STUDY OF FUNDAMENTAL MODE MULTIPOLAR KICKS IN DOUBLE- AND SINGLE-FEED POWER COUPLERS FOR THE CLIC MAIN LINAC ACCELERATING STRUCTURE

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Abstract

Multipolar kicks from the fundamental mode have been calculated in the CLIC baseline accelerating structure with double-feed input and output power couplers. The influence of such multipolar kicks on the main linac beam dynamics has been investigated. Furthermore, an alternative design of the couplers with single-feed has been studied and compared with the double-feed. Such an alternative would significantly simplify the waveguide system of the main linac but potentially introduce an harmful dipolar kick from the fundamental mode. The geometry of the coupler has been optimized in order to minimize such a dipolar kick and keep it below threshold levels determined with beam dynamics simulations. Influence of the higher order multipoles has been investigated as well and acceptable levels have been determined.

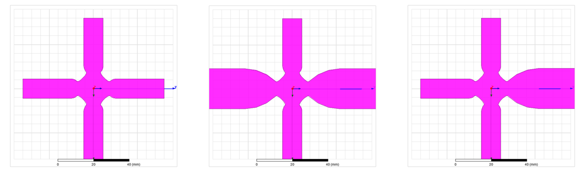
INTRODUCTION

In order to increase RF-to-beam efficiency in CLIC, 312 bunches spaced by 0.5 ns are accelerated in the main linac within one RF pulse. This sets stringent requirements on the transverse wakefield suppression which are met by means of strong damping using four waveguides attached to each cell of the accelerating structure. In Fig. 1, cross-sections of the different cells of the accelerating structure are shown, clearly demonstrating that the shape of the cells is far from being axially symmetric. This means that the electro-magnetic field of the main accelerating mode has non-zero variations in azimuthally direction which can be represented using multipolar decomposition similar to the magnetic field multipolar decomposition used in magnet design [2].

In the regular accelerating cell shown in Fig. 1 (a), the lowest multipole is an octupole (m=3) due to 3 plane symmetry. In order to feed power in and out of the traveling wave accelerating structure it is equipped with input and output power coupler cell which cross-section is shown in Fig. 1 (b) for the CLIC baseline double-feed coupler. In this case, the lowest multipole is a quadrupole (m=2) due to 2 plane symmetry. An alternative single-feed power coupler is also considered in this paper in order to evaluate the impact of the dipolar RF kick which is non-zero due only 1 plane symmetry. Although dipolar RF kick can be minimized by optimizing cell geometry as shown in Fig. 1 (b) it cannot be set to zero if coupler cell is also used for acceleration.

RF-KICK

The impact on the beam dynamics of the RF-multipolar kick described in the previous section has been simulated with the tracking code PLACET using the new element RF-Multipole recently introduced (see [3, 4]). An RF-multipole is an element that behaves like a regular multipole, except for its multipolar coefficients that oscillate in time with frequency f_{RF}, and depend on the longitudinal position z of the article just like an RF field:



(a) (b) (c)

Figure 1: (a) Cross-section of the regular accelerating cell, (b) double-feed power coupler cell, and (c) single-feed power coupler cell in the waveguide damped accelerating structure for CLIC main linac.

$$\tilde{A}_n(r_0, z) = \mathrm{Re}\left\{|\vec{A}_n(r_0)|\, e^{j(k_{\mathrm{RF}} z + \vartheta_n)}\right\},$$
$$\tilde{B}_n(r_0, z) = \mathrm{Re}\left\{|\vec{B}_n(r_0)|\, e^{j(k_{\mathrm{RF}} z + \varphi_n)}\right\},$$

or, more briefly: $\tilde{C}_n(z) = \tilde{B}_n(z) + i\,\tilde{A}_n(z)$. $\vec{B}_n$ and $\vec{A}_n$ are the two phasors representing the normal and the skew coefficients of the rotating multipolar component, $z = ct$ is the longitudinal coordinate of the witness particle with respect to the reference, and $k_{\mathrm{RF}} = {}^{2\pi}/_{c} f_{\mathrm{RF}}$ is the RF wave number. Therefore two real numbers, $|\vec{A}_n(r_0)|$ and ϑ_n, characterize the skew component, and two real numbers, $|\vec{B}_n(r_0)|$ and φ_n, represent the normal component.

Multipole Expansion and Kick Reconstruction

The electro-magnetic field in the CLIC main linac accelerating structure has been computed using the frequency domain finite element code HFSS [1, 5]. Then, the electric and magnetic field maps have been combined and reduced to their most important multipolar components using a software that we specifically developed to ease the integration of arbitrary RF electromagnetic potentials in PLACET. This tool calculates the multipolar coefficients of any electro-magnetic field map using three different techniques, to be chosen on a case-to-case basis: numerical integration over a disk, numerical integration over a circle, fitting procedure. It divides the entire volume occupied by the field in slices along the longitudinal direction, and performs a multipolar expansion in each of the transverse field $(E_x,\ E_y)$, or alternatively E_z, slice by slice to compute the

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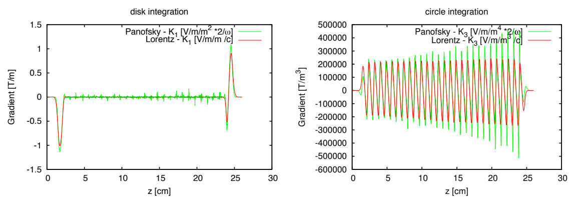

Figure 2: Magnetic-equivalent quadrupolar and octupolar strengths, due to the double-feed couplers, in the baseline accelerating structure, calculated using Panofsky-Wenzel and the Lorentz force for the on-crest particle. The quadrupolar mode reveals the position of the entrance and exit couplers, whereas the octupolar mode is present along the inside of the accelerating structure itself.

coefficients C_n and D_n:

$$E_y + iE_x = \sum_{n=1}^{N} C_n\,(x+iy)^{n-1}\,;\; E_z = \sum_{n=0}^{N} D_n\,(x+iy)^{n}$$

The longitudinal coefficients D_n are homologous to the transverse C_n, as it can be demonstrated using the Panosfky-Wenzel theorem, which gives:

$$D_n = \frac{nc\,C_n}{\omega_{\mathrm{RF}}}.$$

To perform the tracking simulations, these electric multipole coefficients are converted into the equivalent magnetic strengths and then introduced in PLACET. Figure 2 shows the quadrupolar and octupolar normal components of the double-feed coupler along the z axis.

RF-kicks in Double and Single-feed Couplers

The symmetries of the double- and single- feed couplers are such that only certain multipolar modes are allowed. Single-feed couplers impart a dipolar+quadrupolar+sextupolar kick; double-feed couplers impart a quadrupolar kick; and in the overall accelerating structure, which is about 25 cm long, an octupolar mode is present regardless of the couplers associated (as visible in Fig. 2). The integrated RF strengths of these modes are summarized in Table 1.

The single-feed coupler contains an horizontal dipole mode that, if not counteracted, would kick the beam in the same direction throughout the entire linac. To counteract this effect a first-order compensation is put in place, alternating the orientation of two consecutive accelerating structures. This configuration is depicted in Fig. 3

SIMULATIONS

The high-order multipolar kicks described in the previous paragraphs can greatly harm the beam emittance, because they can induce transverse kicks and couplings even in a perfect machine, and they can induce dispersion and emittance growth whenever a bunch traverse an accelerating structure off-axis.

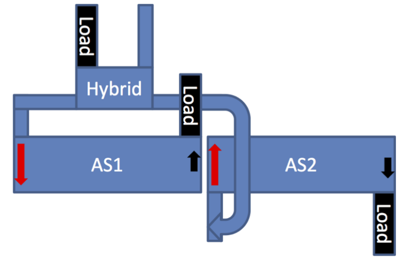

Figure 3: Proposed configuration for the single-feed coupler. AS1 and AS2 are two consecutive accelerating structures, with 180 degrees azimuthal angle between each other. In this configuration the horizontal dipole kick imparted by AS1 is compensated by the kick imparted by the downstream structure AS2.

The impact of the transverse multipolar kicks on the main linac beam dynamics has been studied in a number of different cases. In the following simulations, the nominal CLIC parameters at 3 TeV center of mass energy have been used (see CLIC CDR[6]). Aim of this study was to compare the single-feed coupler configuration against the double-feed.

Impact in a Perfect Linac

The impact of the RF-multipolar kick has been studied in a perfect linac, and compared against the performances of a machine where the couplers have been neglected. The respective horizontal and vertical emittance growths along the linac are shown in Fig. 4. These plots show that the relevant effect is in (c): the horizontal axis in the single-feed coupler case, where the constant dipole kick deflects the beam although it is partially compensated by the alternate design presented in Fig. 3. This emittance growth is completely recovered by applying 1-to-1 correction.

Impact in Presence of Cavity Misalignments

Simulations of cavity misalignments have also been performed, showing that the performances of single-feed and double-feed couplers are comparable. The horizontal axis of the single-feed configuration requires a further step of 1-to-1 correction to cancel out the horizontal kick.

Tolerances on Element Misalignment

The tolerances to element misalignment and cavity imperfections, when the couplers are taken into account, have been studied. Since the single-feed coupler seems to be the most critical due to the constant kick in the horizontal axis, we have focused our attention on this coupler design. The results of the simulations, summarized in Fig. 5, show that the impact of the couplers is negligible with respect to the simulation without couplers.

CONCLUSIONS

The couplers of the accelerating structures break the symmetry of the beam-pipe and induce transverse kicks

Table 1: Integrated strengths of the multipolar kicks for double-feed couplers (DF, baseline), single-feed couplers (SF), and throughout the entire accelerating structure (AS). The numbers marked with the abbreviation PW have been calculated using Panofsky-Wenzel on the E_z expansion; the numbers marked with Lorentz have been calculated using the Lorentz force on the (E_x, E_y) expansion.

MODE	DIPOLE [V]	QUADRUPOLE [T]	SEXTUPOLE [T/m]	OCTUPOLE [T/m^2]
DF input	-	PW: -0.0065 + 0.0033i	-	-
coupler	-	Lorentz: -0.0066 + 0.0033i	-	-
DF output	-	PW: -0.0032 + 0.0105i	-	-
coupler	-	Lorentz: -0.0030 + 0.0106i	-	-
SF input	PW: -14171 -1425i	PW: -0.0064 - 0.0009i	PW: -0.82 - 0.11i	-
coupler	Lorentz: -14173 - 1424i			-
SF output	PW: -6470 +1095i	PW: 0.0030 + 0.0004i	PW: 0.38 + 0.01i	-
coupler	Lorentz: -6481 +1089i			-
AS	-	-	-	PW: -316 +79404i
	-	-	-	Lorenz:-145 +79333i

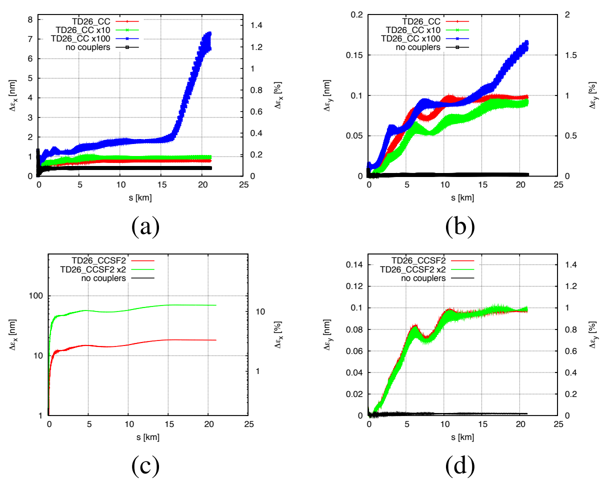

Figure 4: Impact of RF-multipolar kicks on a main linac without imperfections for: (a) and (b), horizontal and vertical emittance growth with double-feed couplers; (c) and (d) horiz. and vertical emittance growth with single-feed couplers.

that perturb the beam and induce emittance growth. The transverse deflections in the CLIC accelerating structures have been computed for the baseline design (double-feed) and for an alternative design (single-feed). Their electromagnetic potentials have been modeled through RF-multipolar expansions in order to allow the simulation with the tracking code. The results show that, in the case of static imperfections, the impact of the single- and double-feed couplers on the main linac beam dynamics is comparable and overall negligible. Further studies of dynamic imperfections will need to be performed.

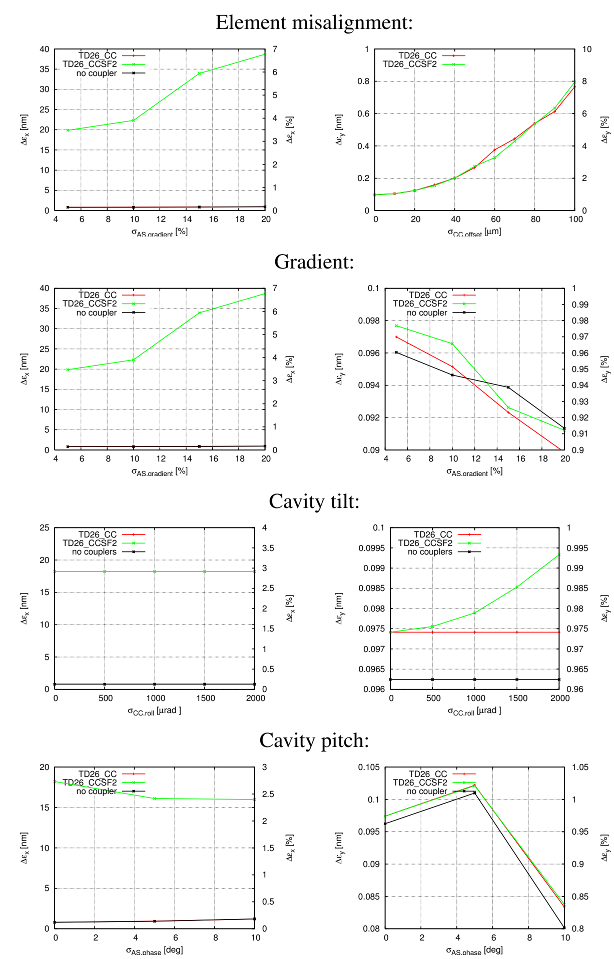

Figure 5: Tolerance to various imperfections for the singe-feed coupler design. In black is the result of the simulation when the couplers are neglected.

REFERENCES

[1] A. Grudiev, W. Wuensch, *"Design of the CLIC Main Linac Accelerating Structure for CLIC Conceptual Design Report"*, Proceedings of Linear Accelerator Conference LINAC2010

[2] S. Russenschuck, *"Field computation for accelerator magnets: analytical and numerical methods for electromagnetic design and optimization"*, Weinheim : Wiley, 2010

[3] A. Latina et al., *"Improvements in the PLACET tracking code"*, this conference

[4] http://cern.ch/project-placet

[5] ANSYS HFSS, www.ansys.com

[6] CLIC Conceptual Design Report, CERN, 2012