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Status of the ATF2 Lattices

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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 multipolemeasurementswhich 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 patent for the ATF2 Ultra-low lattice when sorting the magnets according to the skew sextupolar component. Besides, the ATF2 Nominal lattice will also benefit from the new sorting. Tuning results of the new lattices under realistic imperfections are reported.

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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 multipole measurements which 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 patent for the ATF2 Ultra-low lattice when sorting the magnets according to the skew sextupolar component. Besides, the ATF2 Nominal lattice will also benefit from the new sorting. Tuning results of the new lattices under realistic imperfections are 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] chromatic level, 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. 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 knowledge 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 increases. Depending on the beam size definition, this increase ranges from a few to 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 particles.
- SHINTAKE: it corresponds to the theoretical measurement of the Shintake monitor. It represents the convolution between the bunch and the interference pattern field. More information can be found in [5]
- RMS: it corresponds to the obtained value from the code MAPCLASS [6]. This code uses the output of MADX 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 multipols 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 multipols is well above the tolerance in all different beam size criteria. Whereas for the ATF2 Nominal lattice only with the RMS criterion gives a σ_y^* significantly above the tolerance.

OPTICS MODIFICATION

In ref. [7] it was shown that not all multipols 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 multipols on the IP beam size is reduced. However β_x^* will increase, hence the horizontal beam size, deviating 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 the chromatic aberrations. This process is done by MADX [8] 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, whereas for the Ultra-low β^* a not satisfactory solution is found since σ_y^* is above 35nm. The study of intermediate lattice in terms of β_y^* would help to understand the impact of the multipols when going to ultra-low β^* value. In these sense two intermediate lattices with β_y^* equal to 50μm and 75μm have been designed.

In Fig.1 is plotted σ_y^* versus β_y^*. The results of all 4 lattices are connected by the red line, which evidences the existence of an optimum β_y^* between 25 and 50 μm. For smaller values than this optimum β_y^*, the present aberra-

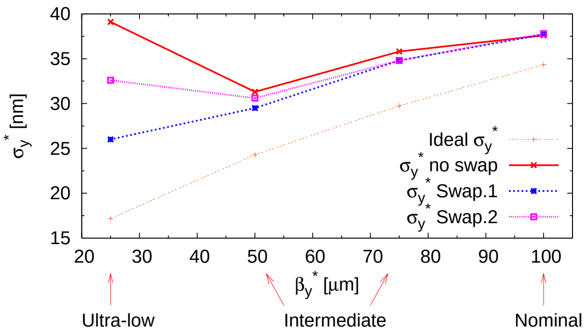

Figure 1: Obtained σ_y^* for different β_y^* (25, 50, 75, 100μm) with β_y^*=10mm. Each line refers to a different magnet sorting. Red line corresponds to the present sorting. Blue and magenta lines correspond to the sortings options Swap.1,2 respectively. Orange line describes the ideal beam size.

tions 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 line.

The present multipols in the current magnets preclude 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 the CLIC one, therefore the tuning of the CLIC 3TeV chromaticity level cannot be tested.

Applying an order by order analysis to the ATF2 Ultra-low β^* lattice it can be inferred that the sextupolar order is precluding to go below 30nm. Thus the sextupolar component of the quadrupols are the main aberration source. One possible way to reduce the impact on the beam size from the sextupolar component could be to re-distribute the magnets according to this component.

SORTING OPTIONS

Sorting the quadrupoles according to their field quality and placing them in the most sensitivity locations could help to minimise the aberrations impact for the ATF2 ultra-low lattice.

A sensitivity study for all 22 quadrupole locations has been done in order to figure out the most relevant locations. Considering an ideal lattice it has been increased the skew component at each location at a time, until the vertical beam size at the IP increases by 2%. The same procedure has been done for the skew octupole component. The blue lines in Fig. 2, 3 show the obtained amount of relative skew component which increases σ_y^* by 2% at each location. Locations are ordered according to their relevance. It is shown only the 11 most important locations, beyond these the obtained tolerance increases enough to be satisfied by the present quadrupols.

In order to determine the best quadrupols in terms of field quality, all the quadrupols except the FD have been sorted according to their integrated skew component divided by the integrated quadrupolar field. Upper and bottom plot in Fig. 4 show the best 9 quadrupoles according to the skew sextupolar and octupolar component respectively.

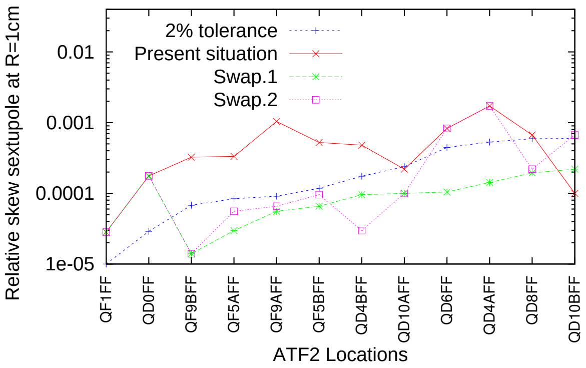

Figure 2: Relative sensitivities for the skew octupolar component. The horizontal label, refers to the location in the beam line labelled by the present quadrupole.

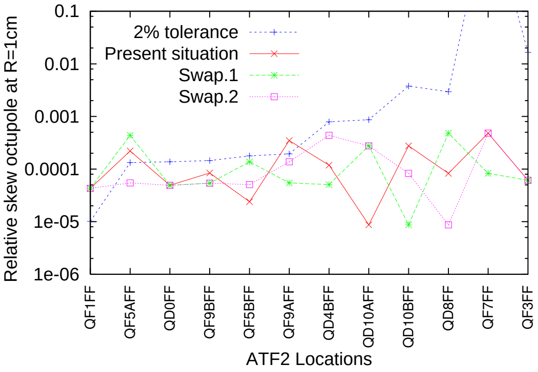

Figure 3: Relative sensitivities for the skew octupolar component. The horizontal label, refers to the location in the beam line labelled by the present quadrupole.

From Fig. 4 it can be extracted the swapping proposals for the quadrupoles with the exception of the FD. Two possible quadrupole sortings 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 obtained values in Fig. 4 are translated into relative component at R=1cm in order to compare with the found tolerances. The comparison is made in Fig. 2, 3. Blue line represent the 2% vertical beam size increase, red line represents the present skew sextupolar component, green and magenta lines the expected skew sextupolar component by swapping the magnets according to the swap.1, and 2 respectively. It has been assumed that the multipolar component remain proportional to the quadrupole strength variation, which may not be the case.

It is concluded from Fig. 2 that the present skew sextupolar component exceeds the 2% tolerance in almost all relevant locations. Whereas for the swap.1 proposal the skew sextupolar components are below the tolerances. Reagard-

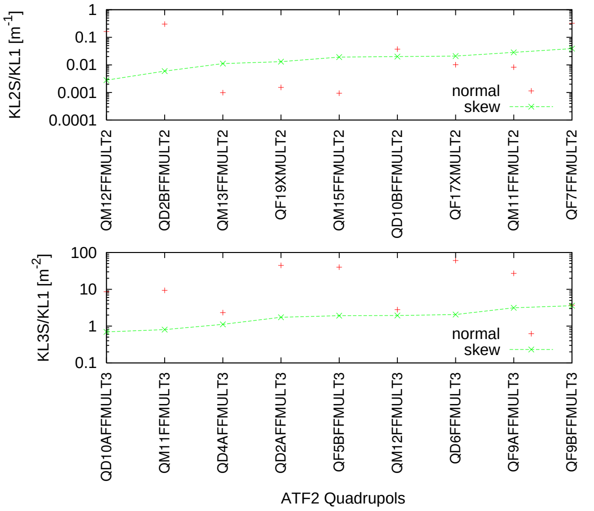

Figure 4: (top): Best 9 ATF2 quadrupoles according to their skew octupolar component. (bottom): Best 9 ATF2 quadrupoles according to their skew sextupolar component.

ing the swap.2 option, in the first 6 relevant locations the skew component are below the tolerance.

Concerning the skew octupolar component, in general the situation is much betters. The present multipols and the swap.1 option satisfy the tolerances in all locations except 2. When considering the swap.2 option, all tolerances are satisfied. In Fig. 3 is shown the comparison.

After re-ordering the quadrupols and optimizing the sextupoles, the obtained vertical beam size at different β_y^* is 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 obtained σ_y^* for the ATF2 Nominal lattice and the intermediate lattices are comparable to the obtained one with the present quadrupols distribution. It can be conluded that σ_y^* is very sensitive to the sextupolar component of the quadrupols, therefore a proper magnet sorting avoid the detrimental effect of the multipolar component of the quadrupols on the beam size.

TUNABILITY OF THE SWAP.1 LATTICE

A key feasability issue of a lattice is its tunability. The tuning procedure is the process of bringing the system to its ideal performance under realistic lattice errors conditions.

Our statistical study is formed by a hundred of seeds. The initial assigned errors is a random misalignment of quadrupoles and sextupoles within a Gaussian distribution of 30 μm rms. The final doublet magnets are tilted randomly 50 μm. Quadrupoles and sextupoles are tilted 300 μm. A strength error of 10^{-4} is assumed for all magnets.

A 10% random error is assumed on the RMS vertical beam szie measurement.

When all errors are considered, the initial vertical beam size on average is 385 μm +- 206 μm. The designed tuning algorithm consists in applying iteratively a set of tuning knobs. These knobs control the following beam size aberrations at the IP:

- Dispersion knobs: η_x,η_y

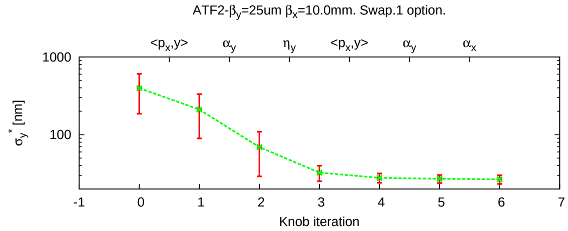

Figure 5: History of the vertical beam size at the IP reached along the tuning algorithm.

- 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 average beam size is 26.7nm. 68% of the seeds reach a final beam size below 30.0nm.

CONCLUSIONS

The ATF2 optics has been modified in order to accomodate the impact of the multipols present in the ATF2 line. A plausible solution has been found for the ATF2 Nominal lattice. Nevertheless, this solution is not satisfactory for the ATF2 Ultra-low β^*.

In order to minimize the detrimental effect of the multipols, 2 different quadrupol sortings have been studied. It has been observed that sorting the quadrupols according to only their sextupolar component (swap.1) is more effective than according to their sextupolar and octupolar component (swap.2). The obtained vertical beam size for the swap.1 option is 26nm, only 10% bigger than the vertical beam size without considering the multipols.

For the swap.1 lattice the tuning studied demonstrates that 68% of the seeds reach a σ_y^* <30nm.

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