FINAL CROSS SECTION DESIGN OF THE STRIPLINE KICKER FOR THE CLIC DAMPING RINGS*

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Abstract

The CLIC design relies on the presence of Pre-Damping Rings (PDR) and Damping Rings (DR) to achieve, through synchrotron radiation, the very low emittance needed to fulfill the luminosity requirements. Kicker systems are required to inject and extract the beam from the Pre-Damping and Damping Rings. In order to achieve both low beam coupling impedance and reasonable broadband impedance matching to the electrical circuit, striplines have been chosen for the kicker elements. In this paper the final design for the DR kicker is presented, including an optimization of the geometric parameters to achieve the requirements for both characteristic impedance and field homogeneity. In addition, a sensitivity analysis of characteristic impedance and field homogeneity to geometric parameters is reported.

INTRODUCTION

The extraction kicker system for the CLIC DR will extract, horizontally, a beam with a peak current of 110 A and bunch length of $\sigma_z = 6$ ps, for the 1 GHz baseline, which corresponds to 1 ns spacing between bunches. In the case of the 2 GHz baseline, i.e. 0.5 ns bunch spacing, the beam peak current will be 120 A and the bunch length $\sigma_z = 5.3$ ps. In both cases the beam energy will be 2.86 GeV.

A set of prototype striplines will be built under the CDTI program (IDC-20101074): it is planned to install the prototype striplines in ALBA for beam impedance and field homogeneity measurements during 2013, with a d.c. power supply and closed bumps. It may be feasible also to install the striplines and pulse generator (inductive adder) for testing in a straight section of the Final Focus System in ATF2 during 2014. The main specifications for the CLIC DR, CLIC PDR and ATF2 are shown in Table 1. A draft of the ALBA specifications is being prepared.

The stripline design has been carried out by using two different simulation codes: HFSS and CST Particle Studio, which work in the frequency and the time domains, respectively. The striplines design can be divided into three steps:

- Cross section design. The striplines cross section determines their characteristic impedance and field homogeneity. The cross section is optimized by simulating a slice, orthogonal to the length of the striplines, with HFSS.

Table 1: Specifications for the CLIC DR, CLIC PDR and ATF2.

Parameter	CLIC DR	CLIC PDR	ATF2
Beam energy (GeV)	2.86	2.86	1.30
Deflection angle (mrad)	1.5	2.0	1.5
Aperture (mm)	20	40	20
Effective length (m)	1.7	3.4	1.7
Field rise (ns)	$560^a/1000^b$	$428^a/1000^b$	560/1000
Field fall (ns)	$560^a/1000^b$	$428^a/1000^b$	560/1000
Pulse flat top (ns)	$900^a/160^b$	$900^a/160^b$	900/160
Flat top reproducibility	$\pm1\times10^{-4}$	$\pm1\times10^{-4}$	$\pm1\times10^{-4}$
Extraction stability	$\pm2\times10^{-4}$	$\pm2\times10^{-3}$	$\pm2\times10^{-4}$
Field inhomogeneity (%)	$\pm0.01^c$	$\pm0.1^d$	$\pm0.01^c$
Repetition rate (Hz)	50	50	1.56
Vacuum (mbar)	10^{-10}	10^{-10}	10^{-10}
Stripline pulse voltage (kV)	±12.5	±17.0	±5.5
Stripline pulse current (A)	±250	±335	±115
Beam current (A)	$110^a/120^b$	$70^a/50^b$	$60^e/20^f/30^g$
Bunch length (ps)	$6^a/5.3^b$	$10^a/14^b$	16.7
Bunch spacing (ns)	$1^a/0.5^b$	$1^a/0.5^b$	$2.8^f/140^g$

^{a}1 GHz baseline ^{b}2 GHz baseline
^{c}over 1 mm radius ^{d}over 3.5 mm radius
^{e}single-bunch mode ^{f}20-bunch mode ^{g}3-bunch mode

- 3D design using HFSS. By simulating the complete stripline geometry the transitions between the beam pipe and the striplines can be optimized.

- 3D design using CST Particle Studio. The coupling impedance and wake fields resulting from the beam passing through the stripline aperture are studied.

In this paper we present the results for the first step; the second step is presently being studied, and the preliminary results for the third step can be found in [1].

DESIGN STUDY OF THE STRIPLINES CROSS SECTION FOR THE CLIC DR

The striplines operate in two modes: odd and even mode. When the electrodes are excited with opposite polarity voltages, the current flow is in opposite directions in each stripline electrode and an electromagnetic field is created between the electrodes, giving a transverse kick to the beam: this is the odd mode. When unkicked circulating beam passes through the aperture of the striplines,

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it induces image currents in the electrodes: the direction of current flow is the same in both electrodes - this is the even mode. This generates an electromagnetic field, which gives a longitudinal kick to the beam and can produce beam instabilities. Therefore, two different characteristic impedances should be taken into account when studying the coupled striplines: odd mode characteristic impedance (Z_{odd}) and even mode characteristic impedance (Z_{even}).

Ideally, in order to avoid reflections when powering the electrodes, due to impedance mismatches, the odd mode characteristic impedance of the striplines, feedthroughs, coaxial cables and inductive adder [2] must be 50 Ω. In reality, the even mode characteristic impedance of striplines is higher than the odd mode. Therefore, the goal of the striplines design for the CLIC DR, is to achieve 50 Ω characteristic impedance in the even mode, to minimize impedance mismatches seen by the beam, while keeping the odd mode characteristic impedance as close as possible to 50 Ω. Furthermore, a very demanding field inhomogeneity of $\pm$ 0.01 % in the centre of the stripline aperture, over a circle of 1 mm radius, is required (Table 1).

Four possible electrode cross sections have been considered for the design of the striplines (Fig. 1): all of them have a cylindrical stripline beam pipe, since it is the easiest shape for manufacturing from a commercial pipe.

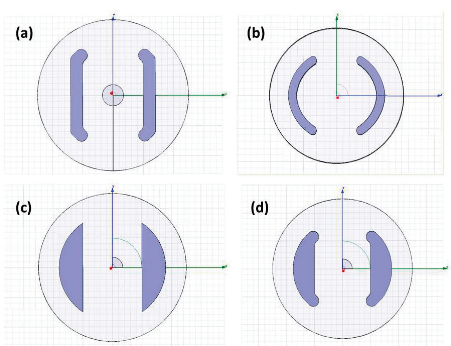

Figure 1: Electrode cross sections studied for the CLIC DR striplines: (a) flat; (b) cylindrical; (c) half moon; (d) modified half moon.

To optimize the cross section and to choose the most suitable geometric configuration, analyses of both characteristic impedance and field homogeneity have been carried out. For these analyses the ratio between the electrode height (Fig. 2) and the stripline beam pipe radius (h/R) has been varied.

For flat electrodes (Fig. 1(a)), the results for the characteristic impedance and field inhomogeneity are shown in Fig. 3 and Fig. 4, respectively. The main results are collected in Table 2.

The analyses have been carried out for three different stripline beam pipe radii: 20, 25 and 30 mm. The minimum radius analyzed is 20 mm since this is the minimum radius to avoid potential problems of electric breakdown (Kilpatrick limit [3]). For flat electrodes, the most suitable radius is 20 mm from the characteristic impedance point of

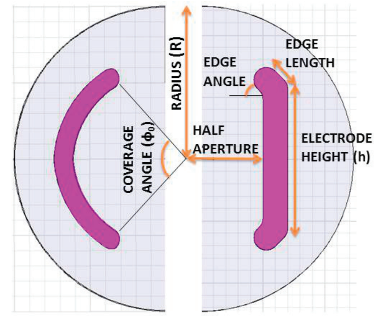

Figure 2: Geometric parameters for both cylindrical and flat electrode cross sections.

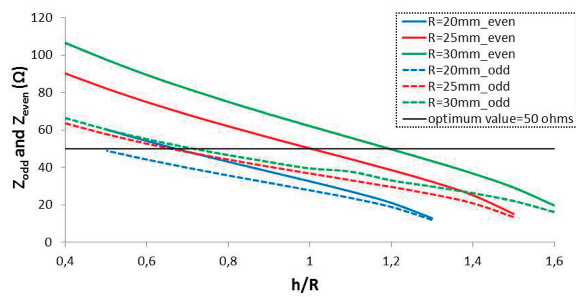

Figure 3: Odd and even mode characteristic impedance versus the cross section parameters, for flat electrodes.

view, see Fig. 3 and Table 2, since with this radius the ratio of the odd to even mode characteristic impedances is closer to unity than for a larger radius. This result is as expected: the odd mode characteristic impedance is due to both the capacitance between an electrode and the stripline beam pipe, and the capacitance between the electrode and the virtual ground created between the electrodes. In contrast, the even mode characteristic impedance is only due to the capacitance between an electrode and the beam pipe. Therefore, if the striplines are relatively close to the stripline beam pipe, in comparison to the seperation of the electrodes, the capacitance between the electrode and the beam pipe will dominate and hence the ratio between both characteristic impedances will be small.

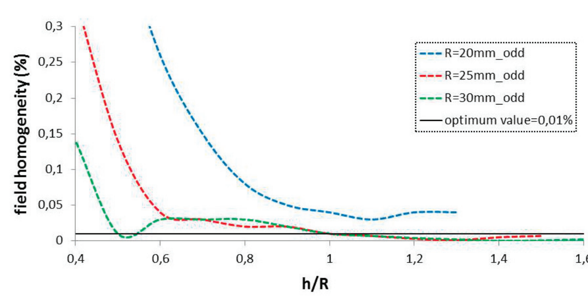

Figure 4: Odd mode field inhomogeneity versus the cross section parameters, for flat electrodes.

On the other hand, Fig. 4 and Table 2 show that for flat electrodes and 20 mm stripline beam pipe radius the field homogeneity does not meet the requirements. For a 50 Ω even mode characteristic impedance the ratio between total electrode height and stripline beam pipe radius is 0.68: with this ratio, the odd mode field inhomogeneity is ±0.16%. For a 25 mm radius, a ±0.01% field inhomogeneity is achieved with a ratio of 1 between the total electrode height and the stripline beam pipe radius: hence this is the preferred ratio. The modified half moon electrodes, together with a stripline beam pipe radius of 30 mm, allows to achieve the field homogeneity; however the odd mode characteristic impedance is smaller than for flat electrodes with a 25 mm radius. Similar analyses have been carried out for the other electrode shapes: the main results for the studied electrode shapes are shown in Table 2.

Table 2: Optimization results for the different electrode shapes for a 50 Ω even mode characteristic impedance.

Config.		R(mm)	h/R;ϕ_0	Z_{odd} (Ω)	Field inhomog.(%)
Flat		20	0.68	40.7	±0.16
Flat	(a)	25	1	36.8	±0.01
Flat		30	1.18	33.7	±0.005
Cylindrical	(b)	20	150°	37.0	±1.3%
Half moon		20	0.53	41.7	±0.4
Half moon	(c)	25	0.58	37.7	±0.1
Half moon		30	0.60	35.2	±0.03
Mod. half moon		20	0.60	41.7	±0.26
Mod. half moon	(d)	25	0.86	37.6	±0.02
Mod. half moon		30	1	34.2	±0.01

In the case of cylindrical electrodes, the parameter equivalent to the ratio between the electrode height and the stripline beam pipe radius is the coverage angle, which is defined as the angle that each electrode forms with the beam pipe. For 25 mm and 30 mm radii, to obtain 50 Ω even mode characteristic impedance, a coverage angle larger than 180° would be required: this is impossible to achieve.

FINAL CROSS SECTION OF THE STRIPLINES FOR THE CLIC DR

In order to optimize both even and odd mode characteristic impedances the stripline beam pipe radius should be as small as feasible. In addition, ideally, the stripline beam pipe radius should be identical to the surrounding beam pipe radius, to minimize wake fields: however the value of the stripline beam pipe radius is limited by the Kilpatrick limit. Flat electrodes (Fig. 1(a)) allow the required field homogeneity, at the centre of the aperture, to be achieved with a minimum stripline beam pipe radius (Table 2). For the CLIC DR extraction kicker, a stripline beam pipe radius of 25 mm is needed to achieve the required field homogeneity. A commercial pipe is to be used which has an inner radius of 24.625 mm. The resulting final values for the geometric optimization of the cross section, Fig. 2, are shown in Table 3. Mechanical tolerances of the electrodes position and inclination angle are presently being studied.

Table 3: Final design of the flat electrode stripline cross section for the CLIC DR kicker.

Parameter	Optimum value
Stripline beam pipe radius	24.625 mm
Aperture	20 mm
Electrode height	24.2 mm
Electrode thickness	4 mm
Electrode edge length	4.9 mm
Electrode edge angle	45°

With the optimized flat electrodes and a stripline beam pipe radius of 24.625 mm, the even mode characteristic impedance is 50.4 Ω and the odd characteristic impedance is 37.3 Ω. Furthermore, the field inhomogeneity is ±0.01%, as required.

CONCLUSIONS

The cross section optimization of the stripline kicker for the CLIC DR is almost complete: the 50 Ω even mode impedance and ± 0.01 % field inhomogeneity, over a circle of 1 mm radius centred between the striplines, have been achieved by using flat electrode striplines with 20 mm aperture and a cylindrical beam pipe of 24.625 mm radius. For the optimum geometry, the odd mode characteristic impedance is 37 Ω, and this will result in power reflections, which must be damped before the end of rise time, to meet the demanding specifications [2]. Ongoing simulations include studies of the alignment tolerance required for the striplines and beam pipe and the required precision in the magnitude of the positive and negative voltage pulses to achieve the required field homogeneity at the centre of the striplines.

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