DESIGN STUDY OF THE STRIPLINES FOR THE EXTRACTION KICKER OF THE CLIC DAMPING RINGS*

C. Belver-Aguilar, A. Faus-Golfe, IFIC (CSIC-UV), Valencia, Spain
M.J. Barnes, CERN, Geneva, Switzerland
F. Toral, CIEMAT, Madrid, Spain

Abstract

Pre-Damping Rings (PDRs) and Damping Rings (DRs) are needed to reduce the beam emittance and, therefore, to achieve the luminosity requirements for the CLIC main linac. Several stripline kicker systems will be used to inject and extract the beam from the PDRs and DRs. Results of initial studies of the stripline cross-section and the beam coupling impedance, for a non-tapered beam pipe, have previously been reported. In this paper, we present the analysis to study the final choice of the cross-section design, based on impedance matching and field homogeneity requirements, the power reflected in the transition between an electrode and the input coaxial feedthrough, and the predicted beam coupling impedance. Mechanical tolerances for the stripline manufacturing process are presently being studied. The striplines are planned to be prototyped by December 2012.

GEOMETRIC DESIGN STUDY

The stripline kicker proposed for the extraction kicker of the CLIC DRs consists of two parallel electrodes of 1.7 m length inside a cylindrical vacuum pipe: each electrode is powered by an inductive adder [1]. The two electrodes are charged to opposite polarity; there is a virtual ground midway between the electrodes. The striplines will be powered, via coaxial feedthroughs, from the beam exit end: the upstream feedthroughs will be connected to resistive loads, see Fig. 1. The stripline kicker operates as two coupled transmission lines, each of which should ideally have a characteristic impedance matched to 50 Ω. Coupled transmission line theory shows two operating modes for the stripline kicker, since three conductors are involved in the signal transmission, i.e. both electrodes and the vacuum beam pipe. These modes are known as odd and even mode: odd mode when the electrodes are excited with opposite polarity voltages, and even mode when the electrodes are excited by the unkicked circulating beam when passing through the aperture of the striplines [2].

Flat and Half-moon Electrode Cross-sections

The electrode cross-section was previously selected by studying several shapes for the striplines and optimizing them in order to achieve $50\,\Omega$ even mode characteristic impedance, and $\pm 0.01\%$ of field inhomogeneity over a circle of 1 mm radius at the center of the aperture [2]. An additional constraint was to achieve an odd mode characteristic impedance as close as possible to $50\,\Omega$. Flat electrodes allowed for an optimum characteristic impedance and field homogeneity with a minimum stripline beam pipe radius of 25 mm. A small stripline beam pipe radius diminishes the non-desirable effects of the wakefields and results in closer values of even and odd mode characteristic impedances.

* Work supported by IDC-20101074 and FPA2010-21456-C02-01

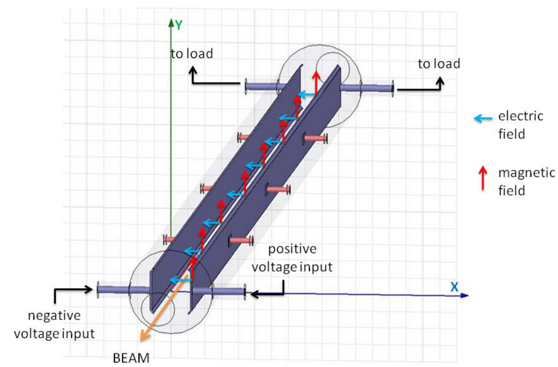

Figure 1: 3D model of a stripline kicker [4].

Recent studies have shown that a modified half-moon electrode, with a reduced coverage angle (see Fig. 2), allows for a better optimization of the odd mode characteristic impedance with a stripline beam pipe radius of 20 mm.

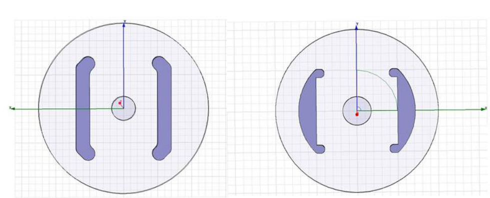

Figure 2: Cross-section of the striplines for flat electrodes (left) and modified half-moon electrodes (right). The circle drawn in the center is 3.5 mm radius in both striplines.

For flat electrodes with 50 Ω even mode characteristic impedance, an odd mode characteristic impedance of 36.8 Ω was achieved with a stripline beam pipe radius of 25 mm [2]; for the newly studied modified half-moon electrode the odd mode characteristic impedance is 40.9 Ω. To increase this value closer to 50 Ω, the capacitance between

ISBN 978-3-95450-119-9

an electrode and the virtual ground, midway between both electrodes, must be decreased relative to the magnitude of capacitance to the beam pipe ground. This can be achieved either by increasing the distance between the electrode and the virtual ground, or reducing the cross-sectional area of each electrode. The distance between an electrode and the virtual ground, 10 mm, is a fixed value, which corresponds to the half-aperture for the CLIC DR. The modified half-moon electrode, which is thicker than the flat electrode, allows for a smaller coverage angle of the electrodes and hence a reduced cross-sectional area.

In addition, field inhomogeneity requirements for the CLIC DR, i.e. $\pm 0.01\%$ over 1 mm radius, can also be achieved by the half-moon electrode shape. As shown in Fig. 3, the field homogeneity is better in the case of the modified half-moon electrode. Furthermore, a better efficiency can be expected since the electric field between the striplines is higher for the half-moon electrode shape.

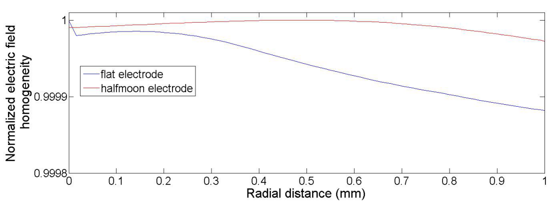

Figure 3: Field homogeneity over 1 mm radius for flat electrodes (blue) and half-moon electrodes (red).

The modified half-moon electrodes have been studied further and, in the following, the features of the half-moon and flat electrodes (Fig. 2) are compared, which allows the final geometric design of the striplines to be chosen.

COAXIAL FEEDTHROUGH TO STRIPLINE TRANSITION

A total of four coaxial feedthroughs are required to transfer power from the inductive adders to the two electrodes and from the electrodes to the two, matched impedance, loads. The feedthroughs are coaxial outside of the stripline beam pipe but the connection from a feedthrough to an electrode cannot be coaxial (see Fig. 4): hence the characteristic impedance of the connection to the electrode is not $50\,\Omega$. Furthermore, during the kicker operation, the stripline characteristic impedance is lower than 50 Ω (see above). These impedance mismatches result in reflections: the impedance of the connection to the electrode can be calculated using S-parameters.

HFSS has been used to calculate the reflection parameter S_{11}, looking into an input port when the corresponding output port is resistively terminated. Initially the value of the termination was modelled as 50Ω, however future simulations will consider values not exactly equal to 50Ω. The results of the initial simulations are shown in Fig. 5.

The simulation used a frequency sweep between 100 kHz to 1 GHz and the results were extrapolated to DC.

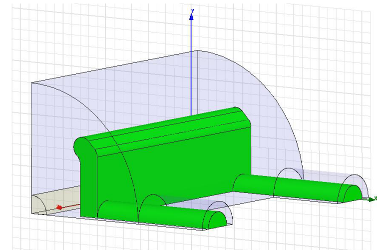

Figure 4: Feedthrough simulation with HFSS.

For a good signal transmission, the S_{11} parameter should be less than 0.1 for frequencies below 0.5/T, where T is the rise time of the pulse from the inductive adder [4]. In the case of the CLIC DR, this frequency corresponds to 0.89 MHz and 0.5 MHz for the 1 GHz and 2 GHz baselines, respectively [2].

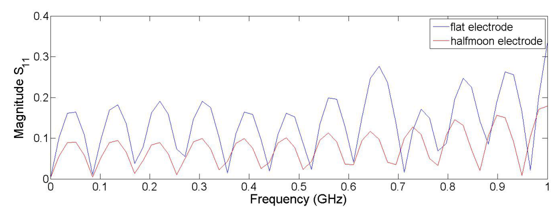

Figure 5: S_{11} looking into an input port, when the corresponding output port is terminated with $50\,\Omega$, for flat electrode (blue) and modified half-moon electrode (red), for a frequency range from DC to 1 GHz.

Figure 5 shows that the reflection parameter changes with a maximum-minimum pattern: the shape of the curves depend on the coaxial feedthrough to stripline transition. For CLIC the S_{11} parameter must be below 0.1 for a good signal transmission. The modified half-moon electrode shows an excellent transmission, i.e. low reflection up to 300 MHz, whereas for the flat electrode shape the reflection parameter is above 0.1 over the whole frequency range. Therefore, from the power transmission point of view the modified half-moon electrode presents a better transmission.

BEAM COUPLING IMPEDANCE

Beam coupling impedance is a very important parameter for the striplines. Since the DRs are periodic, it is important to reduce as much as possible the effect of the field produced by the beam itself, in the striplines, when the kicker is not operating, in order to diminish the wakefield effects in the unkicked circulating beam. The permissible beam coupling impedance, of the striplines, is 0.05 Ω/turn and 200 kΩ/m for the longitudinal and transverse beam coupling impedance, respectively [5].

The beam coupling impedance, for an untapered beam pipe with flat electrodes, has previously been studied and

ISBN 978-3-95450-119-9

the results, reported in [6], show good agreement between analytical calculations and predictions from simulations. These previous results for a flat electrode, together with the new CST Particle Studio predictions for the modified half-moon electrode, are shown in Fig. 6. The modified half-moon electrodes have lower longitudinal beam coupling impedance than the flat electrodes. This is easily understandable by using the analytical formulas [6], because in the modified halfmoon the coverage angle is reduced from 2 radians to 0.9 radians, decreasing the longitudinal beam coupling impedance. The simulations give a higher value for the transverse beam coupling impedance in the case of half-moon electrode than in the case of flat electrode, that is in contradiction to the analytical formulas because the stripline beam pipe radius is reduced from 25 mm to 20 mm. Therefore, further simulations of beam coupling impedance are required.

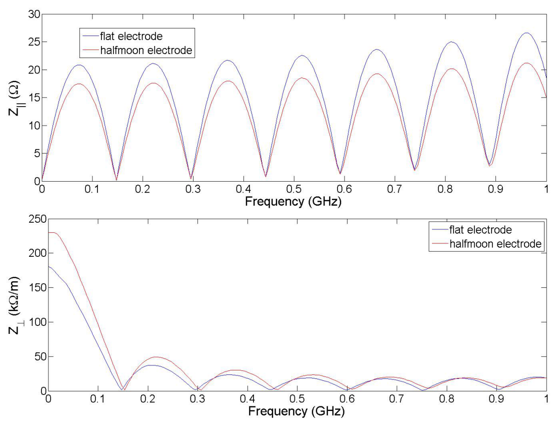

Figure 6: Longitudinal (top) and transverse (bottom) beam coupling impedance for flat and modified half-moon electrodes, in a frequency range from DC to 1 GHz.

MECHANICAL TOLERANCES

Two possible errors during the manufacturing process are being taken into account when studying both designs of electrodes: (1) the position and inclination angle of an electrode (see Fig. 7), and (2) the dimensions of both electrodes and the beam pipe. The tolerances being studied are in a range of $\pm$ 0.5 mm and $\pm$ 1 degree.

In order to define mechanical tolerances both even and odd modes must be taken into account, by studying the variation of the common mode and differential mode impedances as a function of various mechanical parameters. Common and differential mode impedances are related to even and odd mode impedances, respectively, by $Z_{\text{comm}} = Z_{\text{even}}/2$ and $Z_{\text{diff}} = 2Z_{\text{odd}}$.

Studies of the tolerances are presently being carried out: initial predictions show that an error in the position of an electrode will affect the characteristic impedance of the stripline, whereas if an electrode is placed with a certain inclination angle, both the characteristic impedance and the field homogeneity will be affected.

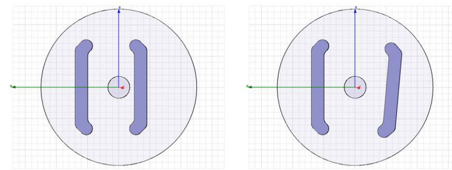

Figure 7: Offset of $\pm$ 5 mm in the position of an electrode (left) and for an inclination angle of $\pm$ 15deg (right): these values are only used for a better visualization.

CONCLUSIONS

Studies of the cross-section of the striplines for the extraction kicker of the CLIC DRs have shown that for a 50 Ω even mode characteristic impedance of the striplines, the modified half-moon electrode shape results in an odd mode characteristic impedance closer to 50 Ω than the flat electrodes. Furthermore, a good field homogeneity and higher efficiency is expected with this modified half-moon electrodes. Simulations show that the longitudinal beam coupling impedance is lower for the modified half-moon electrodes than for the flat electrodes, whereas the flat electrode shape seems to be better from the transverse beam coupling impedance point of view. The reflection coefficient predicted looking into the input port, with a 50 Ω on each output port, shows that the transmission is better in the case of modified half-moon electrodes. Therefore, the modified half-moon electrode is now considered as the best choice for the cross-section of the striplines for the extraction kicker of the CLIC DRs. However, further studies of beam coupling impedance are required.

ACKNOWLEDGMENTS

The authors thank Trinos Vacuum-Projects S.L., responsible for building the striplines, and especially D. Gutiérrez.

REFERENCES

[1] J. Holma, M.J. Barnes, Evaluation of components for the high precision inductive adder for the CLIC Damping Rings, Proc. IPAC 2012

[2] C. Belver-Aguilar et al., Final Cross-section Design of the Stripline Kicker for the CLIC Damping Rings, Proc. of IPAC 2012.

[3] D.M. Pozar, Microwave Engineering, Third Edition.

[4] I. Rodríguez, Calculation Methodology and Fabrication Procedures for Particle Accelerator Strip-line Kickers: Application to the CTF3 Combiner Ring Extraction Kicker and TL2 Tail Clippers, PhD thesis (2009).

[5] G. Rumolo, CERN, private communication.

[6] C. Belver-Aguilar et al., Beam Impedance Study of the Stripline Kicker for the CLIC Damping Ring, Proc. IPAC 2012.

ISBN 978-3-95450-119-9