

# MULTI OPTICAL TRANSITION RADIATION SYSTEM FOR ATF2\*

C. Blanch Gutierrez, J. Alabau-Gonzalvo, A. Faus-Golfe, J.J. Garcia-Garrigos,  
IFIC (CSIC-UV), Valencia, Spain

J. Cruz, D. McCormick, G. White, M. Woodley, SLAC, Menlo Park, California, USA

## Abstract

In this paper we describe the calibration tests, software development and first measurements of a Multi Optical Transition Radiation System (mOTR) located in the beam diagnostics section of the extraction line (EXT line) of ATF2, installed in close proximity to an existing multi wire scanner system (WS). The mOTR system is currently in routine operation. Its beam profile data are being used to generate beta matching and 2D emittance measurements. In addition to lattice diagnostics, these data also form the basis for the coupling correction system. The emittance measurement itself is fully automated and takes less than a minute to perform. This system is advantageous over the WS system due to its speed of operation (the data coming from single-shot measurements). We are currently developing algorithms to allow for 4D emittance reconstruction, which we will be testing this autumn with crosschecks from the WS system.

## INTRODUCTION

The Accelerator Test Facility (ATF), built at KEK (Japan), consists of a 1.3GeV s-band linac, injecting electrons into a prototype Damping Ring (DR) constructed to test the mechanism for production of low-emittance beams required for future linear colliders. Beam is extracted from the ATF DR into ATF2. This is a Final Focus System (FFS) prototype for a future linear collider that has been recently built to obtain a focused vertical beam spot size of 37nm (with an extracted vertical emittance of 12pm.rad) and to control the beam position at the few-nano-meter level at the Interaction Point (IP) [1]. The transport beam line from the DR to the FFS is called the extraction line (EXT line), which contains a beam diagnostics section where the mOTR system has been installed. The OTR monitors are based on the transition radiation effect, a light cone emitted in the specular direction when the charged particle crosses the interface of two media with different dielectric constant [2]. The light emitted from an OTR target is focused using a microscope objective lens (Mitutoyo 10X with a numerical aperture of 0.28 and 1 $\mu$ m resolving power) onto the imaging plane of a CCD camera allowing for a single-shot determination of the 2D beam profile at that point. Due to the relatively high measurement rate, this system is a valuable tool for scanning parameters as a function of emittance, e.g. for investigating possible emittance growth

effects from the DR extraction process [3]. This is an improvement over the WS measurements, which require many pulses, possibly with an overestimation of the beam size due to beam position and intensity jitter. Due to the low rep-rate used at ATF (typically 1.56Hz), this has meant the WS system has not been well suited to parameter scanning vs. emittance tasks which is what motivated the construction of the current OTR system.

## SOFTWARE STATUS

The low-level software interface for the mOTR system is provided as an EPICS interface to the motor controllers for horizontal and vertical motion of the camera stages and focus control as well as image triggering and acquisition from the CCD itself. The high-level user interface is provided through Matlab functions and various Graphical User Interfaces (GUIs). There is functionality for basic motion control commands and calibration thereof, machine protection alarms (to limit the time the targets are exposed to the beam) as well as single-OTR data analysis for beam size measurement (e.g. 2D moment analysis of beam ellipsoid image). A separate emittance panel provides the functionality for generating an emittance measurement with a single button push. The code behind the button push causes each OTR to sequentially acquire a number of images (typically 10). The acquired data is then passed to the ATF2 online model software (the Flight Simulator (FS) [4]) through an EPICS link. There, a 2D emittance reconstruction algorithm processes the data and the results are passed back through the same interface to the user. Some panels from the user interface as seen in the ATF2 Control Room are shown in Fig. 1. In the upper right corner is the main window with some information about the targets and OTR position and some buttons including the one that opens the emittance panel shown in the upper left corner. The windows at the bottom present the twiss and emittance analyses performed as described above. There is also a single OTR main panel that provides shot-by-shot analysis of the image ellipsoid (such as projected beam size, centroid position and statistical errors) and includes some options like calibration, beam finding, target insertion and CCD adjustments (e.g. exposure time). The emittance reconstruction algorithm (after the 3 ellipse parameters have been calculated from the image) is based on the one used for the WS [5]. Since the beam is very flat, the vertical emittance becomes sensitive to coupling. For this reason, it is interesting to develop a 4D emittance algorithm which takes into account the tilt of the beam profile to reconstruct the ten

\* Work supported by FPA2010-21456-C02-00 and by Department of Energy Contract DE-AC02-76SF00515

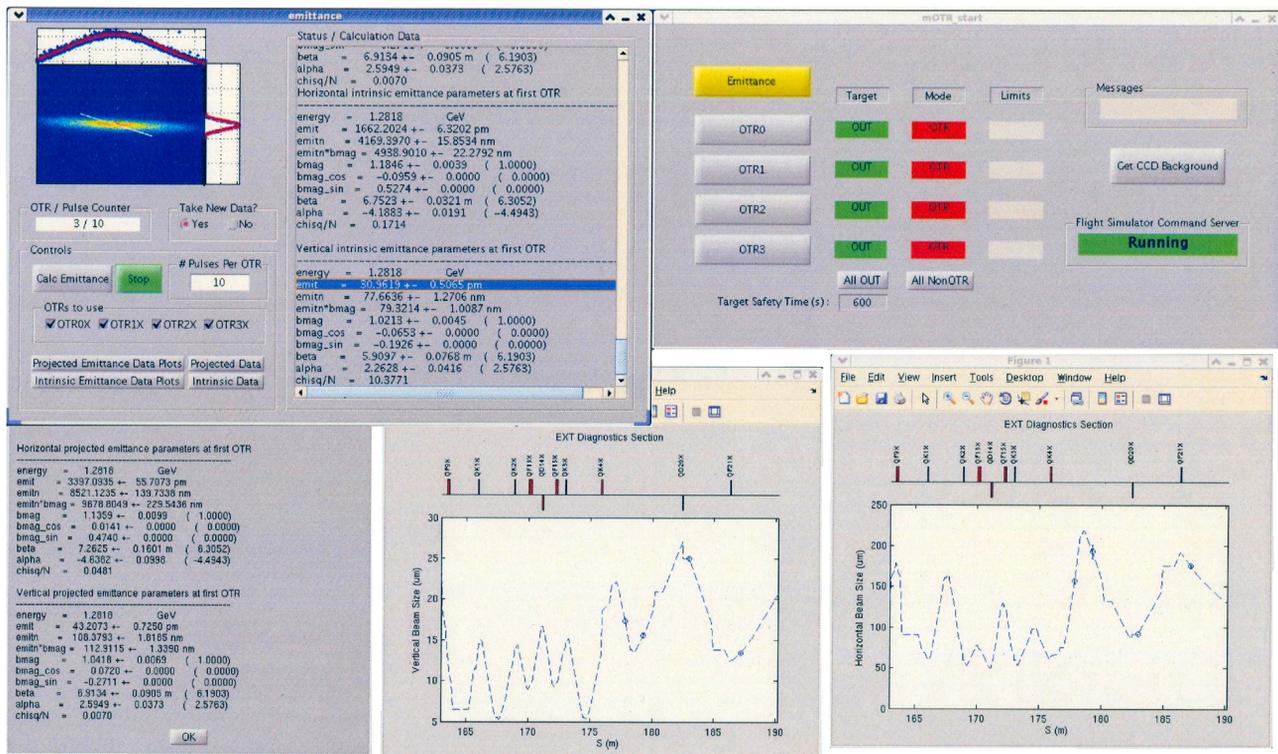


Figure 1: View of the user interface as seen in ATF control room.

beam matrix parameters and then, by diagonalising it, the emittances. The OTR makes this possible because it takes a 2 dimensional beam shot. Other additional functions are being implemented including automatic beam finding (using information about the beam orbit from the BPM system), and automatic coupling corrections (using the the 4D method mentioned above). We will also include functionality to automate the focusing of the microscope lens.

### HARDWARE STATUS

The OTR current design is based on a previous design [6] that was installed and tested in the original extraction system of the ATF (which has since been dismantled to produce the existing EXT and FFS). The new OTR design is an evolution of this old one and includes modifications of the optical system, target actuator, and target material. Additionally the redesigned OTR requires only 30cm of beam line length [7]. Four OTRs were installed in the ATF2 EXT during the first half of 2010 and initial testing led to other improvements in the design (Fig. 2). New target materials were tested and currently in use. OTRs 0 and 1 use  $1\mu\text{m}$  Al foils while OTR 2 and 3 use Aluminium coated  $2\mu\text{m}$  Kapton film. Both these materials have with stood beam currents of  $10^{10}$  electrons/pulse and  $14\mu\text{m}$  Y by  $70\mu\text{m}$  X spots. The target holder assembly was re-designed to include a set of wires below the target. The horizontal and vertical movers are used to scan the wires across the beam to provide a cross check to the sizes measured optically by the OTRs. The calibration system was revamped: includ-

ing a scribed target and a small lamp that can be pushed into the beam pipe to illuminate the target when there is no beam for faster initial alignment of the target. Another currently planned modification is to introduce an additional switchable lens system into the optical path from the lens to the camera. When introduce into the optical path, it will reduce the system magnification and provide a four times larger field of view. This will certainly reduce the time for locating the beam during initial setup or if the beam orbit changes in the OTR area.

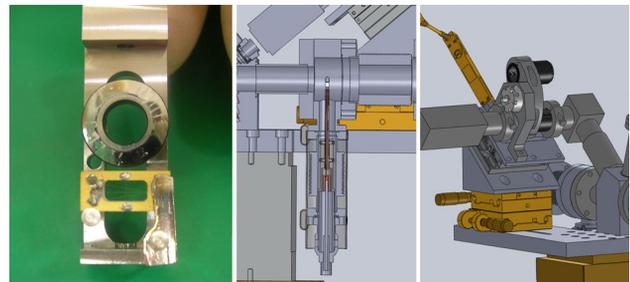


Figure 2: Last hardware changes: Wires under the target holder, calibration lamp and double lens system.

### CALIBRATION AND FIRST MEASUREMENTS

A calibration of the positioning system was made in December 2010. In order to calibrate the scale, the OTR is

moved in the vertical direction and the centroid position versus the mover position curve is fitted. This is needed since the camera is not normal with respect to the target and the target is not normal with respect to the beam direction, so the calibration factor is important to obtain the real vertical size. To assess the relative roll of the system the beam is steered horizontally with an upstream dipole corrector magnet (the response of this beamline devices defines the reference rotation axis). The response in the vertical plane demonstrates the degree of roll with respect to this accelerator reference system. The alignment of all four OTRs is very important for 4D emittance reconstruction since the tilt of the beam is crucial and will be measured when the beam becomes available again. From Autumn 2010 and until March 2011 the OTRs were commissioned and put into general usage during machine operations for beam matching, emittance measurements and coupling correction. For a specific OTR, the calculated vertical and horizontal beam profile size was cross-checked with the wires installed in the holder and found to be in agreement within measurement errors. This check will be performed for the other 3 OTRs in future beam operation periods. There was also one test period where emittances were calculated with the existing WS system and with the 4 OTR system within a few hours of each other. This showed good general agreement at the 10% level, but more systematic studies need to be performed in future data taking periods. Coupling correction is routinely performed by changing the strength in the four skew quadrupoles and fitting  $emit_y BMAG$  measured with the 4 OTRs (Fig. 3), the minimum coupling in each case corresponding to the minima from the parabolic responses. Figure 4 shows the beam profile at one of the OTRs before and after dispersion correction and coupling correction.

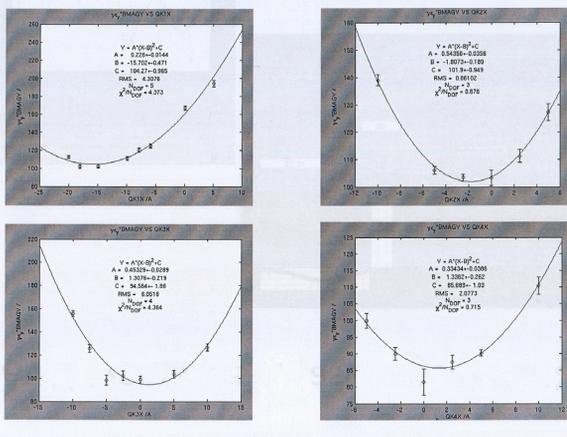


Figure 3:  $emit_y \times BMAG$  versus skew quad intensity for coupling correction.

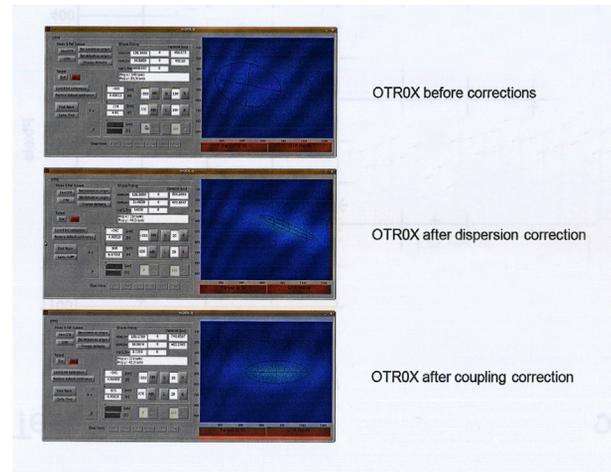


Figure 4: Beam spot after dispersion and coupling correction.

## SUMMARY AND OUTLOOK

ATF2 is currently being brought back into a serviceable condition after the 2011 Tohoku Earthquake. We expect the restart of beam operations will not take place before Autumn 2011. When the beam becomes available, a systematic measurement campaign is needed in order to compare the measurements with realistic simulations and with the values given by the WS. This will validate the mOTR as an emittance diagnostic device.

## ACKNOWLEDGMENTS

We would like to thank the ATF group at KEK for all the support, specially N. Terunuma for his continuous help on the installation.

## REFERENCES

- [1] ATF2 Group, "ATF2 Proposal Vol.1,CERN-AB-2005-035", (August 11, 2005)
- [2] J. Bossert et al., "Optical transition radiation proton beam profile monitor", Nuclear Instruments and Methods in Physics Research A238, (1985), 45-52
- [3] M. Alabau Pons et al., "Experimental Studies and Analysis of the Vertical Emittance Growth in the ATF Extraction Line in 2007-2008", ATF-08-15 Internal Report, (2008)
- [4] G. White et al., "A flight simulator for ATF2: A mechanism for international collaboration in the writing and deployment of online beam dynamics algorithms", EPAC'08, Genoa, TUPP016, (2002)
- [5] I. Agapov et al., "Beam emittance measurement with laser wire scanners in the International Linear Collider beam delivery system", Phys. Rev. ST Accel. Beams 10, 112801 (2007)
- [6] M. Ross et al., "A very high resolution optical transition radiation beam profile monitor", SLAC-PUB-9280, (2002)
- [7] J. Alabau et al., "Multi optical transition radiation system for ATF2", IPAC'10, Kyoto, MOPE050, (2010)