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OPTICS AND EMITTANCE STUDIES USING THE ATF2 MULTI-OTR SYSTEM*

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Abstract

A multi-OTR system (4 beam ellipse diagnostic devices based on Optical Transition Radiation) was installed in the extraction line of ATF2 and has been fully operational since September 2011. The OTRs have been upgraded with a motorized zoom-control lens system to improve beam finding and accommodate different beam sizes. The system is being used routinely for beam size and emittance measurements as well as coupling correction. In this paper we present measurements performed during the winter run of 2011 and the early 2012 runs. We show the reconstruction of twiss parameters and emittance, discuss the reliability of the OTR system and show comparisons with simulations. We also present new work to calculate all 4 coupling terms and form the 4-D intrinsic emittance of the beam utilizing all the information available from the 2-D beam profile images. We also show details and experimental results for performing a single-shot automated coupling correction.

INTRODUCTION

The Accelerator Test Facility ATF2 is an extension of the ATF Damping Ring (DR) built at KEK (Japan) [1, 2]. ATF2 is a scaled Final Focus System (FFS) prototype for a future linear collider, such as the International Linear Collider (ILC) [3] and the Compact Linear Collider [4]. The first ATF2 goal is to generate a 37 nm vertical beam size at the main beam focal point, termed the Interaction Point (IP). A secondary goal is to control the beam position at the nanometer-level at the IP to fully demonstrate the capability of this optics design to reliably deliver high luminosities at future high-energy linear colliders. The mOTR system is located in the extraction line (EXT line) which transports the beam from the DR to the FFS. The mOTR system was installed in the diagnostic section of the EXT during the autumn of 2010. The system consists of four OTR monitors [5], close to the existing wire-scanner system (WS). The WS measurements require many pulses, often with an overestimation of the beam size due to beam position and intensity jitter, and can take many minutes to complete a single set of beam size measurements. The OTRs on the other hand, are able to take single-shot measurements of the beam ellipse at the beam repetition rate (1.5Hz). This enables us to measure the emittance with high statistics and perform correlated measurements, e.g. for studying emittance preservation during extraction from the ATF DR. The minimum beam size that this OTR system is capable of measuring is about 2um (the 2-lobe distribution of the OTR light starts to become a dominant factor at this scale, whereupon a different measurement scheme would be required). The measurement resolution of this system is typically a few-percent.

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HARDWARE STATUS

In ”non-operation” mode, the OTR body is set to a position such that the incoming and outgoing beam pipe are straight. Design constraints to keep the face of the camera optics close to perpendicular to the OTR target dictate that the whole OTR body has to be lowered for operation. This brings the chamber closer to the beam as sketched in Fig. 1. Due to the wakefields generated here, some emittance growth has been observed. For instance, Fig. 2 shows the effect in the vertical and horizontal size in OTR3X when one lowers OTR2X from the position where the bellows are horizontal and aligned with the beam pipe (here around 5.5 mm) to the measuring position (which is the 0 reference position in the plot).

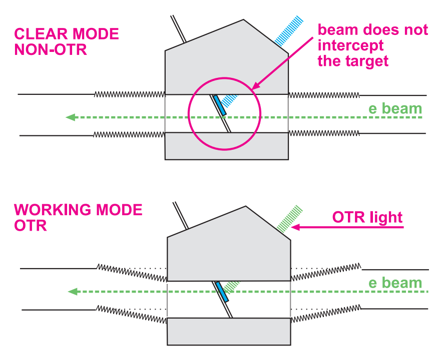

Figure 1: The OTR body is lowered to enable the target to intercept the beam.

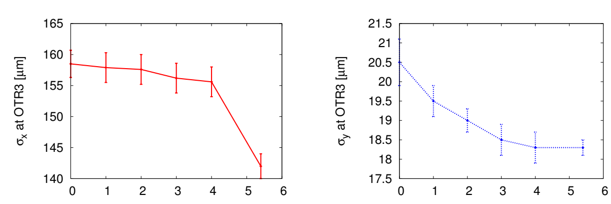

Figure 2: Effect in OTR3X beam size due to wakefields generated in OTR2X when lowering it.

In order to avoid this effect without having to redesign the whole OTR body, a modification of the target holder that brings down the intersection between the optics line and the target has been proposed. The mechanical layout of the new holder is shown in Fig. 3. In this way the whole body has to be lowered only by 1.52 mm instead of 7 mm avoiding the wakefield effect. This new target holder will be installed in June 2012.

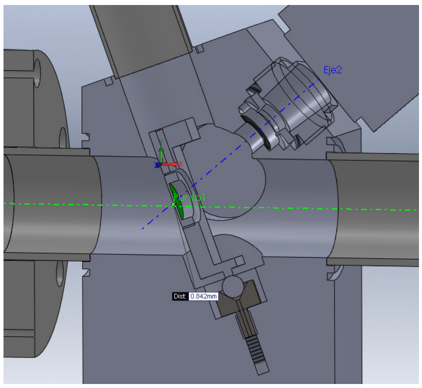

Figure 3: New holder with a hole to introduce the target. The metallic surface is lowered closer to the beam position.

EMITTANCE MEASUREMENT

The mOTR system is being used routinely for ATF2 tuning activities. Its performance has been compared with that of the WS. For example, Figure 4 shows a set of vertical beam size measurements (by both mOTR and WS systems) and the model (in solid line).

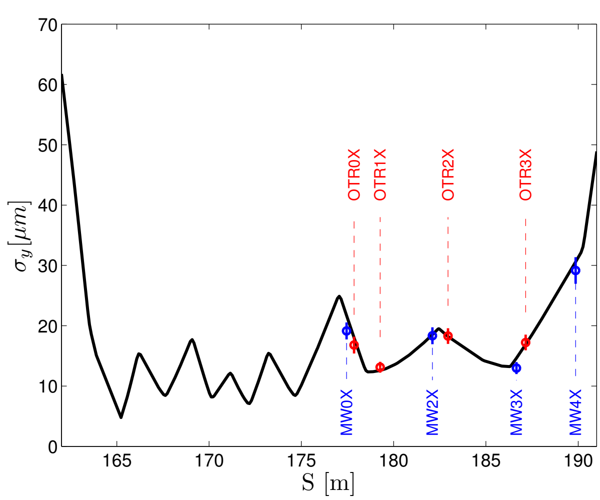

Figure 4: OTR (OTR#X) and WS (MW#X) beam size comparison. This set of measurements was made in the ATF2 run period of December 2011.

The emittance has been measured using both 2D and 4D emittance reconstruction algorithms. With the 2D method, one is able to obtain the projected emittance. The 4D algorithm recently implemented in the ATF2 control room allows one to reconstruct the complete transverse covariance beam matrix, this also gives the values of the intrinsic emittance [6].

Figure 5 shows a comparison between 2D and 4D algorithms. If the incoming beam has no coupling the 2D projected emittance will grow when one couples the beam using a skew quadrupole. The calculated 4D intrinsic emittance should remain constant. A scan of the QK1X skew quadrupole intensity was performed in simulation. A test of the 4D algorithm will be done in June 2012.

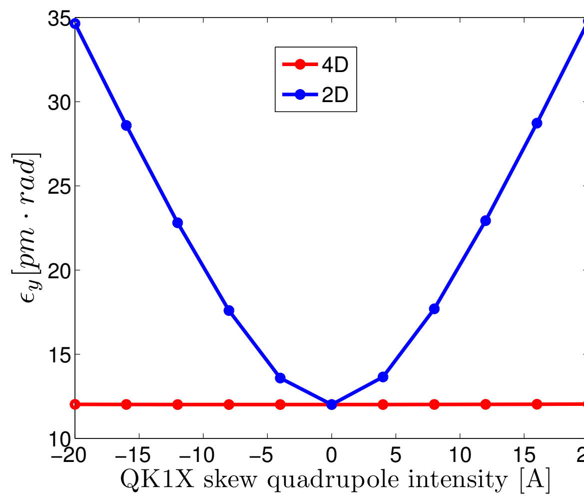

Figure 5: Simulation comparison between 2D and 4D emittances when scanning QK1X skew quadrupole.

In order to have a real 4D emittance reconstruction more research will be made on the algorithm and the OTR locations will be re-examined.

CROSS-PLANE COUPLING CORRECTION

In the diagnostic section of the EXT line, coupling correction after the DR is required to tune the beam in order to reach the primary goal of ATF2. Two different algorithms are proposed to correct the coupling. The so-called 'scan method' consists of sequentially scanning each of the single skew quadrupoles in order to find which intensity minimises the measured vertical emittance. This method is used routinely for beam tuning and works well. This is a model-independent and robust algorithm.

Another proposed faster method is the so called 'response matrix method'. It builds the Jacobian matrix C with elements $C_{ij} = (\frac{\partial \langle xy \rangle_i}{\partial I_j})$ which is the matrix of the linearly fitted coefficients between the intensity of the skew j and the coupling term measured at OTR i. Once C has been built

This methods were simulated and the result is shown in Figure 6, where the angle in a profile monitor just after the IP (MSPIP) is plotted against the angle at the entrance of the EXT line.

$$\begin{pmatrix} \langle xy \rangle_{OTR0} \\ \langle xy \rangle_{OTR1} \\ \langle xy \rangle_{OTR2} \\ \langle xy \rangle_{OTR3} \end{pmatrix} = \begin{pmatrix} C_{11} & C_{12} & C_{13} & C_{14} \\ C_{21} & C_{22} & C_{23} & C_{24} \\ C_{31} & C_{32} & C_{33} & C_{34} \\ C_{41} & C_{42} & C_{43} & C_{44} \end{pmatrix} \cdot \begin{pmatrix} I_{skew1} \\ I_{skew2} \\ I_{skew3} \\ I_{skew4} \end{pmatrix} \quad (1)$$

the intensities that will correct a given coupling measured at the OTRs is calculated using the pseudo-inverse of the response matrix C.

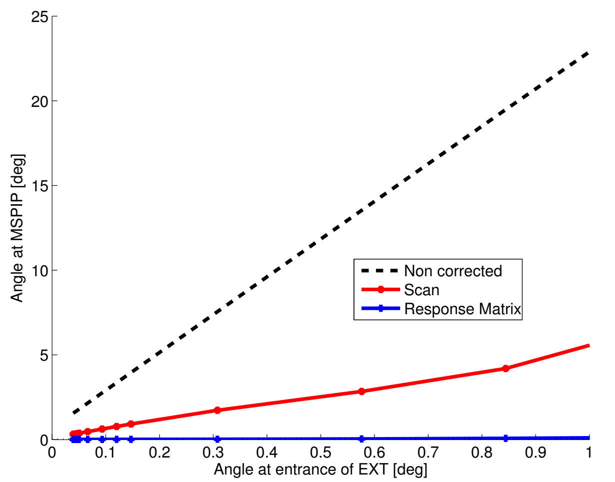

Figure 6: Comparison between coupling correction methods.

The response method was incorporated into the software in the ATF Control Room on December 2012 and measurements were made to test it. The algorithm converged to the same value as the one obtained with the scan method in about three iterations. This method was found to have some advantages: If the response matrix is already saved for a given nominal lattice it can be simply loaded, and it is only necessary to make a measurement with the mOTR. It is then considerably quicker than the manual scan method (one minute against half an hour). Sometimes with the skew scanning method, the solution demands a magnet strength at the limit value, while other skews can be set near to zero. With this alternative method, the intensities seem to be more well distributed. However there are two aspects that can make this procedure unstable. The phase advances between OTRs is not optimised and the mOTR does not sample the phases that the skew quadrupoles are able to cancel (see Fig. 7). This makes it possible to have residual coupling after the mOTR correction. In fact, a big coupling was seen near the IP in December 2011 after some correction. Secondly, being a model-based procedure, this method is obviously more sensitive to lattice mismatches and other lattice errors.

Other methods to correct the coupling are proposed and are to be tested, such as building with a non-linear fitting algorithm the beam that reproduces the measurements and find in simulation the skew settings that minimise the coupling for this beam. In order to ameliorate the coupling correction and the position of the OTRs will be optimised.

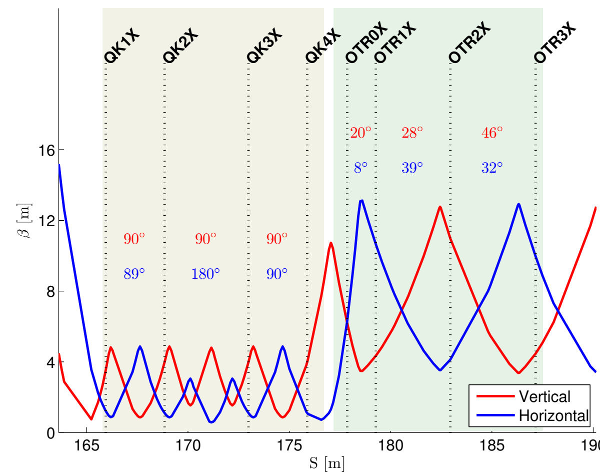

Figure 7: Phase advances between skew quadrupoles and OTRs. β-function in this region is also ploted.

SUMMARY

Although more work needs to be done in single-shot coupling correction and some other improvements can be developed, such as automatic beam finding using the data from the nearer BPMs, the mOTR system is working well and is being used routinely in beam emittance measurements and in coupling correction.

REFERENCES

[1] ATF2 Group, "ATF2 Proposal Vol.1,CERN-AB-2005-035", (August 11, 2005)

[2] P. Bambade et al. (ATF Collaboration), "Present status and first results of the final focus beam line at the KEK Accelerator Test Facility", Phys. Rev. ST-AB Vol. 13, (April, 2010)

[3] J.Bran et al., "ILC RDR", arXiv: 0712.1959 [physics.acc.ph], (2007)

[4] CLIC CDR, to be published.

[5] J. Bosser et al., "Optical transition radiation proton beam profile monitor", Nuclear Instruments and Methods in Physics Research A238, (1985), 45-52

[6] Stephane Fartoukh private communication.