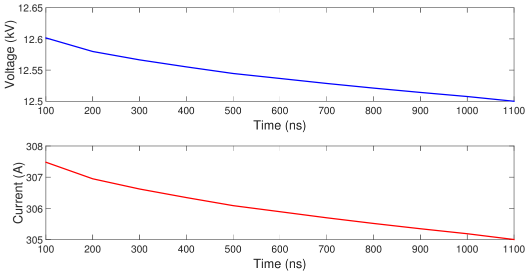

Figure 7: "Flat-top" voltage (blue) and current (red), in order to obtain a "constant" deflecting field (40.5 Ω terminators).

The deflection angles, following the current and voltage pulse modulation, have been calculated: results are shown in Fig. 8.

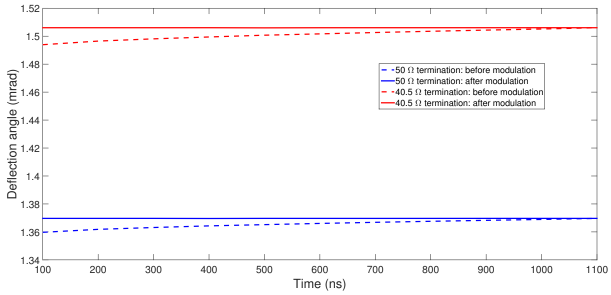

Figure 8: Total deflection angle after voltage/current modulation, for 50 Ω terminating resistors (blue line) and 40.5 Ω terminating resistors (red line).

With 50 Ω terminating resistors the total deflection angle, in the present configuration (aluminium plates, unmodulated waveform), increases during the flat-top from 1.3597 mrad to 1.3697 mrad, which corresponds to an increase of 0.73%. When modulating the pulse current, the predicted stability of the deflection angle is within specification: however the total deflection angle is still 8.7% less than the required 1.5 mrad. Considering 40.5 Ω terminating resistors and modulating the pulse current, the stability of the total flat-top deflection angle is within specification. In addition, the deflection angle of 1.5 mrad is as required for the extraction kicker from the CLIC DRs.

SUMMARY OF THE RESULTS

Driving the striplines with trapezoidal waveforms and considering the electrodes to have an electrical conductivity equal to that of silver, rather than aluminium, improves the flat-top stability of the total deflection angle from 0.73% to 0.52%: however this is still outside the specification of ±0.01%. Appropriately modulating the driving waveforms theoretically results in the required flatness of the total deflection angle.

Table 1: Comparison of the Relative Variation of the Deflection Angle (α), Field Homogeneity (FH) and Odd Mode Characteristic Impedance (Z_{odd}), when Considering Silver Coating and Pulse Modulation

	Al6063 electrodes, (unmodulated pulse)	Silver electrodes, (unmodulated pulse)	Al6063 electrodes, (modulated pulse)
$\Delta\alpha$	0.73%	0.52%	$\ll$ 0.01%
FH	±0.0112%	±0.0078%	±0.0112%
ΔZ_{odd}	1.1%	0.8%	1.1%

CONCLUSIONS

Transient simulations have been carried out in order to consider the effects of 100 ns rise/fall time driving pulses, with a flat-top of 1 μs, upon the predicted characteristic impedance and hence the total deflection angle. The magnetic field, and therefore the magnetic field contribution to the deflection angle is not constant during the flat-top of a trapezoidal current pulse. Two means of improving the flatness of the total deflection angle have been proposed: coating the electrodes with silver or modulating the pulse created by the inductive adder - silver electrodes give the required field homogeneity but do not result in the flat-top stability specifications being met. From the studies, the required output pulse shape from the inductive adder, to compensate the time dependence of the impedance of the striplines, has been derived for both 50 Ω and 40.5 Ω terminating resistors: these waveforms theoretically give the required flat-top of the total deflection pulses. However the field homogeneity is close to, but slightly outside, the specification of ±0.01%. Termination resistors of 40.5 Ω provide the required deflection angle of 1.5 mrad, with a 12.5 kV driving voltage: to achieve the 1.5 mrad with 50 Ω terminating resistors requires that the nominal driving voltage is increased to 13.7 kV. With 40.5 Ω terminating resistors it is not necessary to increase the nominal drive voltage, except for modulation. PSpice simulations to study reflections with 40.5 Ω and 50 Ω terminating resistors will be carried out next.

REFERENCES

[1] CLIC Conceptual Design Report (CDR), Volume 1, www.project-clic-cdr.web.cern.ch/project-clic-cdr/CDR-Volume1.pdf, 2012.

[2] J. Holma, M.J. Barnes, L. Ducimitière, "Measurements on Magnetic Cores for Inductive Adders with Ultra-flat Output Pulses for CLIC DR Kickers", *Proceedings of IPAC 2016*, THPMW032.

[3] C. Belver-Aguilar, “Development of Stripline Kickers for Low Emittance Rings: Application to the Beam Extraction Kicker for CLIC Damping Rings”, PhD thesis, 2015.

[4] C. Belver-Aguilar, M.J. Barnes, L. Ducimitière, “Review on the Effects of Characteristic Impedance Mismatching in a Stripline Kicker”, *Proceedings of IPAC 2016,* THPMW034.

[5] Opera2D User Guide, Version 17R1. Cobham Technical Services, Vector Fields Software, Oxfordshire, 2014.

ISBN 978-3-95450-177-9