DESIGN AND MANUFACTURING DESCRIPTION OF THE PROTOTYPE STRIPLINES FOR THE EXTRACTION KICKER OF THE CLIC DAMPING RINGS[*]

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Abstract

The Pre-Damping Rings (PDRs) and Damping Rings (DRs) of CLIC are needed to reduce the beam emittances to the small values required for the main linacs. The injection and extraction, from the PDRs and DRs, are carried out by kicker systems. 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. The design of the stripline kicker was previously carried out by modelling the striplines with simulation codes such as HFSS, Quickfield and CST Particle Studio. In order to have a complete analysis of the striplines, the effect of electrode supports and coaxial feedthroughs have been studied in detail. In this paper, electromagnetic analyses of the complete striplines, including fabrication tolerances, are reported. Furthermore, a new idea for impedance matching is presented.

INTRODUCTION

High-energy electron-positron colliders, such as CLIC, will be needed to investigate the TeV physics revealed by the LHC. To achieve high luminosity at the interaction point, it is essential that the beams have very low transverse emittance: the Pre-Damping Rings (PDRs) and Damping Rings (DRs) damp the beam emittance to extremely low values. The injection and extraction from the PDRs and DRs will be carried out using stripline kickers. The striplines consist of two electrodes housed in a conducting cylinder: each of the electrodes is driven by an equal but opposite polarity pulse. The geometric cross-section of the striplines defines the field homogeneity and the characteristic impedance. Three different electrode shapes have been studied for the CLIC DR extraction kickers, all of them use a cylindrical beam pipe: flat electrodes, curved electrodes and half-moon electrodes [1, 2]. Half-moon electrodes are the optimum shape [2], because they allow for both a reasonable impedance matching and excellent field homogeneity.

MANUFACTURING PROCESS

The manufacturing process has commenced, under the Spanish Program "Science for Industry". A schematic of the stripline kicker and the mechanical tolerances of both an electrode support and an electrode are shown in Fig. 1.

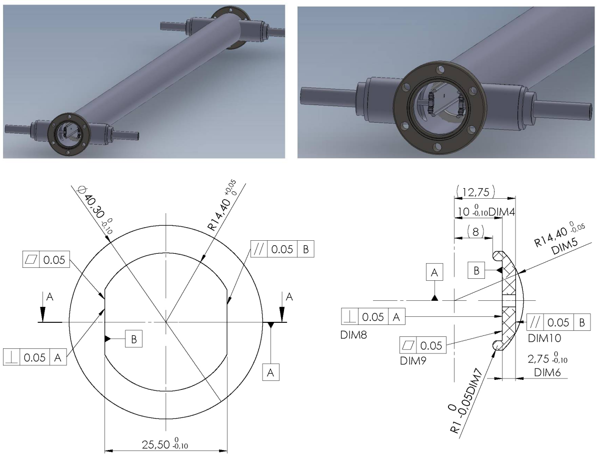

Figure 1: Prototype striplines and fabrication tolerances for the electrode supports and the electrodes.

In the following, the manufacturing tolerances and material choices for the prototype stripline kicker are presented, as well as a detailed study of the electrode supports and feedthroughs.

Fabrication Tolerances

The effect of fabrication tolerances, upon field homogeneity over a 1 mm radius, has been studied using the 2D code Quickfield. The geometric errors considered are the horizontal and vertical position and the inclination angle of an electrode.

All these parameters are mechanically defined by the tolerances of the electrode supports and the electrodes (Fig. 1). Table 1 summarizes the field inhomogeneity results for three different types of manufacturing errors.

The maximum field inhomogeneity specified over a 1 mm radius is ± 0.01%. As shown in Table 1, a manufacturing error in either the horizontal or vertical position of an electrode may increase the field inhomogeneity beyond specification, whereas an error in only the inclination angle will not. The possibility of relaxing the field inhomogeneity requirements is being studied [3].

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Table 1: Field Inhomogeneity for the Maximum Geometrical Errors Expected During Manufacturing

	Maximum error	**Field inhomogeneity**
Horizontal	± 0.2 mm	± 0.015 %
Vertical	± 0.1 mm	± 0.02 %
Inclination	0.06°	± 0.01 %

Material Choices

The beam pipe housing the stripline electrodes is a stainless steel tube of 1.712 m length. The internal diameter of the tube is 40.5 ± 0.2 mm. Aluminium has been chosen for the electrodes, because it is relatively easy to achieve the tight tolerances required during manufacturing. The electrode supports will be manufactured using Macor, which is a machinable glass ceramic [4]. All the materials and components chosen, such as feedthroughs, are compatible with ultra-high vacuum (UHV).

Study and Optimization of Electrode Supports

The electrodes have a total length of 1.639 m and, ideally, must be perfectly aligned along their entire length. The cylindrical supports used in the CTF3 kicker [5] will not be used, because it is not possible to achieve the required precision for the electrode alignment. In order to ensure the alignment a new solution has been proposed, which consists of fixing the electrodes outside the aperture by using four Macor rings, of 10 mm thickness each. Once the electrodes are aligned and fixed to the Macor rings, this assembly will be placed inside the stainless steel tube, and its angular position will be guaranteed by two grub screws embedded in the striplines pipe wall.

The number of Macor rings and their thickness has been selected by studying the mechanical requirements and the impedance mismatch introduced by the rings. The impedance mismatch results in power being reflected: this has been investigated using CST Microwave Studio (MS) and HFSS.

Without Macor supports the frequency between peaks is approximately 95 MHz (Fig. 2 (top)), which corresponds to the two-way delay of the electrodes. Figure 2 (bottom) shows that the Macor rings increase the magnitude of the reflection parameter S_{11}, starting from 300 MHz, of every third peak. The separation between these maxima corresponds to the distance, there and back, between the equally-spaced Macor rings (510 mm). However, the frequency content of the driving pulse (≈100 ns rise and fall times), will only extend up to ≈10 MHz. Hence, since the Macor rings mainly affect the S_{11} above 300 MHz, they are not expected to significantly influence the ripple of the driving pulse.

A beam with a longitudinal bunch length of 50 mm circulating in the aperture of the striplines has been simulated with CST Particle Studio (PS). Several simulations were made using different bunch lengths from 20 mm to 150 mm, and there was no difference in the beam coupling impedance up to 9 GHz: this is the highest frequency output, from CST PS, for the 20 mm bunch length. The simulation has been used to study the wakefields and their frequency domain counterpart, the beam coupling impedance.

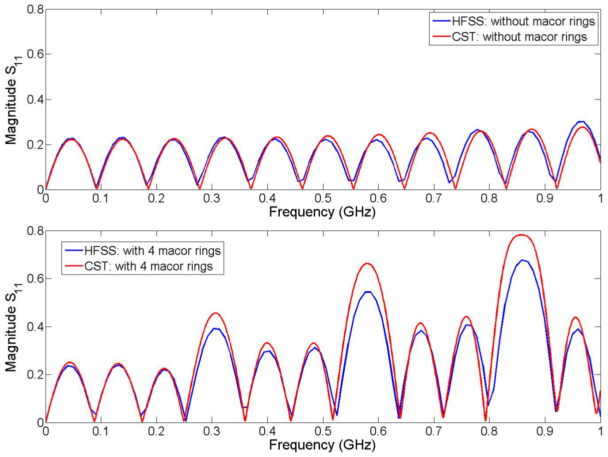

Figure 2: Magnitude of S_{11} predicted by HFSS and CST MS, for striplines without (top) and with (bottom) Macor rings.

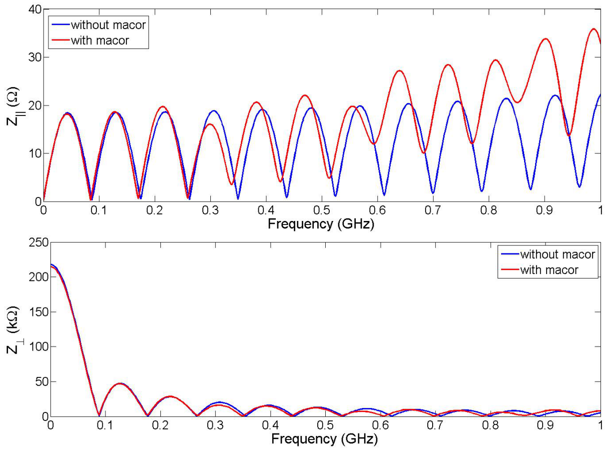

Figure 3: Longitudinal (top) and transverse (bottom) beam coupling impedance for striplines with and without Macor rings, simulated with CST PS.

The presence of the Macor rings increases the energy lost by the beam particles when passing through the aperture. Hence there is an increase of the longitudinal beam coupling impedance above ≈300 MHz (Fig. 3), whereas the transverse beam coupling impedance is not significantly affected because the rings do not change the cross-section of the striplines.

Feedthroughs Study and Optimization

A total of four feedthroughs will connect the stripline electrodes with an inductive adder [6] and matching loads.

The Kyocera 15kV-F-UHV coaxial feedthroughs will be used [7].

To study the effects of the feedthroughs upon the power reflected, a model with ideal coaxial feedthroughs was first used. Once we chose the Kyocera feedthroughs, they were simulated (Fig. 4), and both results were compared.

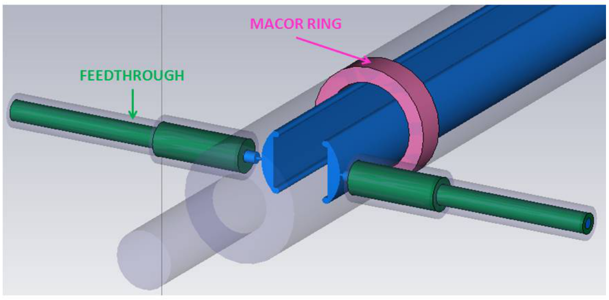

Figure 4: CST MS model used to optimize the electrode supports and the feedthroughs.

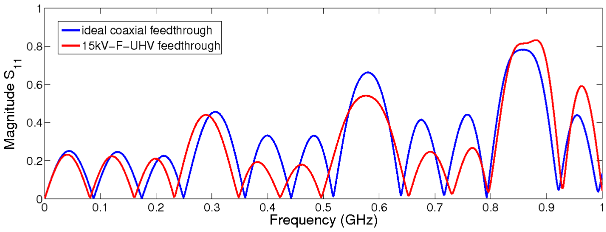

Figure 5: Predicted magnitude of S_{11} for striplines with ideal coaxial feedthroughs and with the 15kV-F-UHV.

Figure 5 shows that up to ≈800 MHz the magnitude of the S_{11} parameter is generally lower with the commercial feedthroughs than with the ideal feedthroughs. This is due to the the impedance of the connection between the feedthrough and the striplines being lower than 50 Ω. Furthermore, a frequency shift is observed in the maxima and minima pattern for the two models. This is due to the change in the dielectric from only vacuum (ideal coaxial) to Al_2O_3 and back to vacuum (Kyocera coaxial feedthrough): the different dielectric constant results in a change in the velocity of the pulse signal, and therefore a frequency shift.

NEW IDEAS FOR MATCHING CHARACTERISTIC IMPEDANCES

For the optimized half-moon electrode shape, the odd mode characteristic impedance is 41 Ω [2]. Since the inductive adder will be connected to the striplines with transmission lines of 50 Ω impedance and each stripline will be terminated with 50 Ω, there is an impedance mismatch at both the input and output of the striplines: impedance mismatches can increase the pulse ripple and rise-time. A new idea has been proposed to match the characteristic impedance for both the odd and even modes of excitation of the striplines. The proposal is to connect a matching resistor, Z_m, between the electrodes, on the load side of the striplines. When the kicker is not pulsed the voltages induced on the electrodes are only due to the beam (even mode); the matching resistor is invisible to the even mode signals. When the kicker is pulsed, the striplines are driven with opposite polarity voltages (odd mode) and thus current flows in the matching resistor. The odd mode termination impedance is equal to:

$$Z_{odd} = \frac{Z_{even} Z_m}{2Z_{even} + Z_m}$$

This formula shows that for an odd mode impedance Z_{odd} = 41 Ω and an even mode impedance Z_{even}= 50 Ω a matching resistor of Z_m = 450 Ω is required.

The matching resistor will result in the odd mode impedance of each stripline being terminated in 41 Ω. However the odd mode input impedance of the striplines is still mismatched to the transmission line impedance. In addition a drawback of the impedance matching resistor is that it increases the pulse current which must be supplied by the inductive adder by approximately 20 %.

CONCLUSIONS

The electromagnetic design of the striplines, including a detailed study of both the electrode supports and the feedthroughs, has been completed. The stripline design provides the performance specified for the extraction kicker of the CLIC DRs: excellent field homogeneity, good power transmission and broadband low beam coupling impedance. The effect of manufacturing tolerances has been studied. In addition a new method of impedance matching has been proposed. A prototype of the extraction stripline kicker for the CLIC DR is presently being manufactured by Trinos Vacuum Projects (Valencia, Spain).

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