SLAC-PUB-14564

Status of the ATF2 Lattices*

E. Marín, R. Tomás (*CERN*), P. Bambade (*LAL*), T. Okugi, T. Tauchi, N. Terunuma, J. Urakawa (*KEK*), A. Seryi (*JAI*), G. White, M. Woodley (*SLAC*)

Abstract

The current status for the ATF2 Nominal and Ultra-low β^* lattices are presented in this paper. New lattice designs have been obtained in order to minimise the impact of the last interpretation of multipole measurements that have been included into the model. However, the new ATF2 Ultra-low design is not able to recover the expected vertical beam size at the IP with the current magnet distribution. Therefore, different quadrupole sorting have been studied. A significant gain is evident for the ATF2 Ultra-low lattice when sorting the magnets according to the skew-sextupolar components. The ATF2 Nominal lattice is also expected to benefit from the new sorting. Tuning results of the new ATF2 Ultra-low lattice under realistic imperfections are also reported.

INTRODUCTION

ATF2 is a test facility with the aim of testing the Final Focus System (FFS) based on local chromaticity correction that has been proposed in [1]. The ATF2 Nominal lattice is the scale-down version of the final focus system proposed for the future linear colliders. To prove the performance of the CLIC 3TeV [2] optics with its intrinsic level of chromatic aberrations, the ATF2 Ultra-low β^* is a proposal [3], [7] to reduce the vertical beta function at the IP (β_y^*) by a factor 4 beyond the existing design. The expected vertical beam size at the IP (σ_y^*) is 20nm. The ILC project and the ILC low-power [4], would also largely benefit from this test, in particular by gaining experience in exploring larger chromaticities and facing tuning difficulties as β_y^* decreases.

In the nanometre beam size regime, lattice aberrations are a major contributor to the beam size. The magnitude of the multipolar components present in the ATF2 magnets is a concern. This is extremely relevant for the final doublet magnets, so called QF1FF and QD0FF. In January 2011, a careful analysis of the collected data in two different measurement campaigns allowed to determine the multipole components of the quadrupole and sextupole magnets present in the ATF2 beam line.

When all the multipolar components are introduced into the model, the beam size at the IP was found to be larger than the required by the design. Depending on the beam size definition, this increase ranges from a few to many hundreds percent. For this study, three different beam size definitions have been considered:

- CORE: it corresponds to the width of a Gaussian fit of 10000 macro-particles.
- SHINTAKE: corresponds to a model of the theoretical measurement made by the IP beam size (S̈hintake) monitor. It represents the convolution between the bunch and the interference pattern field of the monitor. [5]
- RMS: it corresponds to the obtained value from the code MAPCLASS [6]. This code uses the output of MADX [8] to map an initial Gaussian distribution to the IP.

ATF2 Lattice	σ_x^* [μm]	σ_y^* [nm]		
	RMS	CORE	SHI	RMS
Nominal ideal	3.0	37.2	37.3	38.0
Nominal mults	3.9	39.3	41.8	66.9
Ultra-low ideal	3.0	20.4	22.8	23.1
Ultra-low mults	3.7	30.0	42.3	80.1

Table 1: Comparison between different IP beam size definition for both ATF2 lattices with and without multipoles.

Table 1 compares the ideal beam size to those obtained when all the multipoles are included into the model according to the different beam size definitions. It can be concluded that for the ATF2 Ultra-low β^* lattice, the impact of the multipoles is well above the tolerance in all different beam size criteria. For the ATF2 Nominal lattice however, only with the RMS criterion gives a σ_y^* significantly above the tolerance.

OPTICS MODIFICATION

In ref. [7] it was shown that not all multipoles contribute in the same manner to the σ_y^*. Thanks to an order by order analysis done by MAPCLASS, it was inferred that the skew dodecapole component of QF1FF was the main source for the observed beam size increase.

The strategy is to modify the optics by reducing the β_x-function at QF1FF, thus the impact of the QF1FF multipoles on the IP beam size is reduced. However β_x^* will increase, hence the horizontal beam size that deviates from the final focus system designs of the linear colliders projects.

By using the matching quadrupoles located at the beginning of the final focus, β_x^* is increased from 4mm to 10mm. Afterwards the sextupoles have to be optimised in order to compensate for the chromatic aberrations. This process is done by MADX implementing the simplex algorithm [9] in combination with the code MAPCLASS.

By increasing β_x^* a satisfactory solution is found for the ATF2 Nominal lattice. For the Ultra-low β^* configuration, the solution found does not meet with design criteria since σ_y^* is above 35nm. The study of intermediate lattices configurations in terms of β_y^* in future will help us to under-

[1]Work supported in part by Department of Energy Contract DE-AC02-76SF00515

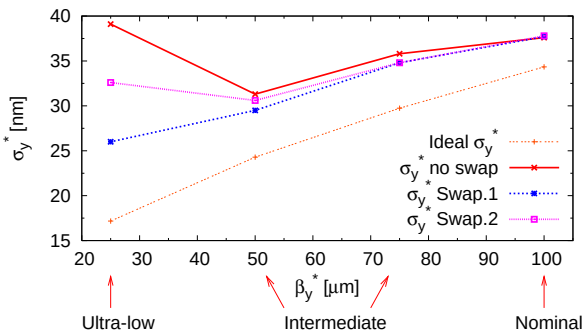

Figure 1: Calculated σ_y^* for different β_y^* (25, 50, 75, 100μm) with β_y^*=10mm. Each curve refers to a different magnet sorting. Red curve corresponds to the present sorting. The blue and magenta curves correspond to the sorting options Swap.1,2 respectively. Orange curve describes the ideal beam size.

stand the impact of the multipoles when going to the ultra-low β^* value. To this end, two intermediate lattices with β_y^* equal to 50μm and 75μm have been designed.

Figure 1 shows σ_y^* versus β_y^* for different lattice configurations. The red curve shows results obtained from all 4 lattices. This data suggests the existence of an optimum β_y^* between 25 and 50 μm. For smaller values than this optimum β_y^*, the expected aberrations cannot be compensated by the sextupoles. Moreover these aberrations are the cause of the observed beam size increase with respect to the ideal beam size represented by the orange curve.

The measured multipolar components preclude the possibility to reach the expected vertical beam size for the ATF2 Ultra-low β^* proposal. Increasing β_y^* is not a preferred solution because doing so, the chromaticity decreases and is no longer comparable to that of CLIC, therefore the tuning of the CLIC 3TeV chromaticity level cannot be tested.

By applying an order by order analysis to the ATF2 Ultra-low β^* lattice it can be inferred that the sextupolar contributions are precluding the possibility to generate a vertical spot size below 30nm at the IP. It is then, the sextupolar components of the quadrupoles that are the main aberration source here. One possible way to reduce the impact on the beam size from the sextupole components could be to re-distribute the magnets,using the values of these components as a sorting criterion.

SORTING OPTIONS

Sorting the quadrupoles according to their field quality and placing them in the positions calculated to be most sensitive to multipole errors could help to minimise the impact of aberrations present at the IP for the ATF2 ultra-low lattice.

A sensitivity study for all 22 quadrupole locations has been performed in order to calculate the most sensitive locations. Using an ideal lattice (error-free), skew sextupole components at each location are increased until σ_y^* increases by 2%. This is repeated for the skew octupole

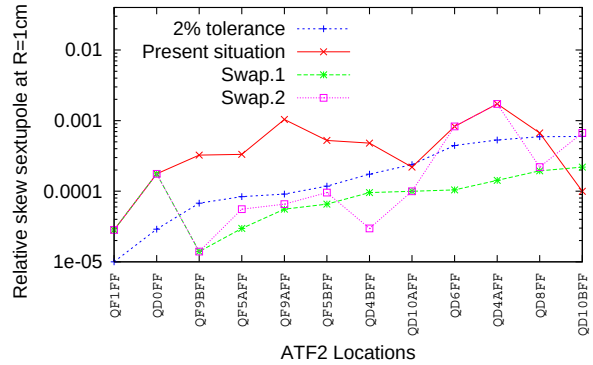

Figure 2: Relative sensitivities for the skew octupolar component. The horizontal label, refers to the location in the beam line labelled by the present quadrupole.

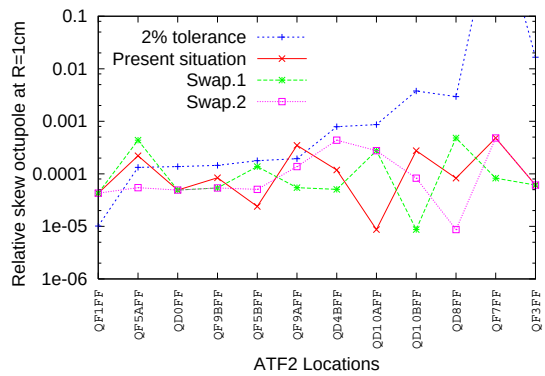

Figure 3: Relative sensitivities for the skew octupolar component. The horizontal label, refers to the location in the beam line labelled by the present quadrupole.

components. The blue curves in Fig. 2, 3 show the amount of relative skew component at each location in the lattice that increases σ_y^* by 2%. Locations are ordered according to their sensitivity. Only the 11 most important locations are shown, beyond these the calculated tolerances are acceptable and the present quadrupoles are sufficient.

In order to determine the best quadrupoles in terms of field quality, all the quadrupoles except the FD have been sorted according to their relaticve integrated skew component. The upper and lower plots in Fig. 4 show the best 9 quadrupoles according to the skew sextupole and octupole components respectively.

From these we form a swapping proposal for the quadrupoles. Two possible quadrupole orderings are considered:

- *Swap.1*: quadrupoles are sorted according to only their skew sextupolar component.
- *Swap.2*: quadrupoles are sorted according to their skew sextupolar and octupolar component.

The data shown in Fig. 4 are translated into relative components at R=1cm in order to compare with the calculated tolerances. The comparison is made in Fig. 2, 3. The blue curve represents the 2% σ_y^* increase. The red curve represents the skew sextupolar component. The green and magenta curves show the expected skew sextupole compo-

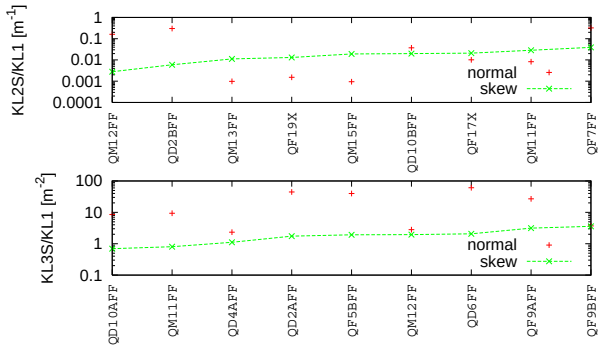

Figure 4: (upper): Best 9 ATF2 quadrupoles according to their skew octupolar component. (lower): Best 9 ATF2 quadrupoles according to their skew sextupolar component.

nent after swapping the magnets according to the swap.1, and 2 criteria respectively. It was assumed that the multipole components remain proportional to the quadrupole strength, which may not be the case.

It was concluded from the data shown in Fig. 2 that the present skew-sextupole component exceeds the 2% tolerance in almost all considered locations. For the swap.1 proposal all the skew-sextupole components are below the tolerances. For the swap.2 option, only the first 6 high-sensitivity locations,satisfy the tolerances. Concerning the skew octupole components, in general the situation is much better. The measured multipoles and the swap.1 option satisfy the tolerances in all locations except 2. When considering the swap.2 option, all tolerances are satisfied. Fig. 3 shows the comparison.

After re-ordering the quadrupoles and optimising the sextupoles, the resulting calculated σ_y^* at different β_y^* are show in Fig 1. For the Ultra-low β^* lattice, the obtained vertical beam size at the IP is 26.0nm and 32.5nm for swap options 1 and 2 respectively. The σ_y^* values calculated for the ATF2 Nominal lattice and the intermediate lattices are comparable to those calculated with the present distribution of quadrupoles. It was concluded that σ_y^* is very sensitive to the sextupolar components of the quadrupoles. Therefore, the suggested re-configuration of the magnet positions is strongly suggested to avoid the demonstrated detrimental effects of the measured multipole components.

TUNABILITY OF THE ATF2 ULTRA-LOW β_Y^* SWAP.1 LATTICE

A key factor determining the feasibility of a lattice design is its tunability. The tuning procedure is the process of bringing the system to its design performance under realistic lattice errors conditions.

We perform a Monte Carlo study for the ATF2 Ultra-low β_y^* swap.1 lattice based on hundred of seeds. The assigned errors include a random misalignment and tilt with a Gaussian distribution of 30 μm rms and 300 μrad respectively for all quadrupoles and sextupoles. A relative strength error of 10^{-4} is also applied to all magnets. A 10% random error is assumed on the RMS vertical beam size measurement.

When all errors are considered, the initial $< \sigma_y^* >$ is 385 μm. The designed tuning algorithm iteratively applies a set of tuning knobs that control the following beam size aberrations at the IP:

- Dispersion knobs: η_x,η_y
- Coupling correction: $< x, y >$,$< x, p_y >$,$< p_x, p_y >$
- Waist correction: α_x,α_y

These knobs required to be iterated several times, since they are not fully orthogonal.

The results are presented in Fig 5. The coupling <p$_x$,y>, α_y and η_y knobs are the most effective in the tuning procedure. After 6 knob iterations the obtained mean σ_y^* is 26.7nm. 68% of the seeds reach a final beam size below 30.0nm.

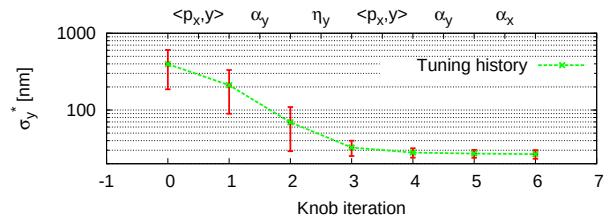

Figure 5: History of the σ_y^* along the tuning process.

CONCLUSIONS

The ATF2 optics have been modified in order to accommodate the impact of the measured multipoles. An acceptable solution has been found for the ATF2 Nominal lattice. Nevertheless, modifying the optics is not satisfactory solution for the ATF2 Ultra-low β^* configuration.

In order to minimise the detrimental effect of the multipoles, 2 different quadrupole configurations have been studied. It has been observed that sorting the quadrupoles according to only their sextupole components (swap.1) is more effective than according to their sextupole and octupole components (swap.2). The calculated vertical beam size for the ATF2 Ultra-low β_y^* swap.1 option is 26nm, only 10% bigger than the vertical beam size without considering the multipoles. For this lattice design, the tuning studied demonstrates that 68% of the seeds reach a σ_y^* <30nm.

REFERENCES

[1] P.Raimondi and A.Seryi, Phys. Rev. Lett.**86**, 3779-3782

[2] "CLIC 2008 Parameters" , CERN-OPEN-2008-021 ; CLIC-Note-764.

[3] D. Angal-Kalinin et al, "Exploring ultra-low β^* values in ATF2 -R&D Programme proposal", CARE/ELAN Document-2008-002.

[4] A. Seryi et al "POWER SAVING OPTIMIZATION FOR LINEAR COLLIDER INTERACTION REGION PARAMETERS", these proceedings.

[5] Y. Honda et al, "Shintake BSM and gamma detector" at the Fifth ATF2 project meeting.

[6] R. Tomás, "MAPCLASS: a code to optimize high order aberrations" CERN AB-Note-2006-017 (ABP), and "Nonlinear Optimization of Beam Lines", Phys. Rev. ST Accel. Beams **9**, 081001 (2006).

[7] E.Marin et al, "ATF2 ultra-low IP betas proposal"

[8] MADX: http://mad.web.cern.ch/mad/.

[9] J.A. Nelder and R. Mead, Computer Journal, 1965, vol 7.

[10] ILC Reference Design Report:http://lcdev.kek.jp/RDR/

[11] D. Schulte, "Beam-Beam Simulations of the Proposed ILC Parameters", EUROTeV-Memo-2005-004-1.