BEAM IMPEDANCE STUDY OF THE STRIPLINE KICKER FOR THE CLIC DAMPING RING*

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Abstract

CLIC Pre-Damping Rings (PDR) and Damping Rings (DR) are required for reducing the emittance of the electron and positron beams before being accelerated in the main linac. Several stripline kicker systems are used to inject and extract the beam from the PDR and DR. Wake fields produced by the charged particles passing through the aperture of the stripline kickers may become an important source of emittance growth; for this reason, simulations of longitudinal and transverse beam impedance in the frequency domain, and their equivalent in the time domain are needed. First analytical approaches, future simulations and tests planned are presented in this paper.

INTRODUCTION

A charged particle beam travelling inside a vacuum chamber induces electromagnetic fields, known as wake fields, which act back on the beam itself. This gives an additional voltage and energy gain and hence affects the longitudinal dynamics: in addition there is a transverse momentum kick which deflects the beam. Furthermore, when a charge crosses a vacuum chamber discontinuity, the abrupt change in the cross section of a beam pipe causes secondary fields to be reflected at the sharp edges of the transition.

Knowledge of the electromagnetic interactions, between the charged particle beam and the vacuum chamber, is necessary in order to avoid the instability phenomena that may otherwise occur in the CLIC damping rings. Hence studies are being carried out using simulation codes in both the frequency (HFSS) and time domains (CST Particle Studio).

TRANSITION BETWEEN THE DR BEAM PIPE AND THE STRIPLINE BEAM PIPE

An abrupt change in the cross section of a beam pipe will radiate fields when the beam passes by. However, if one uses long gradual tapers instead of abrupt step transitions, the total energy loss may be significantly reduced. Indeed, an infinitely long taper reduces the radiated energy to zero. In [1], there is an approximate criterion to choose a reasonable taper length (l) valid for short bunches when the main contribution to the losses comes from the high frequency impedance:

$$\frac{l\sigma_z}{(b_1 - b_2)^2} > 1 \quad (1)$$

where b_1 and b_2 are the radius of the stripline beam pipe and the adjacent beam pipe, respectively, and σ_z is the bunch length.

In the case of the CLIC DR, where the beam pipe is presently specified to be of 10 mm radius (b_2), the optimum stripline beam pipe radius is 25 mm (b_1) [2], and the bunch length is 1.8 mm and 1.6 mm for the 1 GHz and 2 GHz baselines, respectively. Therefore, a reasonable taper length is 125 mm and 140 mm for 1 GHz and 2 GHz baselines, respectively. Conical transitions will be used to connect the 10 mm radius DR beam pipe to the 25 mm radius stripline beam pipe, Fig. 1.

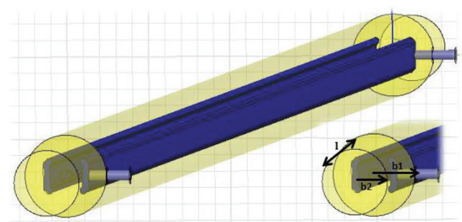

Figure 1: 3D geometry of the stripline kicker for CLIC DR, including the beam pipe conical transition.

Feedthroughs

High voltage vacuum feedthroughs are required to connect the input and output of each stripline electrode to a pulsed power supply [3] and a resistive terminator, respectively. In the ideal case the impedance of the striplines, feedthroughs, pulse generator and resistive terminator would be matched to 50 Ω at all frequencies; in reality this is not the case. It is proposed to use the 15 KV-F-Coaxial UHV feedthrough, from Kyocera: this is characterized, by the manufacturer, from d.c. up to 100 MHz.

The transition between the feedthroughs and electrodes is important from the good pulse transmission point of view, especially at high frequencies: an abrupt connection between the feedthroughs and the electrode can produce large reflections. A highly optimized transition is proposed in [4], where the feedthrough is connected to a tapered electrode. Studies are presently being carried out to determine whether, for beam coupling impedance reasons, an optimized transition to the feedthrough is required.

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BEAM COUPLING IMPEDANCE

The allowable broad band impedance in the CLIC DR is $1\,\Omega/n$ –where n is the number of turns– for the longitudinal beam coupling impedance and $10\,M\Omega/m$ in the transverse plane. This allowable beam impedance is for the complete DR, which is composed of many systems including both injection and extraction kicker systems: the permissible beam coupling impedance, per kicker system, is assumed to be 5% of the longitudinal impedance allowance, i.e. $0.05\,\Omega/n$, and 2% of the transverse impedance allowance, i.e. $200\,k\Omega/m$ [5].

Analytical equations for the longitudinal and transverse coupling impedance, $Z_{\|}$ and $Z_{\perp}$ respectively, for untapered stripline beam position monitors, are shown in [6]:

$$Z_{\|} = 2Z_c\left(\frac{\phi_0}{2\pi}\right)^2\left[2sin^2\left(\frac{\omega L}{c}\right) - isin\left(\frac{2\omega L}{c}\right)\right] \quad (2)$$

$$Z_{\perp} = \left[\frac{Z_{\|}}{\omega}\right]_{pair}\left[\frac{c}{b^2}\right]\left[\frac{4}{\phi_0}\right]^2\left[sin^2\left(\frac{\phi_0}{2}\right)\right] \quad (3)$$

where Z_c is the characteristic impedance of striplines, ϕ_0 is the coverage angle of a single electrode [2], L the striplines length and c the speed of light.

To take into account the tapers, these analytical equations must be multiplied by an additional term [7]:

$$\left[\frac{\sin^2\left(\frac{\omega l}{c}\right)}{\left(\frac{\omega l}{c}\right)^2}\right] \quad (4)$$

where l is the taper length.

For the proposed striplines [2] of 1.7 m length, the even mode characteristic impedance (Z_e) is 50 Ω and the coverage angle (ϕ_0), for each stripline, is 2.0 radians. Hence the low frequency peak for the longitudinal coupling impedance calculated by the analytical equation (2) is approximately $20\,\Omega$: the first peak is at 44 MHz, which corresponds to a quarter wavelength of the striplines, and the peaks are separated by 88 MHz. With a taper of 125 mm length, corresponding to the 1 GHz CLIC baseline, it is possible to reduce the longitudinal coupling impedance almost to zero above 1 GHz (Fig. 2). In the case of transverse coupling impedance, the first peak calculated by the equation (3) corresponds to a value of approximately $120\,k\Omega/m$; with a taper of 125 mm (1 GHz operation mode) it is reduced to almost zero above 1 GHz (Fig. 3). Similar results have been found for the 2 GHz CLIC baseline, with a 140 mm taper length.

Initial longitudinal beam coupling impedance simulations, using CST Particle Studio, were carried out during 2011 [8]. Although the predictions were in reasonable agreement with the analytical predictions up to 500 MHz, several problems were subsequently identified in the model: these problems include transitions between electrodes and the stripline beam pipe which were not modelled well. In addition, the coverage angle previously used

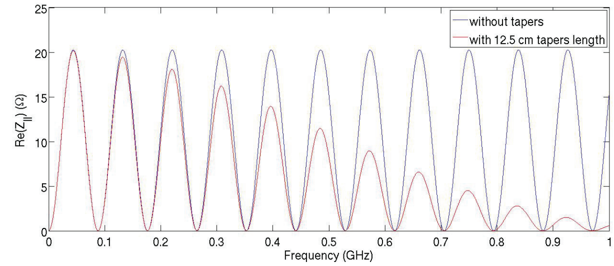

Figure 2: Analytically calculated longitudinal beam impedance for both untapered and tapered striplines of 1.7 m overall length.

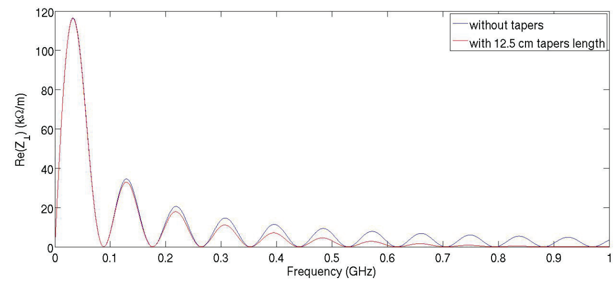

Figure 3: Analytically calculated transverse beam impedance for both untapered and tapered striplines of 1.7 m overall length.

in the analytical equations for flat electrodes was not well defined. The CST model of the striplines has being upgraded: the new model consists of striplines of 1 m length excited by a bunch of 30 mm bunch length, to reduced the simulation time in comparison with more realistic but significantly shorter bunches. The first results with an abrupt transition between the stripline and the beam pipe (untapered kicker), see Fig. 4, are shown in Fig. 5 and Fig. 6 for longitudinal and transverse beam coupling impedance, respectively.

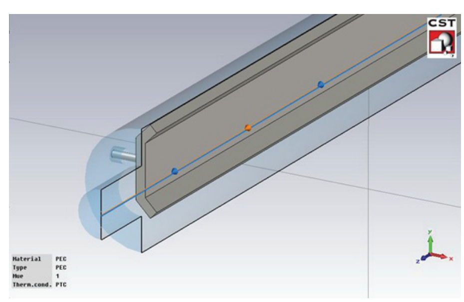

Figure 4: Stripline kicker simulated by CST with an abrupt transition towards the adjacent beam pipe.

The predictions from the simulations agree well with the results from the analytical equations. Therefore, this CST model will be used to study the effect upon the beam coupling impedance of: (1) conical beam pipe transitions, (2) mismatched impedances at the ports (e.g. due to a non-ideal resistive terminator and/or pulsed power supply), and

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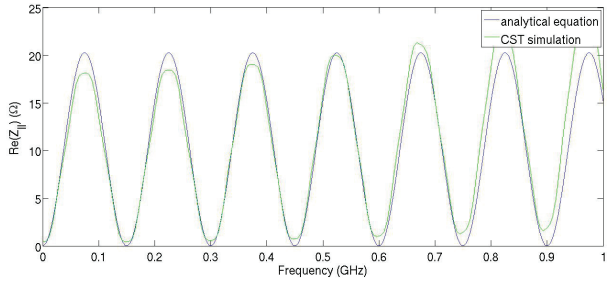

Figure 5: Longitudina beam coupling impedance results from both the analytical equation and the CST simulation.

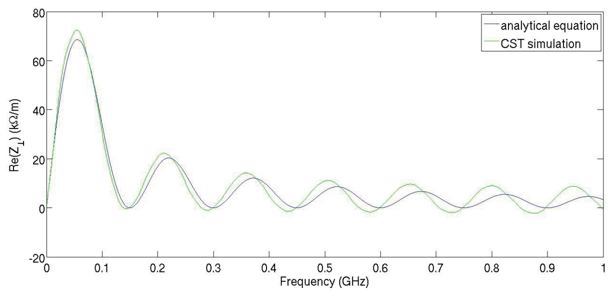

Figure 6: Transverse beam coupling impedance results from both the analytical equation and the CST simulation.

(3) the transitions between the feedthroughs and the electrodes.

Higher Order Modes

A detailed study, including several beam effects have commenced: these include heating, coupled bunch instabilities, microwave instability and tune shifts.

STRIPLINE KICKER PROTOTYPE AND FUTURE TESTS

The design of a set of striplines is being finalized and will be prototyped during the next months. This prototype is designed to take into account the main parameters of the striplines required for the CLIC DR extraction kicker: however the prototype design will be modified to permit testing with beam in ATF2. The results of detailed tests and measurements (see below) will be compared with predictions to validate the design procedure; hence, the procedure can later be used, with confidence, to design the actual CLIC PDR and DR striplines.

The tests planned are the following:

- Laboratory test at CERN: verification of the stripline dimensions, field homogeneity, longitudinal and transverse beam coupling impedance, vacuum performance and high voltage performance.
- Tests and measurements at ALBA: using d.c power supplies instead of a pulse generator, to determine transverse beam coupling impedance and, if possible, longitudinal beam coupling impedance. Field homogeneity measurements will be carried out with the d.c. power supplies and a closed bump.
- Tests and measurements in ATF2: the complete stripline kicker will be tested, together with inductive adders which are presently being designed [3]. The kicker will be installed in a straight section in the Final Focus System, where many cavity BPMs with high resolution can be used to measure the stability and jitter of the beam deflection.

CONCLUSIONS

The effect of tapers has been investigated: tapers of 125 and 140 mm, for 1 and 2 GHz CLIC baselines, respectively, are needed between the stripline beam pipe and the DR beam pipe to reduce the beam coupling impedance at high frequencies. For these taper lengths, both the longitudinal and the transverse beam coupling impedances are almost zero above 1 GHz. There is good agreement between the longitudinal and transverse beam coupling impedance, for untapered striplines, predicted using CST and derived from analytical equations. The CST model will be used to study a range of effects. Once the prototype striplines are built, measurements of field homogeneity and beam coupling impedance will be compared with both the analytical predictions and the results from simulations.

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