Coping with Alignment Tolerances on CLIC Components in the 10 μm Range

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Abstract

For the main linac of CLIC it has been established that when alignment tolerances on position monitors are relaxed beyond a given figure, of the order of a few microns, trajectory correction processes involving several correctors and beam-position monitors, of either 'dispersion-free' or 'wake-free' type, provide the best performance when they are used to control the beam trajectory and hence minimize the emittance blow-up. This paper describes the application of these methods to the linac with new injection energy and different scaling laws with energy applied on the lattice quadrupole strengths and on the accelerating section lengths as suggested elsewhere. Results show that with these parameters reflecting the most recent CLIC specifications it is possible to tolerate misalignment r.m.s. distributions of up to 10 μm for some machine main components like pick-ups and accelerating structures, whereas quadrupole offsets are adjusted within these tolerances from larger initial excursions. The desired requirements on the final vertical emittance value are met.

1. INTRODUCTION

It has already been shown [1], in the case of the CLIC main linac, that it is beneficial to use correction algorithms involving several correctors and pick-ups, and dealing not only with the trajectory but minimizing also quantities describing effects which are energy dependent (dispersion, wake fields). For a given structure of the linac, in particular for the same pick-up distribution and the same scaling law with energy applied on focusing strength and accelerating section length, processes involving these algorithms allow one to relax the alignment tolerances well beyond the values tolerated by 'one-to-one' type corrections if the aim is to preserve the final normalized emittance within its nominal limit which, in the case of CLIC, is $\gamma\varepsilon_y = 20 \times 10^{-8}$ rad·m in the vertical plane. For an injection energy E_{inj} = 5 GeV, and with the usual $(E/E_{inj})^{1/2}$ scaling law applied on both the focusing strength and the section length in order to maintain constant the stability margin along the linac [2], it is possible to tolerate misalignment r.m.s. values of the order of 5 μm [1] on pick-ups and RF cavities. This value is larger than tolerances that can be accepted by 'one-to-one' schemes by a factor of two.

Recently, some of the nominal parameters of CLIC were revisited. In particular, it is now suggested [3] to raise the injection energy to implement better a necessary bunch compression stage prior to injection. Hence the injection energy is increased from 5 GeV to 9 GeV. Moreover, different scaling laws from the one mentioned previously are also proposed [3]. Instead of the same usual criterion $(E/E_{inj})^{1/2}$ applied on focal strength and section length, a different scaling is chosen for each of the two parameters, to balance better the effects of wake fields and chromaticity when the beam energy increases. Raising the injection energy decreases proportionally the influence of wake fields which are dominant at low energy. In addition, the new scaling policy aims at a reduction of the importance of chromatic effects at high energy. Both suggestions must then lead to a more stable machine. It appeared then interesting to test again the possible misalignment errors that can be tolerated with this new situation on the main machine components such as lattice quadrupoles, pick-ups and RF cavities: the previously established tolerances of 5 μm (r.m.s.) were increased by a factor of two for these three types of elements, and the correction process was resumed with an algorithm of either Dispersion-Free (DF) or Wake-Free (WF) type [1]. This was first tried on a machine with the new injection energy value and keeping the old scaling law and then considering both parameters with their new configuration. The basic principles of the method have been presented in Refs. [1] and [4], and its application for CLIC is described in detail in Ref. [5].

2. E_{inj} = 9 GeV – SCALING IN $(E/E_{inj})^{1/2}$

With an increased injection energy value and keeping the same scaling law, the accelerating sections between two quadrupoles are shorter. Along the 3200 metres of the linac, the total number of quadrupoles, where correctors and pick-ups are supposed to be located, increases from 320 to 400. Both the higher injection energy and the reduced section length contribute to reduce the relative impact of wake fields at low energy with respect to chromatic effects which are then enhanced near the end of the linac at high energy. Figure 1, showing the evolution of the vertical normalized emittance along the linac after correction, illustrates the results obtained in this case.

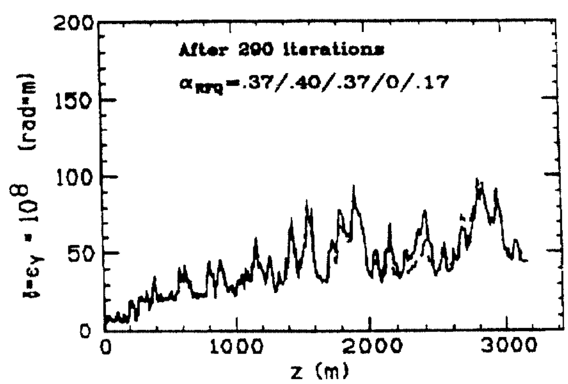

Figure 1. Vertical emittance blow-up along the linac with a scaling according to $(E/E_0)^{1/2}$ and aligment r.m.s. errors of 10 μm on quadrupoles, pick-ups, and cavities.

A total of 290 iterations was necessary, each on 6 to 10 pick-ups and correctors, correcting several times a given region by varying during the process the relative weight of trajectory and dispersive terms, as discussed in Ref. [1]. Once more the nominal trajectory had to be stressed in the early stage of the process, which indicates the probable need of a pre-alignment procedure, using for example a 'one-to-one' scheme, prior to the application of a DF or WF algorithm. At low energy, wake fields remain important and an emittance value $\gamma\varepsilon_y$ = 25×10^{-8} rad·m is observed at 800 m after 130 iterations, the final value being $\gamma\varepsilon_y = 45 \times 10^{-8}$ rad·m, i.e. a factor of two beyond the expected goal. A DF algorithm was in this case more efficient than a WF one in the final part of the linac, from 2500 m onwards. Chromatic effects are larger at high energy and it is helpful to decrease slightly the focusing strength by diminishing the excitation of the RF quadrupoles (controlled by parameter α_{RFQ}) which provide a relative focusing strength of a few per cent. In Figures 2 and 3 are represented the corrected trajectory and dispersive terms for an energy excursion $\Delta p/p_0 = \pm 3.5\%$. It was preferable near the end to stress the correction of the trajectory rather than that of the dispersive terms.

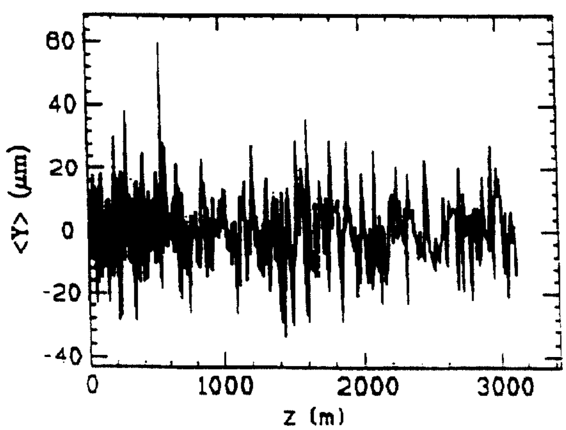

Figure 2. Corrected trajectory.

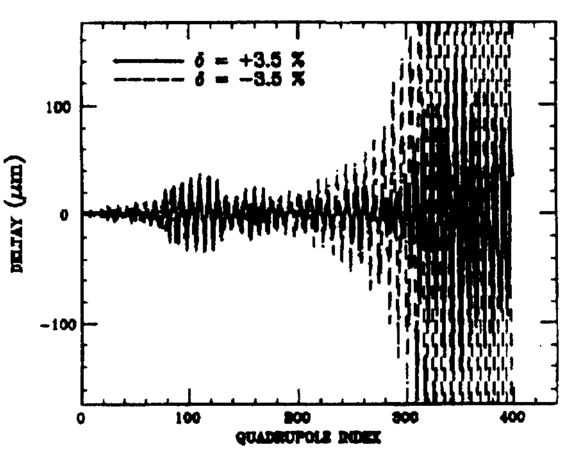

Figure 3. Corrected dispersive terms ($\Delta p/p_0 = \pm 3.5\%$).

3. E_{inj} = 9 GeV – NEW SCALING POLICY

In the new scaling strategy the accelerating section length is scaled according to $(E/E_{inj})^{0.3}$ and the quadrupole strength follows $(E/E_{inj})^{0.6}$ [3]. For an injection energy E_{inj} = 9 GeV, the total linac structure comprises 440 quadrupoles. The influence of wake fields is further reduced at low energy where they dominate, and the effect of chromaticity at high energy is relatively decreased as well. It was found easier and faster to control the emittance blow-up on this machine. Using a DF algorithm, a value $\gamma\varepsilon_y = 15 \times 10^{-8}$ rad·m is reached at 850 m after only 60 iterations (Figure 4) and by stressing essentially the trajectory term. A final value $\gamma\varepsilon_y$ = 28×10^{-8} rad·m is obtained after a total of 230 iterations. Considering the longitudinal bunch distribution between $+3\sigma_z$ and $-2\sigma_z$ (still 97.6% of the full beam) brings this value down to $\gamma\varepsilon_y = 22 \times 10^{-8}$ rad·m (plotted points). These results are again obtained by placing the main emphasis on the term related to the trajectory and in addition by a careful optimization of the focusing provided by the RF quadrupoles: the effect of setting α_{RFQ} at 0.33 instead of 0.26 (4% instead of 3.2% of the total focusing strength) in the last 850 metres of the linac is also illustrated on Figure 4.

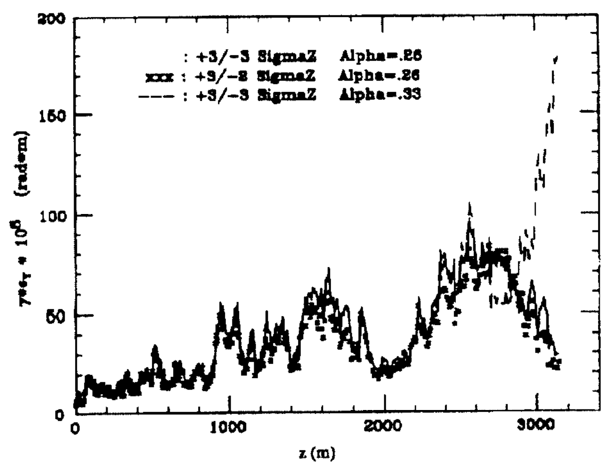

Figure 4. Vertical emittance blow-up along the linac with the 'new scaling' strategy and alignment r.m.s. errors of 10 µm on quadrupoles, pick-ups, and cavities.

However, near the end of the linac where chromatic effects are stronger, it was helpful to put the emphasis on the dispersive term in the algorithm. This is also reflected in Figure 5 where are represented the dispersive terms at the end of the process: their correction is more efficient than in the previous case discussed in Section 2. In Figure 6, and as was already the case in Figure 2, it is indicated that after correction, the achieved trajectory peak-to-peak amplitude is about twice the value of the pick-up aligment r.m.s. error which is assumed (10 µm in both cases). This corresponds to a reduction by a factor of 25 compared to the non-corrected trajectory.

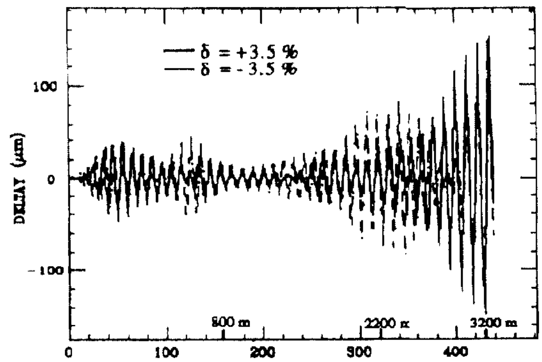

Figure 5. Corrected dispersive terms ($\Delta p/p_0 = \pm\ 3.5\%$).

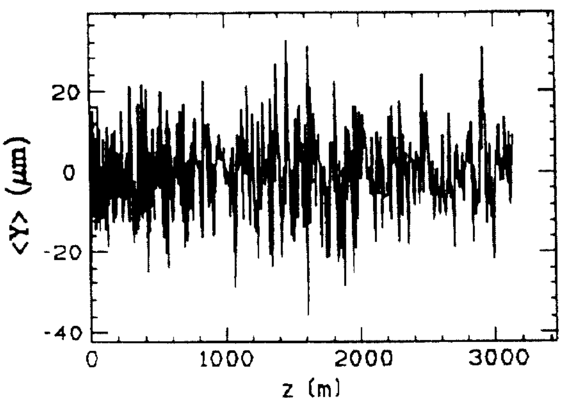

Figure 6. Corrected trajectory.

4. ADDING MORE PICK-UPS

So far, pick-ups and correctors were assumed to be located at lattice quadrupoles. Recently, it was suggested [3] to distribute pick-up stations regularly inside the accelerating sections. The effect of these extra pick-ups was also investigated. This should allow to reduce the trajectory excursions in the RF sections and hence wake field effects. In the example treated, pick-ups are supposed to be installed approximately every 2 metres and their number is then increased from 440 to 1670 along the whole linac. With the scaling of the section length there is one extra pick-up at the beginning of the linac between two quadrupoles, and up to four near the end.

In the first part of the linac, at low energy, no noticeable change of the algorithm efficiency is observed. However, when the process is resumed in the last kilometre in presence of three or four pick-ups added within each half cell, a significant reduction of the spike which was affecting the emittance blow-up is obtained (Figure 7 compared to Figure 4); 30 extra iterations are then performed. In the case of a 'one to few' scheme [3], the role of these additional pick-ups is important to reduce the disturbance of alignment errors which are very critical if one relies on the reading of one pick-up only. In a minimization process based by definition on several pick-ups (and correctors), this statistical improvement is automatically provided and the benefit of extra pick-ups is less obvious.

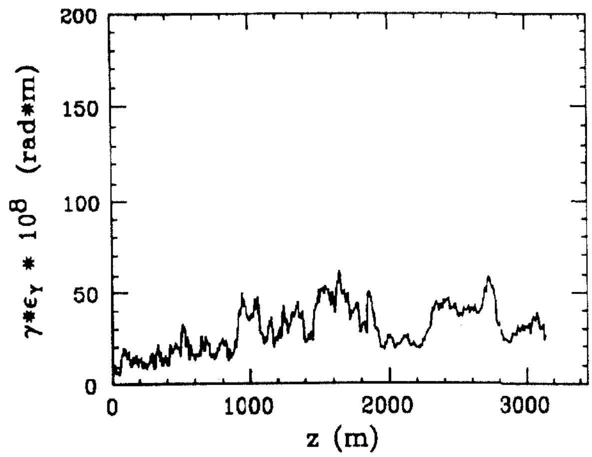

Figure 7. Vertical emittance blow-up with 30 iterations more in the last kilometre, with one pick-up every 2 metres.

5. DISCUSSION AND CONCLUSION

With the more recent parameters proposed for the CLIC main linac (injection energy of 9 GeV and different energy scaling for accelerating section length and focusing power) [3], it is possible to relax the alignment tolerances on cavities and pick-ups in the region of 10 µm with a pick-up located at each lattice quadrupole only. A process involving algorithms of the 'dispersion-free' or 'wake-free' type can be used to preserve the normalized vertical emittance within $\gamma\varepsilon_y = 20 \times 10^{-8}$ rad·m. Keeping the same conditions, a factor of more than four is gained compared with 'one-to-one' schemes which are easier to implement. With more pick-ups in the RF sections, 'one-to-few' processes allow one to reach $\gamma\varepsilon_y = 60 \times 10^{-8}$ rad·m with these tolerances [6]. Including these extra pick-ups in a process of the type mentioned may increase the efficiency of the method by decreasing the number of iterations needed to meet an emittance target value and relax the tolerances a little more. This provides an interesting safety margin, as do other possibilities which could also be envisaged (for example the movement of cavity girders). However, it is again necessary to underline the fact that such processes do not rely only on the strict application of an algorithm based on trajectory measurement. They need to be accompanied by the presence of diagnostics to measure the emittance evolution at 10 or 15 stations along the linac in order to make a better decision on the strategy to adopt, i.e. where to iterate and on which machine length. But the 10 µm range for alignment tolerances of the CLIC main linac components can be reasonably contemplated.

6. REFERENCES

[1] C. Fischer, Proc. PAC, Washington DC, 1993 and CERN SL/93-20.
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[3] G. Guignard, Proc. PAC, Washington DC, 1993 and CERN SL/93-20.
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