Operational Experiences Tuning the ATF2 Final Focus Optics Towards Obtaining a 37nm Electron Beam IP Spot Size

G. White, A. Seryi, M. Woodley, E. Marin, Y. Kamiya, S. Bai, B. Bolzon, K. Kubo, S. Kuroda, T. Okugi, et al.

OPERATIONAL EXPERIENCES TUNING THE ATF2 FINAL FOCUS OPTICS TOWARDS OBTAINING A 37 NANO-METER ELECTRON BEAM IP SPOT SIZE*

Glen White, Andrei Seryi, Mark Woodley (SLAC, Menlo Park, California). Eduardo Marin (CERN, Geneva). Yoshio Kamiya, (ICEPP, Tokyo). Sha Bai (IHEP Beijing, Beijing). Benoit Bolzon (IN2P3-LAPP, Annecy-le-Vieux). Kiyoshi Kubo, Shigeru Kuroda, Toshiyuki Okugi, Toshiaki Tauchi (KEK, Ibaraki). Philip Bambade, Yves Renier (LAL, Orsay). Sachio Komamiya, Masahiro Oroku, Yohei Yamaguchi, Takashi Yamanaka (University of Tokyo).

Abstract

The primary aim of the ATF2 research accelerator is to test a scaled version of the final focus optics planned for use in next-generation linear lepton colliders. ATF2 consists of a 1.3 GeV linac, damping ring providing low-emittance electron beams (<12pm in the vertical plane), extraction line and final focus optics. The design details of the final focus optics and implementation at ATF2 are presented elsewhere **[1]**. The ATF2 accelerator is currently being commissioned, with a staged approach to achieving the design IP spot size. It is expected that as we implement more demanding optics and reduce the vertical beta function at the IP, the tuning becomes more difficult and takes longer. We present here a description of the implementation of the tuning procedures and describe operational experiences and performances.

THE ATF2 ACCELERATOR AND TUNING METHODS

More details about the ATF2 accelerator, its optics and diagnostics systems as well as details about the commissioning so far can be found in [1]. Details about the tuning process and simulation studies thereof can be found in [2].

For the primary tuning goal, the ATF Damping Ring (DR) is required to deliver a beam with normalised horizontal/vertical emittance 3um-rad / 30nm-rad into the ATF2 extraction line system (EXT)* with an energy of 1.28GeV, bunch charge 1.6 nC single bunch, rep. rate is 1.56Hz. The DR is currently delivering a beam within these design parameters [3].

The inflector optics in the EXT extracts the beam from the ring and delivers it into the final focus system (FFS). Within the EXT, we correct for anomalous horizontal and vertical dispersion using a pair of normal and a pair of skew quadrupole magnets in areas of design horizontal dispersion. We also correct for betatron coupling using four skew quadrupoles and five wirescanner stations containing 10um tungsten wires. Using the wirescanners, we measure the horizontal and vertical Twiss parameters of the beam and check betatron matching into this section. We typically find the beam well matched in the EXT region. The dispersion correction system is designed to predominantly correct for magnetic and alignment errors within the EXT itself, although it can also correct for small dispersive and coupling aberrations coming from the DR itself; the coupling system is designed to cope with internal and incoming coupling sources (this is a scale-model of the full ILC system).

The beam, having been well matched and decoupled in the EXT is next analysed at the interaction point (IP). The beam is focused to a waist at either the primary IP, or the post-IP (PIP) ~40cm downstream of the primary IP. At the IP, the beam can be analysed using the IPBSM "Shintake Monitor" [4] or 10um vertical and horizontal scanning tungsten wires. At the PIP we have x, y and 45-degree 10um tungsten wires and y and +/- 1.3 degree 5 um carbon wires on 2 separate wire scanner actuators. The IPBSM is the primary diagnostic device for final beam tuning down to the goal vertical beam size. It calculates the vertical beam size by scanning an interference pattern created by overlapping laser beams. It can also measure the horizontal beam waist size using a "laserwire" mode where it scans a 10um laser waist across the horizontal dimension of the electron beam waist. The vertical measurement mode of the IPBSM is sensitive to vertical beam waist sizes as low 20 nm (depending on background conditions) and up to 3-4 microns. It achieves this by using a variety of crossing angles between the interacting laser beams, creating an interference fringe pattern with variable pitch. The wirescanners provide an alternate measurement system when the beam waist is larger in the vertical dimension than can be resolved with the IPBSM. The wirescanners were the primary measurement system during the commissioning of the IPBSM, and have been used to calibrate the IPBSM at the larger beam spot sizes. The beam waist is moved between IP and PIP locations using a knob that adjusts the strengths of the QF1FF and QD0FF final quadrupole doublet system.

The initial matching of the beam through to the IP is checked by scanning the strength of QD0FF and inferring the emittance and Twiss parameters of the beam using the technique of [5] which looks at the parabolic response of the measured horizontal and vertical σ^2. Re-matching can be performed if required using a set of six matching quadrupoles at the entrance to the FFS. The final doublet and select FFS quadrupoles can also be used to fine-tune

* work supported in part by Department of Energy Contract DE-AC02-76SF00515. French Ministry of Research Contract ANR-06-BLAN-0027 and "Toshiko Yuasa" French Japan Particle Physics Laboratory Contract A_RD_2

the IP beta and horizontal dispersion functions if necessary.

Following the preparation procedures described above, the beam is now found to be within the measurement range of the IPBSM at the primary IP waist position. To tune out remaining aberrations at the IP, multiknobs such as described in [2] and [6] using horizontal, vertical and roll moves of the FFS sextupoles and strength changes thereof are used. Quadrupole rolls in non-dispersive regions can also be used to reduce <x'y> couplimg.

SOME OPERATIONAL EXPERIENCES

We outline here some of the operational details implemented for realising the tuning procedure described above and show some waypoint results current at the time of writing.

Optics Configurations

Simulation studies have shown that the difficulty of tuning this style of FFS optics scales with the natural chromaticity of the system. In our case for a fixed L*, this means a scaling with the design IP beta functions. For the current running period, we are operating with an optics configuration that has ten times the nominal IP beta functions in x and y. This will yield a fully corrected beamsize of approximately 10um * 150nm. This will test the 2,4, 8 and 30 degree crossing-angle modes of the IPBSM, leaving only the 174-degree mode when we implement the nominal optics configuration. The IPBSM detector requires low background conditions to successfully operate; lowering the IP beta functions means increased values for the beam divergence here, which yields higher backgrounds in the detector. The current beam-based alignment and steering procedure yields background conditions that are good enough for the present optics, but more precision will be needed when setting the nominal optics and possibly beyond.

Operating Paradigms

The ATF facility exists not only to service ATF2 and its goals to generate a 37nm vertical beam, but also serves as an R&D machine for many other projects operating in parallel with the ATF2 programme. This has placed constraints on the manner in which the commissioning of ATF2 has progressed up to now. Operationally, this means we are not always able to follow the complete tune-up procedure outlined above due to time constraints. During this commissioning stage, we use the available shift time to test the tools and techniques required for the various tuning steps separately. To achieve the spot size goal however, simulation studies suggest that many continuous days of stable beam operation and iterative application of tuning knobs are required. Now that the main hardware systems and software tuning tools have been tested and are in use, we will start to prepare for such operations. The first of such extended operation runs is pursued during the second week of the May 2010 beam operation period, at the time of writing this report. This will be our first test of stringing together all the tuning procedures outlined here with a goal of commissioning some of the larger crossing-angle modes of the IPBSM and reaching a vertical waist size of order 100nm which is the design for the current optics configuration.

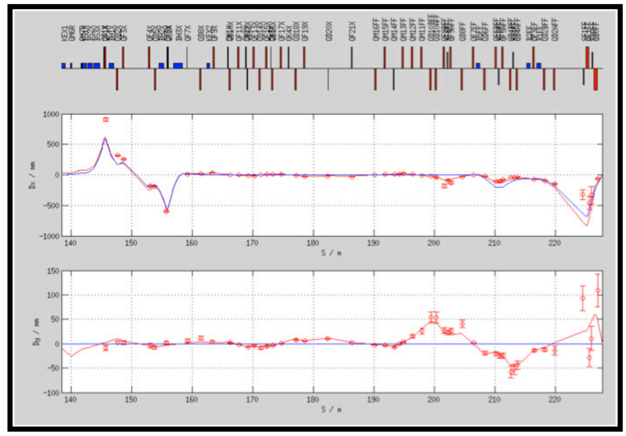

Figure 1: Dispersion measurements on EXT and FFS BPMs with model-based fit.

Online Modelling and Controls

The main ATF control system is based around VSYSTEM [7] and an interface to an online SAD [8] model. To facilitate the ability for collaborators not permanently present at KEK to develop tuning software, we also provide the "Flight Simulator" interface [9]. This complements and extends the functionality of the main system; applications written in both environments are available in the control room to tune the beam. Having parallel model environments has provided useful cross checks of one system against the other on many occasions.

The development of an accurate online model underpins many of the high level applications. An example of how the model is of use can be seen with the dispersion measurement and correction package. The model allows the dispersion function to be accurately fitted and extrapolated to other areas of the beamline such as wirescanner locations, where direct measurements no longer need to be taken (example can be seen in figure 1).

At the start of a tuning shift, the first task is to check the calibration state of the BPM system and the accuracy of the online model. Both of these are achieved by running an automated application, which scans the strength of selected corrector magnets, measures the response on downstream BPMs and compares to the model response matrix calculations, displaying the results graphically.

Setup Procedure, Orbit Steering

The initial setup procedure for ATF2 tuning shifts primarily involves orbit steering such that the beam passes centrally through critical tight apertures, magnetic elements with known higher-order fields and through to the dump well aligned with FFS magnets which themselves have been well aligned to the design orbit trajectory, to within 200 um vertically. The beam is known to have been restored to a good orbit when the background signal on the IPBSM is within measurement limits stipulated by the IPBSM requirements. A fibre loss monitor system strung along the length of the EXT and FFS provides a useful diagnostic for finding point loss sources. Initially, we have been using a quad shunting technique using a selection of quadrupole magnets and screen monitors to establish a good orbit. As the full high-resolution, high-stability BPM system is now operational we can use orbit monitoring to restore a known gold orbit. We still need to prove good, stable BBA BPM-Quad and BPM-Sextupole alignment to make this a reality; this is an ongoing task. Details of the BBA procedure used can be seen in [2].

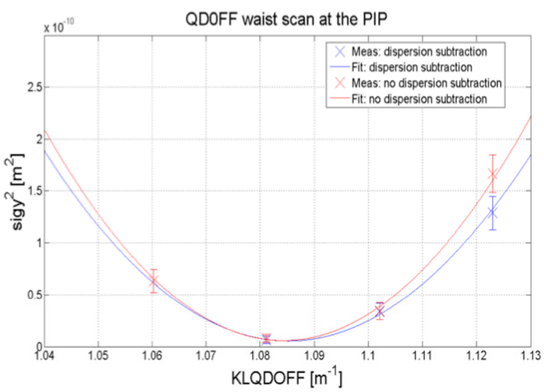

Figure 2: Vertical waist scan at IP using IPBSM and QD0FF.

Beam Characterisation

The analysis of the beam moments, emittances etc come from the EXT, IP and PIP wirescanners. By correcting the x-y coupling of the beam in the EXT line, we have reduced the measured projected vertical emittance to less than the 12pm required for meeting the IP spot size goal. However, this is a very time consuming process at 1.56 Hz, and we typically make only approximate corrections such that we operate with a beam of order 20pm emittance This is sufficient for the initial commissioning goals, however we need to fully correct the beam for the final goal. To this end, we are currently assembling and installing a set of four new OTR devices in the EXT emittance measurement region. These will allow for fast emittance, Twiss diagnostics and coupling correction. During the most recent operations period, we measured ~10-12 pm extracted vertical emittance, with a similar emittance measured in the DR demonstrating the ability to extract the beam without emittance growth. At the IP, we use techniques such as quadrupole scanning to get the IP Twiss match parameters (see for example Fig.2). We can then rematch using the FFS matching quadrupoles.

FFS Sextupole-based Multiknobs

Details of the sextupole multiknob correction system can be found in [2] and [9]. Using the current optics, at the time of writing we have so far managed to tune to a minimum vertical spot size at the IP of 310nm as measured with the IPBSM system (see fig.3). This is crossover point between the "30 degree mode" and "8 degree mode" of the system. At this point the tuning knobs have started to produce only small incremental improvements to the beam size, this makes it difficult to proceed below 300nm. This is because in 30 degree mode we can no longer make scans of the knobs as larger spot sizes cannot be resolved in this mode. We need to make more thorough use of the 8 degree mode to extrapolate below the 300nm point from repeated fits to scans.

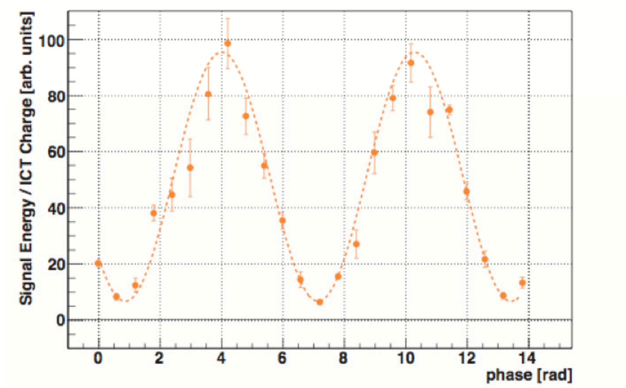

Figure 3: IPBSM Scan of tuned IP vertical beam, 310 +/- 30 (stat.) +/- 40 (syst.) nm

REFERENCES

[1] "Present status and first results of the final focus beam line at the KEK Accelerator Test Facility", P. Bambade et al., Phys.Rev.ST Accel.Beams 13:042801,2010.
[2] "Beam-Based Alignment, Tuning and Beam Dynamics Studies for the ATF2 Extraction Line and Final Focus System", G. White, S. Molloy, M. Woodley, EPAC08-MOPP039, Jul 25, 2008.
[3] "Status of emittance in ATF Damping Ring", S. Kuroda, KEK, ATF2 Project meeting, Dec 2009 http://ilcagenda.linearcollider.org/conferenceDisplay.py?confId=4228
[4] "A nanometer beam size monitor for ATF2", T. Suehara et. al., NIM A 616 (2010) 1-8.
[5] "First beam waist measurements at the Accelerator Test Facility 2 at KEK", S. Bai,et. al. Beijing, Inst. High Energy Phys., Submitted for publication in PRSTAB.
[6] "ATF2 Final Focus Orbit Correction and Tuning Optimisation", A. Scarfe, et. al., EPAC08-MOPP030, Jun 23, 2008.
[7] http://www.vista-control.com/
[8] http://acc-physics.kek.jp/SAD/sad.html
[9] "A Flight Simulator for ATF2: A Mechanism for International Collaboration in the W¡riting and Deployment of Online Beam Dynamics Algorithms", G. White et. al., EPAC08-TUPP016, SLAC-PUB-13304, Jul 25, 200.