IMPROVED CLIC PERFORMANCES USING THE BEAM RESPONSE FOR CORRECTING ALIGNMENT ERRORS

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It has been demonstrated that in the Compact Linear Collider (CLIC) alignment errors of the order of 10 microns r.m.s. can be tolerated on the main linac components, in particular on pick-ups. These results imply the application of trajectory-correction processes involving several correctors and beam-position monitors, of the 'dispersion-free' or 'wake-free' types. The disturbing effects to be corrected have so far been simulated by gradient variation of the lattice quadrupole chains. Recently, the idea of a direct evaluation of these effects was suggested. In particular, one can measure the response of the trajectory when the beam intensity is modulated. By incorporating into the above-mentioned algorithms the measured trajectory differences in order to minimize them, better performances are achieved than when these undesirable effects are simulated. The results presented show a gain of a factor of two on the vertical emittance blow-up.

I. INTRODUCTION

The transverse emittance control is an important issue for future linear colliders. Alignment errors affect the position of lattice quadrupoles and of R.F. cavities. Dispersive effects as well as transverse wakefields are then generated, leading to emittance dilution. The relative importance of these effects is related to each collider design. It is possible to use processes involving the minimization of expressions related to the basic trajectory, measured at nominal momentum, as well as expressions related to trajectories taken for different detuned machine conditions. The efficiency of the method is directly related to the assumptions made on pick-up alignment and resolution errors. These processes can be of the dispersion-free (DF) or wake-free (WF) types as initially suggested at SLAC [1]. In the first, the focusing and defocusing quadrupole chains are detuned by the same relative amount, whereas in the second case their setting is modified in opposite directions. The application of these methods to the Compact Linear Collider (CLIC) main linac is discussed in Ref. [2]. One interesting aspect is that quantities involving trajectory differences are invoked in addition to the basic trajectory. The importance of pick-up alignment errors, supposed to be static during the process, is then diminished and it is possible to rely more on pick-up resolution errors, which will remain confined in the sub-micron range. The last results obtained for CLIC are described in Ref. [3]: assuming alignment errors of 10 μm (r.m.s.) on quadrupoles, cavities, and pick-ups, vertical emittance values of around 20×10^{-8} rad·m can be obtained at the end of the linac (3200 m for a final energy of 250 GeV per beam).

Recently, the idea of a direct evaluation of the wakefields has emerged, instead of their simulation by quadrupole detuning. One way is to measure the beam trajectory at various currents and to minimize differences. This concept was used to perform simulations in the case of the NLC, with promising results [4]. It has also been tried for CLIC.

II. WAKEFIELD CORRECTION WITH MEASURED WAKEFIELDS (MW)

With respect to NLC the transverse wakefield strength is stronger by a factor of 18 (it scales as f_{RF}^3) in CLIC. In the case of the NLC the bunch current is increased for a proper evaluation of the wakefield effects [4]. In CLIC the wakefields dominate all the beam dynamics effects at the nominal bunch charge value ($N_p = 6$ to 8×10^9 particles). Therefore, the problem is rather to find conditions where the influence of the wakefields is small enough and which can be used to determine a trajectory followed by a beam not affected by wakefields. Simulations show that this condition is reached when the bunch population is reduced by one order of magnitude from its nominal value (Fig. 1): the trajectory taken at nominal current with wakefields switched off is similar to the trajectory measured with a bunch charge ten times smaller in the presence of wakefields.

The application of a wakefield correction with measured wakefields (MW) not only requires the measurement of differences Δx_j between trajectories taken for different charges N_p and $N_p/10$, but also their prediction ΔX_j [2]. The determination of ΔX_j requires the knowledge of all the transfer matrix coefficients $R_{12}(i, j)$ from a kick θ_i to each pick-up j with $j > i$ (located downstream). This is needed for the nominal machine and for $N_p/10$ (description of the linac without wakefield). However, in order to avoid having to evaluate these coefficients twice, the linac description used in the absence of wakefield is simply the basic optics model. The implementation of the method is then simpler, but this is an approximation compared to the actual case, as some effects, for example energy dispersion within the bunch, are neglected. Then, in our case:

$$\Delta X_j = X_j \text{ (nominal)} - X_j \text{ (model)}$$

with

$$X_j \text{ (nominal)} = \sum_{i<j} R_{12}(i, j, \text{nominal})\, \theta_i$$

$$X_j \text{ (model)} = \sum_{i<j} R_{12}(i, j, \text{optics model})\, \theta_i$$

For a kick, supposed to be located at lattice quadrupoles, the 50 subsequent pick-ups are considered (one pick-up being installed every two girders).

The results of this MW process application after 800 m (80 cells) are represented in Fig. 2: alignment errors: 10 μm (r.m.s.) on quadrupoles, pick-ups and cavities.

Starting from a pre-aligned machine (Fig. 2a) the emittance evolution is shown (Fig. 2b) after the application of 19 iterations on 18 quadrupoles (nine cells) each, with an overlap of nine half-cells between consecutive iterations. The process converges straight off (no second pass is needed) and is the most efficient when the maximum number of cells is considered per iteration

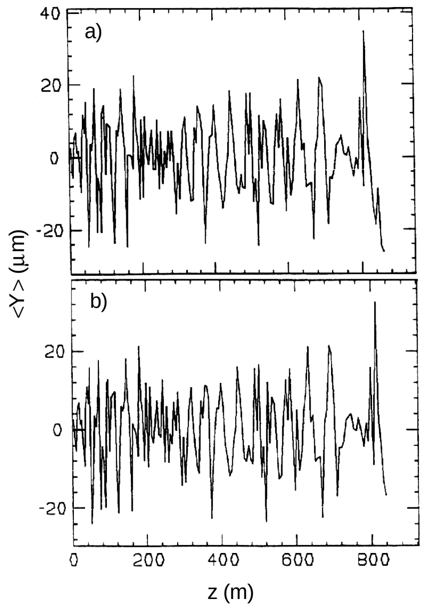

Figure. 1. Measured trajectory on the first 800 m: a) $N_p = 6 \times 10^9$, wakefields OFF, b) $N_p = 6 \times 10^8$, wakefields ON.

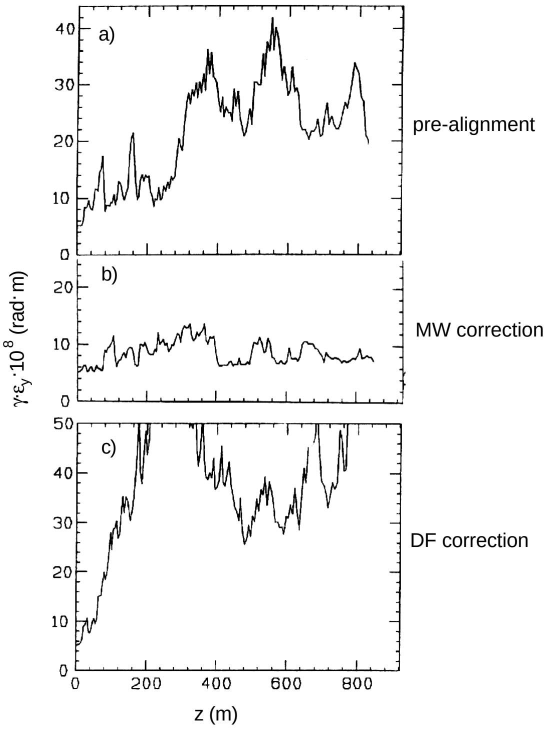

Figure. 2. Vertical normalized emittance over 800 m.

(the 50 pick-ups considered for a kick are distributed over nine cells). The efficiency is best when weighing 10 to 100 times more the term describing wakefield effects compared to the trajectory term.

However, correction of the dispersion on this wakefield-corrected linac, disturbs the results (Fig. 2c). A solution is to consider simultaneously a term describing the effects of wakefields and a term related to dispersive effects.

III. DISPERSIVE WAKEFIELD ALGORITHM (DW)

In order to at the same time minimize wakefields and dispersion, with the first term related to the trajectory, taken for nominal current N_p and nominal momentum p_0, two other terms should come in the algorithm: one related to wakefield effects, dealing with trajectory differences at nominal energy between bunch charges N_p and $N_p/10$,

$$\begin{aligned} \Delta x_j &= x_j(N_p, p_0) - x_j(N_p/10, p_0) \\ \Delta X_j &= X_j(N_p, p_0) - X_j \text{ (optics model)} \end{aligned} \quad (1)$$

and one extra to correct dispersion, describing the differences between a particle having nominal momentum p_0 and another particle with an energy excursion $\pm\delta = \pm\Delta p/p_0$,

$$\begin{aligned} \Delta x_j^{\pm\delta} &= x_j(N_p/10, p_0 \pm \delta p_0) - x_j(N_p/10, p_0) \quad (2) \\ \Delta X_j^{\pm\delta} &= X_j(N_p/10, p_0 \pm \delta p_0) - X_j \text{ (optics model)} . \end{aligned}$$

Each term can be properly weighed with respect to the others. The determination of the quantities X_j coming into the third term requires a further description of the linac ($R_{12}(i, j)$ coefficients) for the energy deviations $\pm\delta$. Again, this was taken from the model at the relevant energies. Using this algorithm gives good results (Fig. 3a): the improvement with respect to Fig. 2b can be appreciated. The terms related to wakefields and dispersion are weighed 100 times more than the term dealing with the trajectory.

The second and third terms can then be combined into a single term which will at once take care of wakefields and dispersion and can be refered to as a Dispersive Wakefield (DW) term. Here, the trajectories with energy excursion $+\delta$ and $-\delta$ and without wakefield, are compared to the nominal trajectory:

$$\begin{aligned} \Delta x_j^{\pm\delta} &= x_j(N_p/10, p_0 \pm \delta p_0) - x_j(N_p, p_0) \\ \Delta X_j^{\pm\delta} &= X_j(N_p/10, p_0 \pm \delta p_0) - X_j(N_p, p_0) . \end{aligned} \quad (3)$$

This scheme is more efficient as the number of trajectories to be measured and calculated is decreased.

IV. RESULTS

The application of a DW correction on the same machine gives the results represented in Fig. 3b. Again, a relative weight of 100 is given to the term describing wakefields and dispersion. The efficiency is as good as when the two terms are distinct (Fig. 3b compared to Fig. 3a). Applying this strategy up to the end leads to the results presented in Fig. 3c: an emittance value $\gamma\epsilon_y = 10 \times 10^{-8}$ rad·m is obtained after 51 iterations from the pre-aligned machine. This represents an improvement by a factor of two compared to the results cited in Ref. [3].

The scheme was tested on another machine with the same longitudinal parameters (RF phase 7°, bunch length 0.17 mm, bunch charge 6×10^9 considered between $\pm 3\sigma_z$) but with completely different alignment-error distribution (still of 10 μm r.m.s.). Results are presented in Fig. 4 after 2000 m and 43 iterations ($\gamma\epsilon_y = 9 \times 10^{-8}$ rad·m is obtained — Fig. 4a) and at the end of the linac after 90 iterations (Fig. 4b). It was necessary to add a few iterations between 2000 m and 3000 m, placing

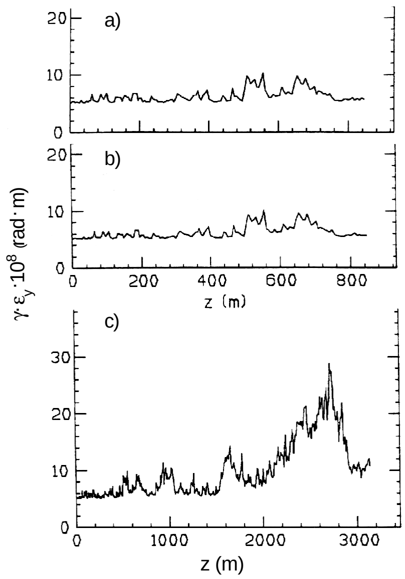

Figure. 3. Vertical normalized emittance evolution: a) MW+DF process; b) and c) DW process.

more emphasis on a wakefield term without dispersive component (MW correction), and also on the trajectory term. A value $\gamma\epsilon_y = 10 \times 10^{-8}$ rad·m is observed at the end of the linac.

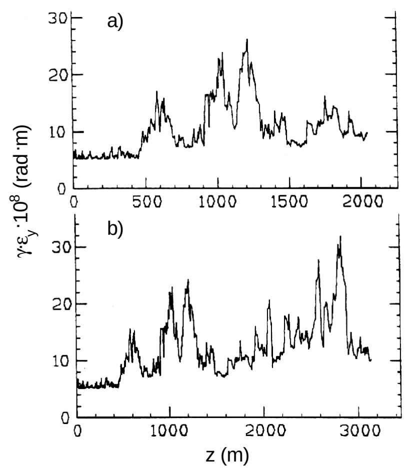

Figure. 4. Vertical normalized emittance: a) DW process after 2000 m; b) at the end of the linac.

A third machine was considered (Fig. 5) with the latest longitudinal parameters proposed for CLIC [5]: RF phase 12°, bunch length 0.2 mm, bunch charge 8×10^9 considered between $\sim +1\sigma_z$ and $\sim -2\sigma_z$ (this machine has an energy spread reduced by a factor of two). As in the previous case, the DW process was efficient in the first half of the linac but the correction process had to be resumed from 1500 m with a MW algorithm, and the basic trajectory term stressed near the end. This strategy kept the emittance below 20×10^{-8} rad·m along the linac and led to a final value $\gamma\epsilon_y = 10 \times 10^{-8}$ rad·m after 95 iterations.

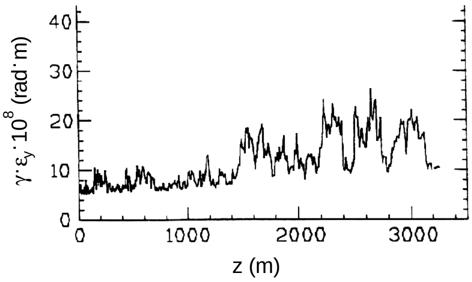

Figure. 5. Emittance growth on the third (nominal) machine.

V. DISCUSSION AND CONCLUSION

A method based on the measurement of wakefield effects by modulating the bunch charge has been tried in CLIC and appears more efficient than when these effects are simulated by quadrupole detuning. This is particularly true in the first half of the linac, where, using the largest number of kicks and pick-ups in a given iteration (only limited by the model description), the process converges straight off, hence limiting the number of iterations needed. Wakefields and dispersive effects can then be combined into a single term in the algorithm; the process is thus easier to implement, the number of machine conditions to be described being reduced. The implementation of such a scheme, in particular the way of regularly modulating the bunch charge during its application, remains to be studied.

At higher energies, this DW algorithm appeared less powerful, and adding a simpler MW algorithm or merely a trajectory correction was sometimes beneficial. A possible reason could come from the model used to describe the machine without wakefields. Another possibility is the artificial splitting of the linac into sectors in the model, without their overlapping. The final vertical emittance value is improved by a factor of two, with a process relying on the beam response, keeping alignment tolerance at 10 μm (r.m.s).

VI. REFERENCES

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