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Plans and Progress towards Tuning the ATF2 Final Focus System to Obtain a 35nm IP Waist*

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Abstract

Using a new extraction line currently being commissioned, the ATF2 experiment plans to test a novel compact final focus optics design using a local chromaticity correction scheme, such as could be used in future linear colliders[1]. Using a 1.3 GeV beam of ~30nm normalised vertical emittance extracted from the ATF damping ring, the primary goal is to achieve a vertical IP waist of 35nm. We discuss our planned strategy, implementation details and early experimental results for tuning the ATF2 beam to meet the primary goal. These optics require uniquely tight tolerances on some magnet strengths and positions, we discuss efforts to re-match the optics to meet these requirements using high-precision measurements of key magnet elements. We simulated in detail the tuning procedure using several algorithms and different code implementations for comparison from initial orbit establishment to final IP spot-size tuning. Through a Monte Carlo study of 100's of simulation seeds we find we can achieve a spot-size within 10% of the design optics value in 80% of cases.

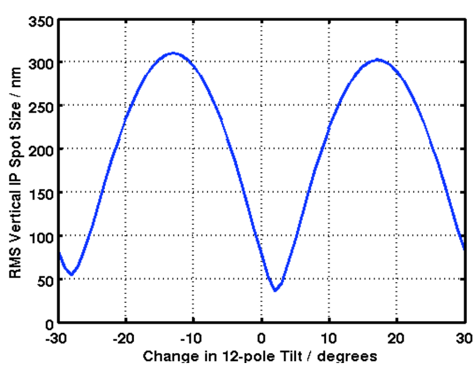

Figure 1: Lucretia model of vertical IP waist size vs. tilt of QF1FF 12-pole component away from measured value of +2 degrees. These results are for a normalised horizontal emittance of 6um.

INTRODUCTION

Details of the ATF2 project can be found elsewhere in these proceedings, and also in the ATF2 proposal document [1]. Details of the exact tuning procedure and simulation environment to study the tuning process for ATF2 can be found here [2]. We report here on recent developments in the simulation of the tuning procedure with measured aberrations of the ATF2 magnets, and also on the expected time required to perform the tuning. Finally we summarise the progress of commissioning the ATF2 beamline.

MEASURED MAGNETIC MULTIPOLES

Magnetic measurements were taken for key magnetic elements of the ATF2 beamline; namely those for the 3 final focus system (FFS) bends, the 5 FFS sextupole magnets and the final doublet quadrupoles (QF1FF and QD0FF). Of all measured multipolar components, 3 were found to have significant effect on the expected IP vertical waist size: the sextupole components of QF1FF and QD0FF and the 12-pole component of QF1FF. The measured strengths of these components are: QD0FF sext: 0.0255; QF1FF sext/12-pole: 0.0274/0.036 (% quadrupole field strength at r=1cm and nominal field values for ATF2 design optics QD0FF=132.2A, QF1FF=77.5A) [3]. IP vertical spot size growth due to the sextupole components can be mitigated by retuning the optics to take these into account, this was successfully done using MAPCLASS [4]. The 12-pole component of QF1FF was measured to be rotated in the x-y plane with respect to the main field component by 2 degrees. This causes a coupling effect and an increase in the vertical IP waist size as demonstrated in figure 1 which shows the results of beam tracking with Lucretia [5] with the 12-pole field of QF1FF added to the nominal ATF2 lattice with varying tilt angles. As can be seen from figures 4 and 5, this effect scales with horizontal emittance. Although negligible with no other errors at the design normalised emittance of 3um, figure 3 shows that when taking into account the full tuning procedure with realistic errors, an effect is still seen. Also, past results at ATF have shown that 3um horizontal emittance is only achievable with bunch charges well below the ATF2 design [6]. Two possible mitigation techniques are proposed; doubling of the IP horizontal beta-function which decreases the beamsize in QF1FF and almost eliminates this effect; direct compensation of this effect by the introduction of a skew dodecupole magnet in the beamline. Figure 4 shows a simulation of the effect of doubling the IP beta x, the scaling with horizontal emittance is vastly reduced. This is also seen by adding a skew dodecupole as close as possible to the front face of QF1FF (0.7456m), with a strength K5L=1424122.25m^{-5}. Here also, the scaling is greatly reduced.

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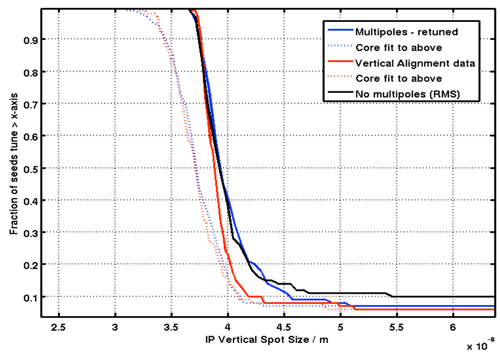


Figure 2: 100-seed tuning simulation results with and without Multipoles (QF1FF 12-pole excluded).

Tuning Simulation Results

Using the ATF2 tuning simulation software [2], the measured multipoles were added to asses their impact on the expected tuning performance. To investigate the impact of the rematching process to mitigate the effect of the sextupolar terms in QF1FF and QD0FF, the simulation was run with and without the inclusion of all the measured multipoles with the exception of the QF1FF 12-pole. Figure 2 summarises the results of this simulation, also in this figure are the results of additionally including the vertical alignment measurement data instead of the gaussian spread of vertical alignments detailed in [2].

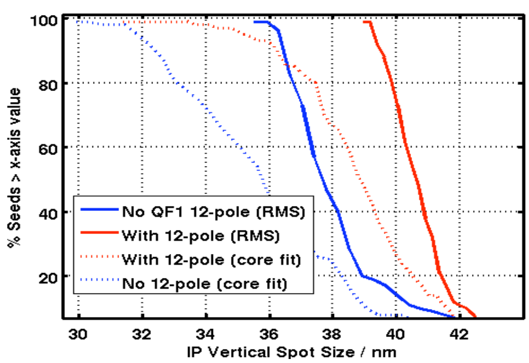
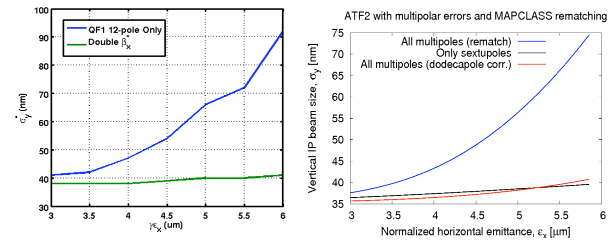


Figure 3: Impact on tuning simulation of adding the measured 12-pole component strength and rotation angle to QF1FF, with 3um horizontal emittance.

As seen, the addition of these multipolar components after rematching results in no degredation in the expected performance. On the contrary, the MAPCLASS rematching has resulted in a tuned lattice which gives better performance in the tails of the distributions shown, this lattice is less sensitive to the more extreme combinations of errors modeled. The RMS measurement of the IP vertical beam size is also less sensitive to larger error conditions with the measured vertical alignment data included (red curve in figure 2). In summary, ignoring the QF1FF 12-pole contribution; 90% of the seeds tune < 41-42nm; 50% of the simulated seeds tune <37-39nm.



Figures 4 (left), 5 (right): Scaling of the IP vertical beam size with horizontal emittance. Fig. 4 shows the effectiveness of doubling the IP horizontal beta function. Fig. 5 shows the effect of adding a skew dodecupole magnet.

If we now add in the size and rotation of the measured QF1FF 12-pole component and re-run the simulations, the results can be seen in figure 3. The normalised horizontal emittance was set to the smallest of the expected range of 3um. As can be seen in figures 4 and 5, the increase in vertical IP spot size is expected to be negligible at 3um horizontal emittance. Thus, the results summarised in figure 3 show the additional effects from realistic error conditions and tuning that will not be fixed from direct mitigation of the 12-pole by methods discussed here. An approximately uniform shift of 2nm larger beam size is seen as a result of adding this 12-pole in all simulated seeds. We need to study in detail the reasons for this, and also to run the full simulations explicitly including the 2 12-pole mitigation techniques.

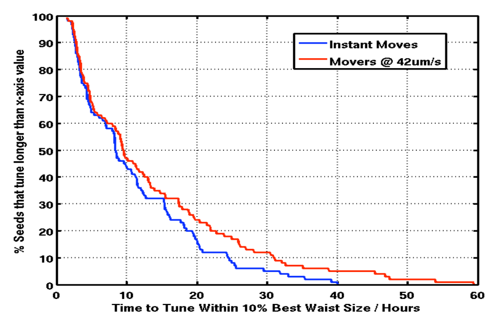


Figure 6: Expected beam time to perform ATF2 tuning (100 simulated seeds).

Figure 6 shows an update on the time estimates to tune the ATF2 beam. Included in these simulations were the finite speed of the magnet mover system. It is expected to be able to tune the beam with <30 hours of beam time in 90% of modeled cases which is feasible for a a typical continuous run period of 1 week. The time taken for the movers to change the x/y/tilt positions of a magnet are important for the FFS sextupoles. The tolerance on the desired final mover position is high for the sextupole multi-knobs to fine-tune the IP aberrations. It can take even longer with the mover system in "trim" mode to achieve this tolerance than modeled here. For this reason an effort is underway to replace the motor drivers and readback ADC's for these 5 mover systems to provide for faster drive and position determination.

ATF2 COMMISSIONING PROGRESS

Commissioning of the ATF2 beamline began in December 2008, with further runs to date in Feb/March and April of 2009. Work is ongoing to commission the principal new hardware for the beamline, namely the high-resolution cavity BPM system and interference-mode laser "shintake monitor" IP beam size monitoring system. See the commissioning paper in these proceedings for more info [1]. In parallel with the hardware commissioning, we have begun to develop and test some of the software tuning tools taken from the simulation environment and ported to the ATF2 "flight simulator" software environment [7]. These are used in parallel to the existing and developing tools in the native ATF software toolset under Vsystem. Tools currently in use include: EXT coupling correction; EXT dispersion measurement and correction; EXT and FFS orbit monitoring and steering; IP sextupole-based tuning knobs; BPM tools (orbit plotting, reference save/restore system. Offline calibration of stripline BPMs), watchdog tools (beam orbit in critical apertures monitoring, operating magnet strengths, online optics checks, model response matrix checks...), magnet standardisation, BBA (Quad shunting to get BPM-Quad offsets, Sextupole BBA to get Sext-BPM offsets), orbit bump tools. Presentations of a number of these tools can be found elsewhere in these proceedings.

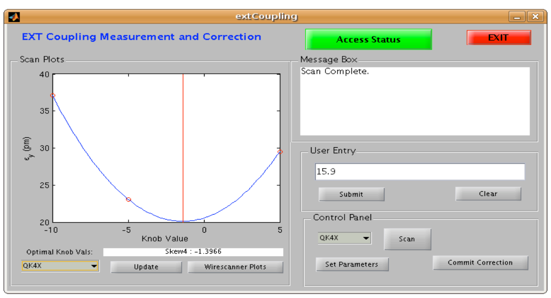


Figure 7: Flight Simulator coupling correction tool.

The current commissioning strategy is to start operations with optics containing a high IP beta configuration and gradually reduce to the design optics as we successfully tune the precious optics. We expect higher beta (lower chromaticity) optics to be easier to tune which provides a good test bed for developing and deploying the software tools. This approach also allows the IP beamsize monitor to commission its different operating modes in a staged way.

In the last run period (April 2009), we were operating with a 100* nominal IP β_y optics (1cm). Although ATF achieved at or better than the design 12pm vertical emittance in the damping ring, we typically saw >20pm emittance in the EXT and FFS. We are only running with half of the required skew quads for coupling correction currently (QK1X and QK4X), it is believed that with the full skew quad compliment and careful orbit control through the extraction region, we will be able to extract the low damping ring emittance. It is expected to have the remaining 2 skew quads before the running periods in the autumn.

Figure 7 shows an example of one of the flight simulator tools in use: the coupling correction tool. This scans the available skew quads in order, minimising the vertical emittance measured using the 5 wirescanners in the diagnostics region of the extraction line. This figure shows a minimum emittance of 20pm after scanning the QK4X skew quad after having already optimised QK1X.

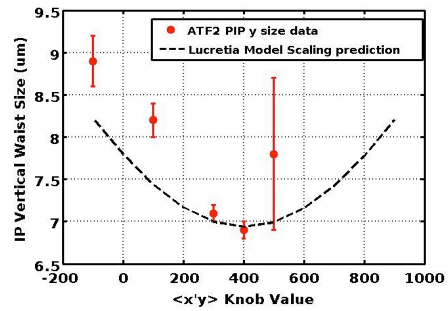


Figure 8: Variance of IP vertical waist size with <x'y> coupling knob.

We were also able to run preliminary tests of the sextupole mover based system for correcting IP aberrations as outlined in [2]. We used the secondary IP location 40cm downstream from the primary IP, using QD0FF to shift the vertical waist to this location. Figure 8 shows the response of the IP beamsize measured with a tungsten wire at this location to one of the knobs- the <x'y> coupling knob. Coupling and dispersion conditions were non-optimal so we had a larger than anticipated IP vertical beam size, however, as indicated by the dashed curve, the response was approximately as expected under these conditions as modeled by Lucretia.

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