

# TRANSVERSE IMPEDANCE MEASUREMENTS AND DC BREAKDOWN TESTS ON THE FIRST STRIPLINE KICKER PROTOTYPE FOR THE CLIC DAMPING RINGS\*

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## Abstract

A first stripline kicker prototype for beam extraction from the CLIC Damping Rings (DRs) has been designed at IFIC and CIEMAT, with excellent field homogeneity, good power transmission and low beam coupling impedance. The prototype has been built by the company Trinos Vacuum Projects, and laboratory tests and measurements have been carried out at CERN to characterize, without beam, the electromagnetic response of the striplines. In this paper, we present the measurements of the transverse beam coupling impedance, using the coaxial wire method, and a comparison with simulations. Furthermore, results of DC breakdown tests, using High Voltage (HV) power supplies, are also reported.

## TRANSVERSE BEAM COUPLING IMPEDANCE MEASUREMENTS

Measurements in the laboratory, without beam, are important to characterize the electromagnetic response of the striplines, and compare the results of the measurements with the electromagnetic simulations. The measurements carried out in this first prototype have been the following: (1) power reflection through the striplines, (2) longitudinal beam coupling impedance, and (3) transverse beam coupling impedance. In addition, DC breakdown tests have been carried out. In this paper, results for the transverse beam coupling impedance, as well as for the DC breakdown tests will be presented.

For transverse beam coupling measurements, two techniques are commonly used: (1) the two wire method, or (2) the moving single wire method [1, 2]. The two wire method consists of inserting two wires in the striplines aperture, and driving them with opposite phase RF waves. With this method, the dipolar component of the transverse impedance is calculated, whereas with the moving single wire method the total transverse impedance (dipolar and quadrupolar components) is measured. The setup for the two measurements is shown in Fig. 1. The results of these measurements have been compared with CST Particle Studio (PS) [3] simulation results for the dipolar and the total transverse beam coupling impedance.

## Two Wire Method

The dipolar component of the transverse impedance of the striplines has been measured by producing a dipolar field with two wires, of 0.5 mm diameter each, driven with opposite phases by using two hybrids. To have a measurable effect, the wire spacing should be significantly smaller than the aperture, due to the fact that the dipolar field created only interacts with the fringe fields and, therefore, the effects are small: a wire spacing of about a third of the aperture appears to be a good compromise [1]. In our case, for an aperture of 20 mm a wire spacing of 7 mm has been chosen. In order to match the two wire line impedance to the impedance of the Network Analyzer, the hybrids and the loads, a matching resistor at the ends of each wire has been used. To calculate the resistance value of each matching resistor, the following equation has been used:

$$R_S = Z_{line}/2 - Z_0 \quad (1)$$

where  $Z_{line}$  is the differential-mode line impedance and  $Z_0 = 50 \Omega$ . The differential-mode line impedance for two wires with opposite polarity is given by:

$$Z_{line} = \frac{120}{\sqrt{\epsilon_r}} \operatorname{acosh} \frac{\Delta}{d} \quad (2)$$

where  $\epsilon_r$  is the relative permittivity of the medium between the wires ( $\epsilon_r = 1$  here),  $d$  is the wire diameter and  $\Delta$  is the wire spacing. In our case, using Eq. (2), the calculated value of  $Z_{line}$  is  $399.7 \Omega$ : low-inductance (carbon film) single series resistors of  $160 \Omega$  have been used for the matching network. The transmission parameter  $S_{21}$  has been measured with the Network Analyzer, and from this measurement the longitudinal impedance  $Z_{||}$  can be estimated by using the formula [1]:

$$Z_{||} = -2Z_{line} \ln(S_{21}) \quad (3)$$

Then the dipolar component of the transverse impedance has been found from the following equation:

$$Z_{\perp, dip} = \frac{cZ_{||}}{2\pi f \Delta^2} \quad (4)$$

where  $c$  is the speed of light, and  $f$  is the frequency at which the  $S_{21}$  parameter is measured. Results for the dipolar horizontal and vertical impedance are shown in Fig. 2, when terminating the electrodes with the “ideal”  $50 \Omega$  resistors from

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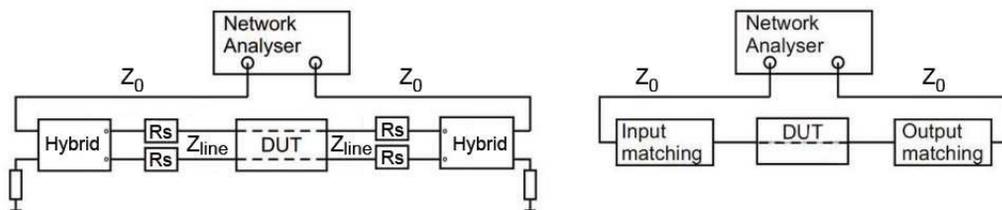


Figure 1: Test setup for the transverse beam coupling impedance measurement, using the two wires method (left) and the single wire method (right) [1].

the Network Analyser calibration kit, and with Diconex terminating loads, which exhibit a frequency-dependent value [4].

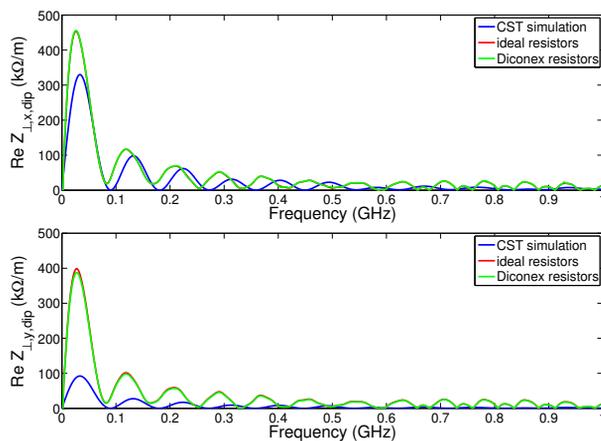


Figure 2: Dipolar horizontal (top) and vertical (bottom) impedance, when terminating the electrodes with the Diconex resistors (green line) or with the “ideal” resistors (red line), compared with the CST simulation (blue line).

For the real part of the horizontal dipolar impedance, a rough agreement has been found between the measurements and the CST simulation: the difference is thought to be due to the presence of the wire detuning the resonances, whereas the simulations are done without a wire. For the simulations also a perfect matching at the feedthroughs is assumed, and in reality the cables used to connect the feedthroughs to the terminating resistors may affect the measurement. In the case of the vertical dipolar impedance, the peak values are much higher for the measurements than for the simulations: the reasons for the discrepancies are under investigation. The results for the dipolar beam coupling impedance measurements in the two planes are quite similar, and do not show significant differences when terminating the electrodes either with the “ideal” resistors or the Diconex terminations: the termination at the end of the cable seems not to matter.

### Single Wire Method

The transverse impedance at a given frequency is proportional to the change in longitudinal impedance due to the lateral displacement of the beam in the plane under consideration (vertical or horizontal), as defined by the Panowsky-

Wenzel theorem [5]. The horizontal transverse beam coupling impedance can be, therefore, calculated from the longitudinal beam coupling impedance measured with a single wire.

For this measurement, the wire is moved horizontally from the center of the aperture, towards the electrodes, up to  $\pm 8$  mm, with steps of 2 mm, with a precision of  $\pm 0.5$  mm. The longitudinal beam coupling impedance can be calculated from the  $S_{21}$  results, using Eq. (3). Then, after a parabolic fit of the longitudinal beam coupling impedance measured as a function of the horizontal distance  $x$  from the wire, we have the following relation at each frequency [1]:

$$Z_{\parallel}(f) = Z_{\parallel,0}(f) + z_1(f)x + z_2(f)x^2 \quad (5)$$

where  $Z_{\parallel,0}$  is the longitudinal impedance measured in the center of the aperture, and  $z_1$  and  $z_2$  are related to the transverse impedance. The quadratic term  $z_2$  is related to the total transverse impedance by:

$$Z_{\perp} = \frac{c}{2\pi f} z_2 \quad (6)$$

The same can be done in the vertical plane. The total transverse beam coupling impedance has been calculated from the quadratic term  $z_2$  using Eq. (6), in both horizontal and vertical planes: a comparison with the CST PS simulation results is shown in Fig. 3 for the total horizontal and vertical impedance. In the simulation, the total transverse impedance has been calculated by displacing both the wake integration path and the beam 1 mm from the center of the aperture.

In the horizontal plane, the results from the measurements are strongly dependent upon the termination and significantly higher than the results from the simulation, whereas they are quite similar in the vertical plane. In the vertical plane only measurements with the ideal terminating resistors were done, due to the non-availability of the Diconex loads at this moment. The high peak values of the horizontal total impedance measured are thought to be mainly due to the difficulty of the measurement for an aperture of 20 mm: the parabola fitted assumes only linear transverse impedance; however, for a small aperture, non-linear effects appear. In the vertical plane, however, although large uncertainties were expected due to the wire sag, high accuracy in the measurement has been found, probably due to the higher beam pipe diameter, which is 40.5 mm.

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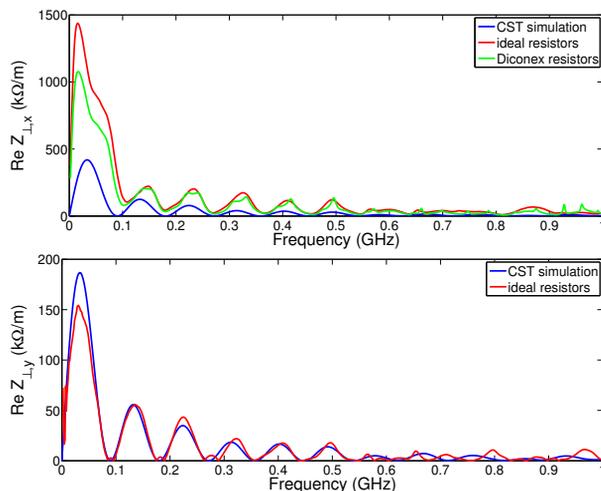


Figure 3: Total horizontal (top) and vertical (bottom) impedance, when terminating the electrodes with the Diconex resistors (green line) or with the “ideal” resistors (red line), compared with the CST simulation (blue line).

## DC BREAKDOWN TESTS

For beam extraction from the CLIC DRs, each electrode will be driven by a pulse of 12.5 kV voltage; for that reason, HV tests on the first prototype are necessary to verify if there are discharges, e.g. on vacuum feedthroughs or between the electrodes and the vacuum chamber, especially where the four Macor rings are placed [6]. First HV tests have been performed using two DC HV power supplies, which are low current with a relatively small output capacitance. The striplines were first pumped down to a final pressure of  $4 \times 10^{-8}$  mbar, and then the electrodes were powered in differential mode. The voltage was increased in small steps and the breakdown events were counted using an oscilloscope for every voltage applied, for durations between 1 and 110 hours, and the breakdown rate (BDR) per hour was calculated.

The HV power supplies, with equal but opposite polarity DC voltage, were connected to the input feedthroughs, whereas the output feedthroughs were connected to P6015 HV probes. These probes are rated at 20 kV DC, and were connected to the oscilloscope in order to see directly the voltage drop due to a sparking event. The oscilloscope was set up to trigger when the voltage dropped significantly on either electrode, and the number of triggers, or acquisitions, were considered to be the number of breakdowns. The breakdown events started at  $\pm 7.0$  kV. From this value, the voltage was increased in steps of up to 0.25 kV. The increase in the voltage in small steps is to allow conditioning: a high BDR may appear immediately following an increase in the voltage, but it often reduces after several hours powering the electrodes at the same voltage.

Figure 4 shows the BDR per hour measured as a function of DC voltage of the electrodes. Occasionally, the voltage was reduced or a test was repeated at the same voltage, to

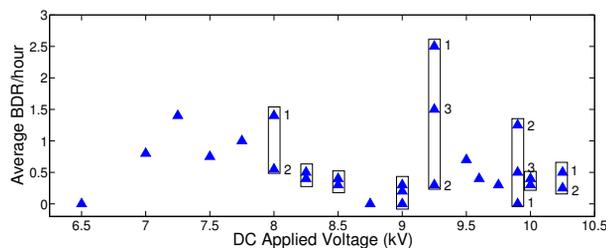


Figure 4: Breakdown rate for HV tests with a DC setup.

determine whether conditioning occurred: the order of tests is shown in Fig. 4 by the numbers next to the rectangles.

The striplines did not exhibit a BDR above 1.5 until 9.25 kV, where a maximum BDR per hour of 2.5 was found. Breakdown could be dangerous in the regions where the Macor ring is placed if the surface of the Macor is contaminated by metal from a spark. The maximum voltage achieved in the tests was  $\pm 10.8$  kV, because one of the power supplies failed. Nevertheless, a higher level of vacuum and pulsed HV tests are needed, since a significant difference in the BDR could be expected. Further DC tests and tests with the inductive adder are planned in the future. The tests, at each applied voltage, will be for a minimum duration of 8 hours in order to obtain reasonable statistics.

## CONCLUSIONS

The laboratory tests of the CLIC DR extraction kicker have been performed in the CERN labs. For transverse beam coupling impedance measurements, two different techniques have been used, the two wires and the single wire method, to calculate the dipolar component and the total transverse beam coupling impedance, respectively. For the dipolar component of the transverse impedance, measurements agree reasonably well with the simulations, whereas for the vertical impedance a disagreement has been found. The total horizontal impedance measurement does not agree with the simulations, probably due to the difficulty of the measurement for a small aperture of 20 mm, although the results match quite well in the vertical plane, where the striplines beam pipe diameter is 40.5 mm. The discrepancies between measurements and predictions are under investigation. Breakdown tests using two DC HV supplies have been carried out up to a voltage of  $\pm 10.8$  kV. To have a better estimation of the BDR expected during kicker operation, further measurements with DC voltage and with a pulsed power supply are planned. In the future, measurements of the striplines with beam will be performed in the ALBA Synchrotron Radiation Accelerator, which will help to study the beam coupling impedance of the striplines.

## ACKNOWLEDGMENTS

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