EMITTANCE PRESERVATION IN THE MAIN LINAC OF CLIC

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Abstract

The luminosity that can be achieved in a linear collider strongly depends on the vertical emittance of the beams at the interaction point. One of the most important sources of emittance growth is the accelerating part of the main linac especially in the case of the compact linear collider, CLIC[1], where the wakefields are strong due to the high frequency of the accelerating structures (30 GHz). Possible lattices for the main linacs for centre-of-mass energies of 1 TeV and 3 TeV are presented which allow the use of BNS-damping for emittance preservation. A new ballistic beam-based alignment technique to keep the emittance growth below the required limit is investigated. The influence of different prealignment and field errors on the correction efficiency is investigated.

1 LATTICE

In CLIC the RF-power fed into the main linac structures is produced by a second beam (drive beam) running parallel to the main beam in the so-called transfer-structures[2]. Each of these feeds two main linac accelerating structures. To facilitate the matching of the optics of the two beamlines they consist of modules. Each main linac module usually supports four structures with dimensions optimised for the 3 TeV machine. The necessary quadrupoles replace one to four of the cavities. A cavity BPM (beam position monitor) is placed in front of each quadrupole. For a parameter overview see Table 1.

The lattice consists of sectors, each containing FODO-cells of equal length and phase advance, and follows the scaling with energy E

$$L(E) = L_0 \left(\frac{E}{E_0}\right)^{\alpha_L}, \quad f(E) = f_0 \left(\frac{E}{E_0}\right)^{\alpha_f}$$

with the initial cell and focal lengths L_0 and f_0 at energy E_0 and the scaling parameters $\alpha_L = 0.5$ and $\alpha_f = 0.5$. Figure 1 shows the beta-function for the 3 TeV case.

The sectors are matched by adjusting the last three and first two quadrupoles. In the 1 TeV machine the phase advance is about 101° per cell while in the 3 TeV case approximately 70°, varying slightly from sector to sector. The smaller phase advance leads to a better stability for drift-like motion than the larger one which gives a better fill factor (ratio of active to total length). The drift-like motion is a significant problem for the small emittance at 3 TeV but not very severe for 1 TeV.

In order to stabilise the beam the so-called BNS-damping is used. In a first short section the RF-phase is set as to increase the bunch energy spread, in the main part of the linac it is chosen to keep the relative energy spread constant and in the last part it is set as to decrease the spread to a full width of less than 1 % in order to pass the final focus system.

Table 1: The parameters of the linacs.

Inital energy [GeV]	9	9
Final energy [GeV]	500	1500
Part. per bunch N	$4 \cdot 10^9$	$4 \cdot 10^9$
Bunches per train n_b	150	150
Dist. betw. bunches d [ns]	0.67	0.67
In. vert. emitt. $\epsilon_{y,0}$ [nm]	50	5
Final vert. emitt. ϵ_y [nm]	70	10
Emitt. budget [%]	40	100
Bunch length σ_z [μm]	50	30
Gradient G [MV/m]	100	150
Fill factor [%]	74	78
Bumps	5	10

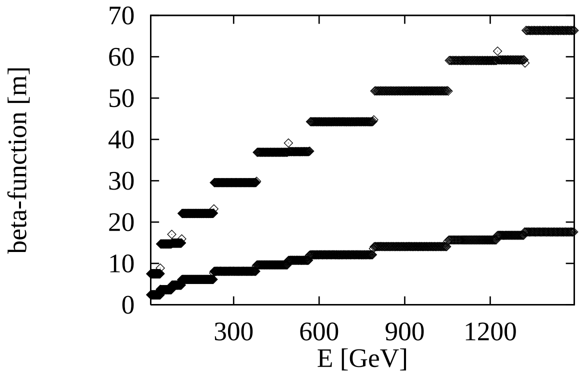

Figure 1: The beta-function along the 3 TeV-linac.

2 ERROR SOURCES

The elements will be accurately aligned (to better than 10 μm) using a system of wires. The simulations were performed using PLACET [3], averaging over 100 cases. All elements are assumed to be scattered around the common axis of the linac according to a normal distribution with a sigma of 10 μm for cavities and BPMs and of 50 μm for quadrupoles. The resolution of the BPMs is

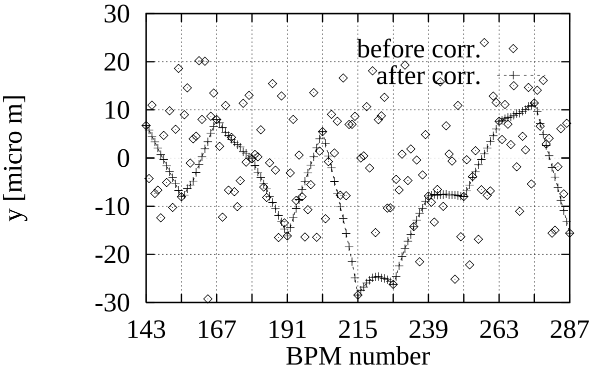

Figure 2: The offsets of the logical BPM centres before and after application of the ballistic alignment in some part of the linac. BPMs on vertical lines define the bin ends.

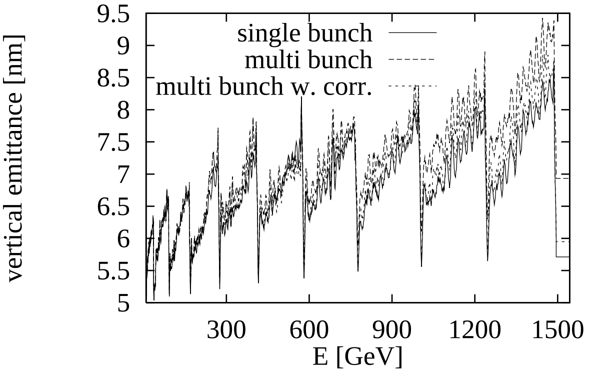

Figure 3: The emittance growth after the beam-based alignment for the 3 TeV machine.

$0.1\,\mu\mathrm{m}$ [4]. For the ballistic method the remnant field of the quadrupoles is assumed to be equally distributed between 0 and $2\,\%$ of the maximal field and to remain constant from one correction cycle to the next. The centre of this field is taken to be shifted from that of the full field by a normal distribution with a RMS-width of $10\,\mu\mathrm{m}$. During the measurement of the response coefficients and the correction the beam is assumed to have a jitter at the linac entry of $0.1\cdot\sigma_y$.

In the following the single bunch effects will be considered. The short range wakefields are taken from [5].

3 CORRECTION

The linac is initially corrected using the ballistic alignment technique[6]. In this method the beamline is divided into bins of twelve (or so) quadrupoles which are corrected one after the other. In the first correction step all quadrupoles of a bin but the first are switched off. With the first correction coil the beam is centred in the last BPM. The offsets of the other BPMs are then corrected such that the centres fall onto the measured beam position. In the second step the quadrupoles are switched on and a simple one-to-one correction is performed. These steps are iterated to reduce the effect of the remnant fields to a negligible level. The quadrupole after the last BPM in the bin is then used as the first one in the next bin. In this way the linac is divided into short sections in which the BPMs are aligned to straight lines with small kinks at the intersections, see Fig. 2.

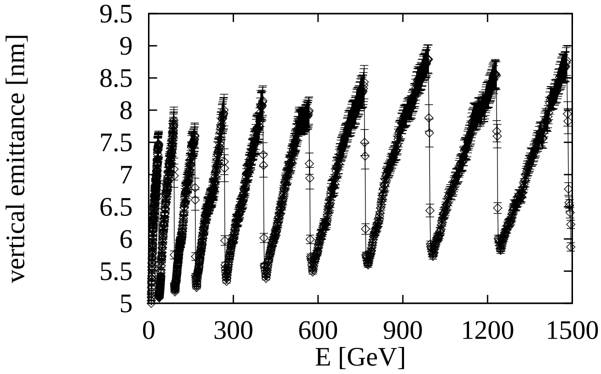

Figure 4: The emittance growth for the 3 TeV machine if also the cavities are aligned with the beam. The errorbars indicate the RMS-variation of the emittance for the 100 simulated cases.

For the 1 TeV case the resulting emittance growth is $\Delta\epsilon_y/\epsilon_{y,0} = 70\,\%$, for 3 TeV $\Delta\epsilon_y/\epsilon_{y,0} = 270\,\%$.

To further reduce the emittance, a number of emittance tuning bumps are used. For each transverse plane they consist of two small groups of structures that can be moved transversely and are separated by a phase advance of about 90°, comparable to those in Ref. [7]. A feedback following these is used to steer the beam back onto its original trajectory. In between the bumps a one-to-one correction is performed for the same purpose. The bumps are distributed so that the phase advance between them is approximately the same.

For the 1 TeV case five bumps were used, leading to an emittance growth of $\Delta\epsilon_y/\epsilon_{y,0} = 18\,\%$. For the 3 TeV case five and ten bumps were tried. As can be seen in Fig. 3, the emittance increase with ten bumps is about $15\,\%$, five bumps lead to $\Delta\epsilon_y/\epsilon_{y,0} \approx 30\,\%$. Smaller energy spreads of the beam and lattices with a smaller total phase advance between bumps are advantages for this correction. The minimal emittance achievable with the final bump is evaluated at the linac exit. Even so, this bump would most likely not be optimised for this but rather for the interaction point. The value is however indicative for the reduction that can be expected at the latter.

As can be seen in Fig. 3 the emittance increases rapidly after each bump, this is due to the initial misalignment of the BPMs. In the case of the 1 TeV machine, this effect is very small. The emittance measurement station is point-like in the simulation—in further studies it should be simulated in more detail. This beating in the emittance can however be suppressed if the cavities are realigned around the beam trajectory after correction. If the error on the final cavity position is $10\,\mu\mathrm{m}$, the emittance growth is comparable to the present case but the variation in the emittance is almost completely suppressed, see Fig. 4.

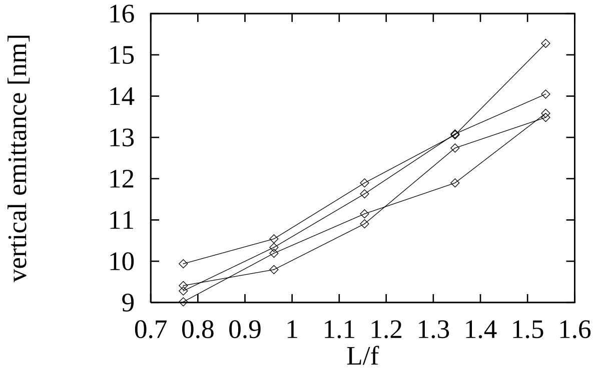

Figure 5: The emittance after $10^6\,\mathrm{s}$ of ground motion using one-to-one feedbacks for different—initially perfect—lattices. The different curves correspond to different focal lengths f ranging from 0.975 to $1.4625\,\mathrm{m}$.

4 STABILITY

Three different effects are considered, the ground motion, beam jitter and quadrupole jitter. To estimate the effect of ground motion the simple ATL-law is used with $A = 0.5 \cdot 10^{-6}\,(\mu\mathrm{m})^2/(\mathrm{sm})$, an upper limit taken from [8].

The effect of ground motion is reduced by using feedbacks to steer the beam back onto its original trajectory. Also a one-to-one correction can be used as a feedback. Further, the emittance bumps can be reoptimised.

For the $1\,\mathrm{TeV}$ machine the emittance growth after 10 minutes is $30\,\%$ if five feedbacks are used. The one-to-one correction yields $\Delta\epsilon_y/\epsilon_y \approx 16\,\%$ after about ten days ($10^6\,\mathrm{s}$), additional reoptimisation of the bumps leads to only $\Delta\epsilon_y/\epsilon_y \approx 6\,\%$. The linac would therefore have to be recorrected about once every month, only.

Due to the small emittance the $3\,\mathrm{TeV}$ machine is more sensitive to drifts, so it seems advantageous to use the one-to-one correction as a feedback. A number of simulations were performed using scaled lattices to find a good choice for L_0 and f_0. In Fig. 5 the emittance after $10^6\,\mathrm{s}$ is shown, in each case the RF-phase corresponding to the smallest energy spread gave the best result and was used. The emittance growth then depends mainly on the phase advance per cell, not on the lattice strength. Shorter focal lengths allow to use smaller energy spreads for BNS-damping, which also reduces the emittance growth. The parameters chosen are $L_0 = 1.5\,\mathrm{m}$ and $f_0 = 1.3\,\mathrm{m}$, not to compromise the fill factor too much. The energy spread used is larger than the one in the figure.

The emittance growth found with this lattice is $200\,\%$ per $10^6\,\mathrm{s}$ or about $20\,\%$ per day. Reoptimising the emittance bumps reduces the growth to about $5\,\%$ per day. Frequent realignment is therefore necessary.

The initial vertical beam jitter leading to an emittance increase of six percent is found to be about $0.3 \cdot \sigma_y$ for the $1\,\mathrm{TeV}$ and $3\,\mathrm{TeV}$ machines, for the multibunch case.

The uncorrelated jitter of the quadrupoles that leads to $6\,\%$ emittance increase with respect to the original position is found to be $4\,\mathrm{nm}$ and $1.3\,\mathrm{nm}$ for the $1\,\mathrm{TeV}$ and $3\,\mathrm{TeV}$ machine, respectively.

5 MULTIBUNCH ISSUES

Since no longrange wakefield calculations are available a very simplified model was suggested [9]. The field is fixed in phase and the amplitude is decaying exponentially over the first ten bunches, with different constants for the first and second five. Afterwards it remains constant. This is thought to be a pessimistic model using the information available on the amplitudes. As is shown in Fig. 3 the emittance growth of the train after correction with a single bunch is $40\,\%$ instead of $15\,\%$ for the single bunch. If the emittance bumps are reoptimised and a one-to-one correction is performed between bumps using the whole train, the resulting emittance growth is below $20\,\%$. The single bunch emittance along the train is almost constant, except for the first few bunches, which are in the transient regime.

For the one-to-one feedback after a given time the results of multi and single bunch simulations are very close, again using a measurement of the whole train in the former. Instead of $20\,\%$ per day for single bunches the emittance growth for the full train is about $25\,\%$ per day, if the bumps are not reoptimised.

6 CONCLUSION

The correction of static misalignments in the CLIC main linac to preserve an emittance of $\epsilon = 5\,\mathrm{nm}$ within a factor two seems feasible. The high sensitivity to drift-like motion requires the ability to do one-to-one recorrections in a feedback mode and to be able to apply a full correction frequently.

7 REFERENCES

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