BEAM-BASED ALIGNMENT OF CLIC DRIVE BEAM DECELERATOR USING GIRDERS MOVERS

G. Sterbini, D. Schulte, CERN, Geneva, Switzerland

Abstract

The CLIC drive beams will provide the rf power to accelerate the colliding beams: in order to reach the design performance, an efficient transport of the drive beam has to be ensured in spite of its challenging energy spread and large current intensity. As shown in previous studies, the specifications can be met by coupling a convenient optics design with the state-of-the-art of pre-alignment and beam-based alignment techniques. In this paper we consider a novel beam-based alignment scheme that does not require quadrupole movers or dipole correctors but uses the motors already foreseen for the pre-alignment system. This implies potential savings in terms of complexity and cost at the expense of the alignment flexibility: the performance, limitations and sensitivity to pre-alignment tolerances of this method are discussed.

INTRODUCTION

To reach the CLIC 3 TeV collision energy [1] [2], two electron drive beams (DB) will be decelerated in 24×2 decelerators [3]. The decelerator is on average ≈900 m long and is made of 2 m long FODO cells. Between the quadrupoles special rf devices, the Power Extraction and Transfer Structures (PETS), extract the DB energy and couple it to the main beam (MB) providing the needed gradient for the MB accelerating structures. At the start of the decelerator, each DB pulse is almost monochromatic with an energy of 2.37 GeV, 101 A of current, ≈240 ns length and 12 GHz bunch spacing (i.e., ≈ 3000 bunches per pulse). Passing through the PETS, the heading bunches of the pulse build up a resonant longitudinal wake that decelerates the trailing bunches: each PETS will provide, after a transient of ≈10 bunches, a steady state deceleration of ≈1.5 MeV for the most decelerated particle of the bunch. At the end of the decelerator the DB is dumped: the first 10 bunches are only partially decelerated (ranging between 2.37 and 0.237 GeV, Fig. 1) while the rest of the pulse is decelerated down to 0.237 GeV providing an overall DB power extraction efficiency of 90%. It is worth noting, Fig. 1, that

- the intra-pulse energy spread at the end of the decelerator is proportional to the DB power extraction efficiency,
- the steady state intra-bunch energy spread ranges between 0.237 and ≈1 GeV.

The transport of such a beam is challenging: relative small misalignments of the decelerator's devices will increase via dispersive effects the beam envelope producing static and dynamic losses of the MB gradient and, finally,

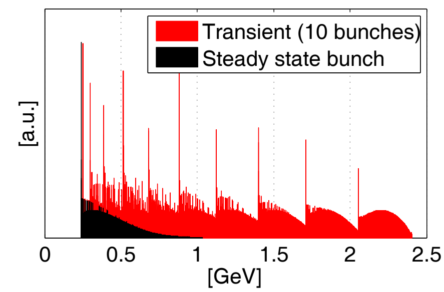

Figure 1: Energy spectrum of the DB bunches.

compromising the overall performance of the collider. For this reason the decelerator alignment is of paramount importance.

Assuming a normalized emittance of 150 μm rad in both planes and a constant FODO phase advance of ≈90 degrees for the most decelerated particle, the 3-sigma maximum beam envelope radius (later referred as DB envelope) of the ideally aligned machine is ≈3 mm (to compare to the radius of the aperture restriction of 11.5 mm). In the CLIC decelerator the assigned budget for DB envelope is half the available aperture (5.75 mm). This target is far to be met even for more advanced CLIC survey methods therefore beam-based alignment (BBA) is required.

ASSUMPTIONS AND METHODS

The possible sources of envelope growth are the transverse misplacement, pitch and yaw (cfr. [5]) of PETS and quadrupoles. Simulations show that the dominant contribution is given by the quadrupole transverse misplacement: to reduce the beam envelope we have to conveniently correct the quadrupole positions.

Since the relation between the envelope and the quadrupole position in non-linear (and, in addition, its systematic measurement along the machine is challenging), the beam envelope is indirectly minimized by minimizing the orbit of the beam (1-to-1 steering, 1-to-1) and, in a second step, the difference between two dispersive orbits (Dispersion Free Steering, DFS). This is possible since the zeros of the linear and non-linear problem correspond to the same machine configuration (the ideally aligned decelerator).

To correct the quadrupole position the straightforward solution is to install two movers (movers BBA, MBBA) for each quadrupole (one horizontal, H, and one vertical, V) or to integrate in each quadrupole two dipole correctors (H and V), dipole BBA, DBBA. This additional hardware can have a significant impact on the integration, complexity and cost of the DB decelerator. Assuming ideal movers and ideal dipoles the MBBA and DBBA are equivalent, so for sake of simplicity we will refer to these methods as quadrupole BBA, QBBA.

In this paper we consider an alternative solution where instead of moving the quadrupoles we move the girder on which the quadrupoles are installed (girder BBA, GBBA).

The girders are connected with articulation points (snake configuration [6]) that can be moved in H and V for the pre-alignment phase [2]. To use the pre-alignment hardware for BBA is not trivial: on the same girder we have two quadrupoles and due to the snake configurations this implies having only one a degree of freedom (out of the two needed) per plane per two quadrupoles. In addition to that, moving the girder will change the position of all the devices that are mounted on it: namely the beam position monitor (BPM) and the PETS. Each time that we move the girder for the GBBA, the induced offset of the BPMs reading has to be taken into account: this can be in principle done via the acquisition software. On the other hand, moving the PETS, due to the reduced effect of the PETS misalignment, increases only marginally the beam envelope.

It is worth noting that the GBBA can recover the full potential of the QBBA (1 degree of freedom per plane per quadrupole) by using, in addition to the girders,

- only half of the number of movers/correctors for the quadrupoles,
- or by making the girders fully independent (doubling the number of of girder movers but saving all the quadrupole movers/correctors).

These two correction configurations can be reduced to special cases of QBBA and are not described in this paper.

The method used for the GBBA is similar to the one used for the QBBA:

- we compute the response matrix, R_0, between the girder movers and the BPM reading assuming the nominal machine and the nominal beam, B_0.
- we compute the a similar response matrix, R_1, assuming the nominal machine and a second beam (nominal bunch current but doubling the bunch spacing), B_1.

We apply the 1-to-1 before each DFS. In the DFS (weighted DFS), we minimize the linear combination of (1) the difference between the orbit of B_1 and B_0 (weighted 100) and (2) the B_0 orbit (weighted 1). In our simulation the decelerator alignment requires only 3 DB pulses: this is not a beam commissioning scenario, since we expect to align the decelerator by segments, but it is a valid approach to compare the final performance of the GBBA respect to the QBBA. By referring to DFS we mean 1-to-1 followed by DFS.

All the simulations are done in PLACET [4] using the longest decelerator, the nominal lattice and considering only the vertical plane.

If not differently stated, we consider in the simulations the parameters summarized in Table 1. The BPM accuracy takes into account electro-mechanical accuracy and rms alignment errors with respect to the laser straight reference. The σ_{quad} represents the rms alignment errors of the quadrupole magnetic center with respect to the girder: it includes error in the measurement of the magnetic center, in its fiducialization and in the alignment of the quadrupole on the girder but it does not include the error in the girder position itself. The σ_{cradle} represents the alignment error of the girder extremities with respect to the ideal laser straight reference. We consider in B_2 fewer bunches than in B_1 (Table 1) since the B_2 steady state is reached after only 5 bunches. The relatively high number of slices per bunch in B_1 and B_2 is required for the response matrices convergence. The last bunch of the simulated beams is weighted to take into account the whole DB pulse.

Table 1: Main Parameters of the Simulations

Parameter	**Value**	**Unit**
BPM accuracy	20	μm
BPM precision	2	μm
σ_{quad}	from 20 to 55	μm
σ_{cradle}	10	μm
Girder Movers resolution	2	μm
Quad Movers resolution	2	μm
B_0 (B_1) # bunches	15 (8)	-
B_0 (B_1) # slices/bunch	120 (120)	-
B_0 (B_1) # macroparticles/slice	1 (1)	-

PERFORMANCE AND LIMITS

A typical performance of the Q/GBBA is shown in Fig. 2. We plotted the probability, $y(x)$, of the decelerator

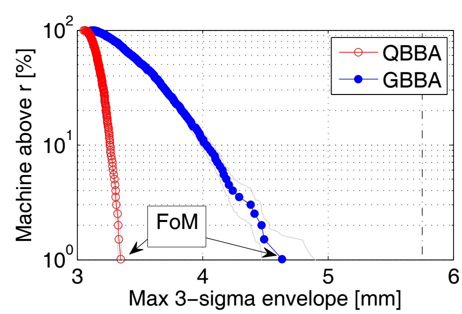

Figure 2: Comparison of performance between Q/GBBA assuming $\sigma_{quad} = 50$ μm.

to have a DB envelope larger than a certain value, x. We consider as figure of the merit (FoM) for a specific BBA the minimum value of DB envelope, $\overline{x}$, observed in the worse 1% of the simulated decelerators: that is $y(\overline{x}) = 1\%$. A lower FoM means a better BBA performance. To have a good statistics we simulated 1000 decelerators for each BBA methods. The probability to have one out of the 48 CLIC decelerators with an envelope larger than the FoM is 48%: this means that the FoM has to be "sufficiently" lower than the specified 5.75 mm limit. We chose the 1% reference to have a limited error bar on the FoM for a reasonable statistics (i.e., CPU time).

From Fig. 2 we can see that the FoM of the QBBA very close to the theoretical limit of the DB envelope while there is a visible deterioration with the GBBA.

An important difference between the GBBA and QBBA is that, under the assumptions of ideal BPM precision, the latter can work considering almost all the eigen-directions of the singular value decomposition (SVD). This is not true for the GBBA where we have to exclude some eigen-direction even in the ideal case. The physical meaning of this result is that when we are too far for the zero solution, minimizing the linear problem associate to the GBBA (steering) does not imply a minimization of the non linear problem (envelope). In that case, as empirical result, is better to weaken the linear correction (i.e., correct less eigen-directions).

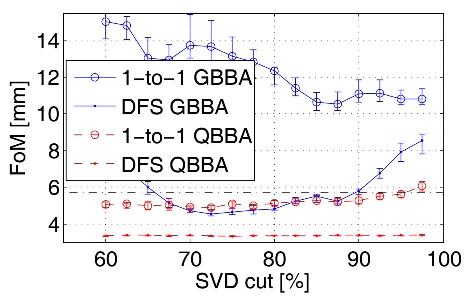

Figure 3: Performance versus SV cut for $\sigma_q = 50\ \mu$m.

We plot in Fig. 3 the FoM of the GBBA varying the number of SV taken into account for the correction (parameters of Table 1, with $\sigma_q = 50\ \mu m$). The curves represent the FoM of the girder alignment taking into account only the 1-to-1 and the DFS. For 1-to-1 GBBA, the optimal point is a SV cut of 85%. We use this value for the computation of DFS GBBA, that yields an optimal DFS SV cut of 75%.

Assuming these values in the G/QBBA algorithms, we show in Fig. 4 the FoM of the GBBA and QBBA for different σ_q. For completeness we show the FoM assuming only 1-to-1 without the weighed DFS. The QBBA final result is independent from the σ_q. This is not true for the GBBA, therefore it is crucial to align the magnetic center of the quadrupoles with respect to the girder references with a $\sigma_q \lesssim 50\ \mu$m.

Another aspect to consider is the girder movers range required for the GBBA. In Fig. 5 we show the rms quadruple positions (1000 machines) with respect to the laser straight reference after BBA assuming a $\sigma_q = 50\ \mu m$: the maximum correction required by the girder movers is less than 0.5 mm that is within the range of the present movers specification (± 3 mm). The rms position of the quadrupole for the QBBA is much less perturbed.

Regarding the ground motion excitation (GM), the GBBA has the exactly the same potential of the QBBA

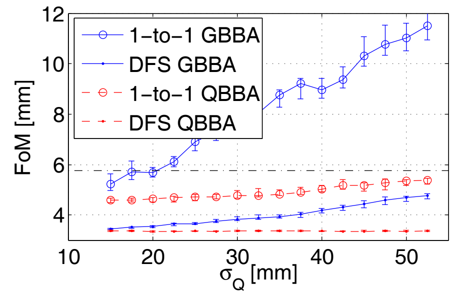

Figure 4: Performace versus σ_q.

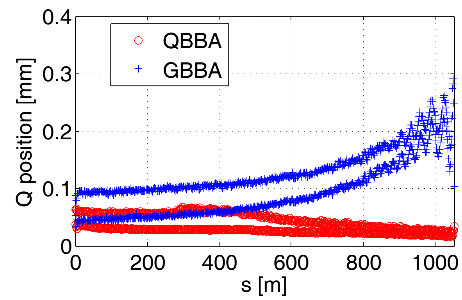

Figure 5: Q positions after the BBA.

since all the ground induced misalignment are transmitted to the quadrupoles via the girder itself. To recover from the GM, 1-to-1 steering is sufficient provided that the BPM induced misalignment is taken into account.

CONCLUSIONS

In this paper we described the principle, the performance and the limit of a BBA that uses the girder movers, instead of quadrupole movers, to steer the DB decelerator. The performance is quantified in a relative way: the deterioration of the steering capability is visible but depends significantly of the alignment of the quadrupole on the girder (σ_q). For $\sigma_q < 30\ \mu$m the girder option appears interesting, for $30 < \sigma_q < 50\ \mu$m the best complexity/flexibility trade-off is not so evident: experiments and considerations at the project scale are required to draw a conclusion. With $\sigma_q > 50\ \mu$m the GBBA capability appears too limited.

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