UPGRADE AND SYSTEMATIC MEASUREMENT CAMPAIGN OF THE ATF2 MULTI-OTR SYSTEM*

A. Faus-Golfe, J. Alabau-Gonzalvo, C. Blanch Gutierrez, J. Resta-Lopez,
IFIC (CSIC-UV), Valencia, Spain
J. Cruz, E. Marin, D. McCormick, G. White, M. Woodley, SLAC, Menlo Park, California, USA

Abstract

A multi-Optical Transition Radiation (mOTR) system made of four stations is being used routinely since September 2011 for transverse beam size measurement and emittance reconstruction in the extraction line of ATF2, providing diagnostic support during the ATF2 tuning operation. Furthermore it is also an excellent tool for fast transverse coupling correction. Due to the compactness of the current design the system has an influence in the increase of the transverse emittance due to wakefield effects when a simultaneous measurement is made. To avoid this effect a new target holder and a new optics has been designed and implemented. In this paper we describe the present status of the ATF2 mOTR system, showing recent performance results, and hardware design improvements.

INTRODUCTION

The Accelerator Test Facility ATF2 at KEK (Japan) [1] is a scaled Final Focus System (FFS) prototype for Future Linear Colliders (FLCs). The ATF2 Goal 1 is to generate a 37 nm vertical beam size at the main beam focal point, termed the Interaction Point (IP). ATF2 Goal 2 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. A mOTR system has been installed in the extraction line (EXT line) which transports the beam from the Damping Ring (DR) to the FFS. This system consists of four OTR monitors [2, 3, 4], placed close to a Wire-Scanner (WS) system. The WS measurements require many pulses, often with an overestimation of the beam size due to beam position and intensity jitter, and can take about half an hour 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 system allows to perform fast emittance measurement with high statistics and correlated measurements, e.g. for studying emittance preservation during extraction from the ATF DR. The minimum beam size that this system is capable of measuring is about 2 μm (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 [5]). In this paper we present several measurement results using the ATF2 mOTR system during various ATF2 run periods during the last two years. Moreover, recent mechanical and optical system improvements to reduce the wakefield effect of a simultaneous measurements in the system are also described.

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EMITTANCE MEASUREMENTS

The mOTR system has demonstrated to be an excellent diagnostic tool for fast emittance reconstruction, speeding up the beam tuning process in the ATF2 extraction line. The OTR results have been several times validated by means of comparisons with WS measurements, simulations and also with and additional WS wire embedded into the OTR target devices [7]. Figure 1 compares the vertical emittance measurements in the EXT line (made by the mOTR system) and in the damping ring during 2011 and half 2012. The lack of measurements after March 2011 is due to the 'Tohoku Earthquake' and the subsequent recovery period to putting the machine back into operation. After the quake and until February 2012, a very high emittance growth was observed in the EXT line with respect to the DR. This was partially solved by applying the following steps: generating 1 mrad y' bump in the extraction section, removing the second extraction kicker and reducing the wakefield effects of the sensible elements.

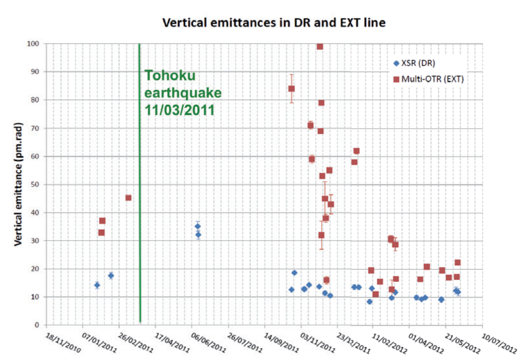

Figure 1: Summary of vertical emittance measurements at different dates in the damping ring and in the extraction line of ATF2 during 2011 and half 2012.

It is important to point out that the mOTR measurements in the ATF2 EXT line have shown to be reliable and stable. On the other hand, a strong dependence on bunch charge has been observed. For instance, Fig. 2 shows the dependence of the vertical emittance on the bunch charge for a set of measurements during November 2012. The vertical emittance increase rate in the EXT line is 2–3 pm per 10^9 electrons, which is much larger than the one observed in the DR ($<$ 0.1 pm per 10^9 electrons). Further investigation is needed to understand these charge dependences.

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It is interesting to mention that the best vertical emittance observed in the EXT line during the 2012 running period (November-December) was $\approx$ 21 pm at 10^9 electrons per bunch.

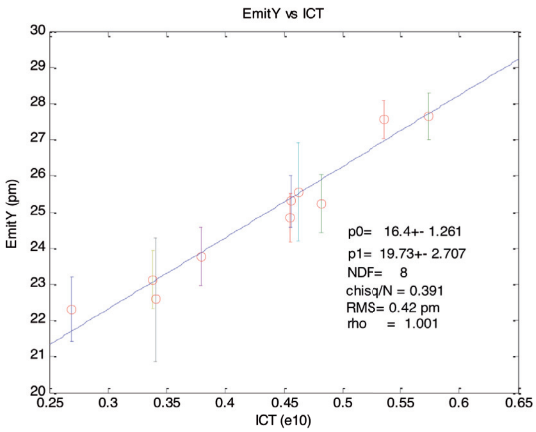

Figure 2: Vertical emittance as a function of the bunch charge (in units 10^{10} particles per bunch) in the ATF2 EXT line.

COUPLING CORRECTION

The system was used with good results for cross-plane coupling correction by using 4 skew quadrupoles to minimise the measured emittance. The correction is performed either by skew quadrupole intensity scan to minimise the emittance (or projected beam size), or by means of the response matrix method algorithm implemented in the ATF2 control software. Figure 3 compares the vertical emittance before and after coupling correction for various sets of measurements during 2012.

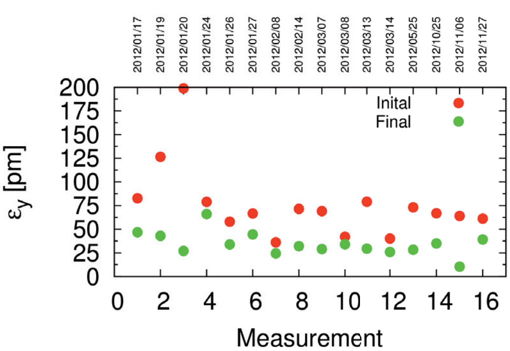

Figure 3: Vertical emittance measured before (initial) and after (final) coupling correction for various sets of measurements in 2012.

Simulation studies to determine the versatility of the mOTR system against different coupling scenarios are carried out. Figure 4 compares the obtained emittance after correcting the coupling between two different algorithms, namely the response matrix and the simplex [6]. The response matrix algorithm minimises the measured tilt at the 4-OTRs (θ_1, θ_2, θ_3, θ_4) while the simplex algorithm minimises the vertical emittance. Each considered scenario in Fig. 4 corresponds to a different coupling between the transverse coordinates which results into a initial vertical emittance of 100 pm.

OTHER APPLICATIONS

The mOTR system is also being used for beta matching functions. Quadrupoles in the inflector section, upstream of the mOTR system, are used for the matching, in order to reduce the Bmag parameter (Bmag=1 is the reference value). Figure 5 illustrates the matching procedure.

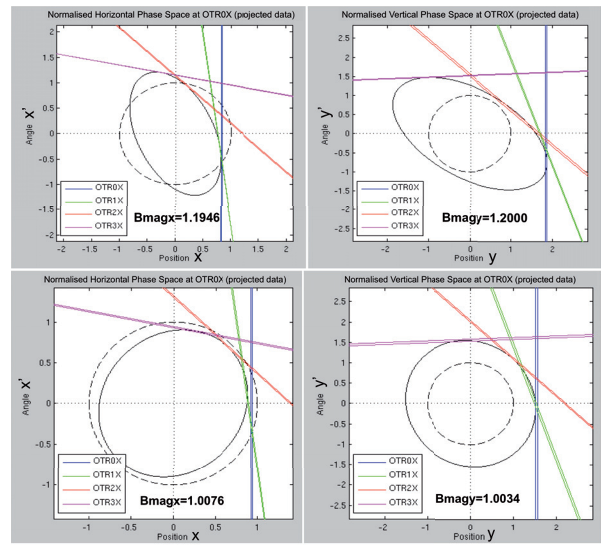

Figure 5: Top: initial normalised transverse phase space before beta matching. Bottom: normalised transverse phase space after 3 beta matching iterations. The dotted ellipse represents the designed (reference) phase space.

Another application of the mOTR system is its use to determine the beam energy spread. Since the mOTR is installed in a dispersion-free section it is necessary then to create it in order to perform this measurement. This is made in ATF2 by a pair of skew quadrupoles labelled QS1X and QS2X, placed upstream of the mOTR system. Then the beam size, σ_y is measured as a function of dispersion D_y: $\sigma_y^2 = \beta_y \epsilon_y + D_y^2 \sigma_E^2$. The value of σ_E^2 is determined by linear fit. An example of this sort of measurement at OTR2 is shown in Fig. 6. A value of $\sigma_E = (8.4 \pm 1.2) \times 10^{-4}$ was obtained in December 2012 (the nominal value is $\sigma_E = 0.8\%$).

HARDWARE UPGRADE TO AVOID WAKEFIELDS

The mechanical structure of the targets and the target holders has recently been re-designed in order to minimise wakefield effects. The OTR wakefield issues were explained in detail in Ref. [7]. Figure 7 shows the new holder mechanical design in comparison with the old one. The new holder has a ramp to guide it inside the actuator pipe and avoid the interference between them. The target is flipped over so the aluminised face (green face) is now on the rear face of the target frame. Due to this the frame

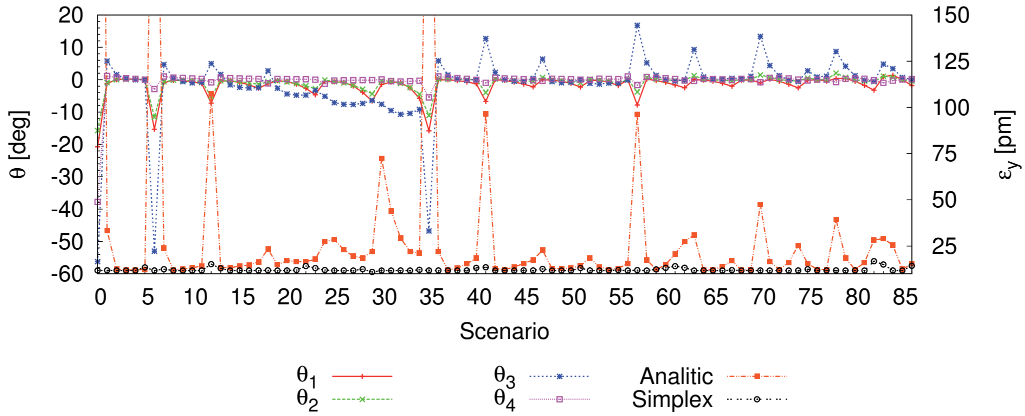

Figure 4: Coupling correction comparison of matrix response method and simplex method for various sets of coupling scenarios.

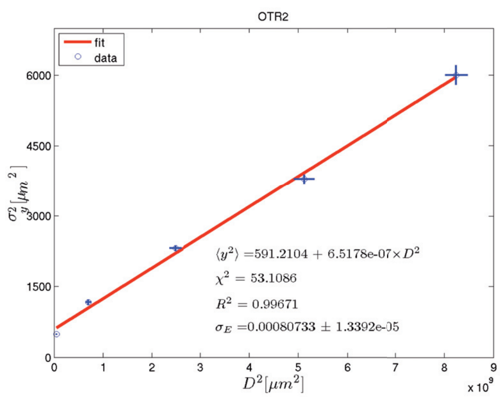

Figure 6: Energy spread measurements at OTR2.

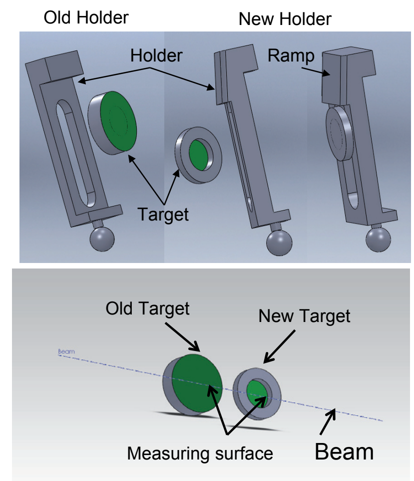

Figure 7: Comparison of old (left) and new (right) target holders.

of the target may cast "shadow" on the measuring surface reducing the working area. For this, the thickness of new target will be reduced from 3.2 mm to 1.5 mm by using a Stainless Steal washer as frame, increasing like this the working area. The new holder places the target towards downstream and down. The center of the target is now 1.5 mm from the center of the beam pipe. So with this set up the beam intercepts the target just lowering the whole OTR body by 1.5 mm. In the measuring configuration the beam remains almost centered within the beam pipe and do not produce wakefield effects.

The optical system has been accordingly modified to increase its working distance while preserving the required resolution. The new optical device (with achromat lens) features a working distance of about 55 mm (the previous working distance was 34 mm) and provides a resolution of 10%.

The installation of the optical system and new target holders was made in February 2013. Measurements are being made to confirm the efficiency of these new targets.

OUTLOOK

The mOTR system is the principal method to characterize the beam in the ATF2 EXT line. Its resolution and stability of the system has been demonstrated by repeated measurements, and validated by comparison with the existing WSs, simulations and also with an additional WS embedded into the OTR target devices.

Although the OTR technique is not new, the complete measurement and correction system of the mOTR system in ATF2 is a significant evolution in the state-of-the-art of such solutions. Of special note it is the large degree of automation and integration with the online modelling systems. It represents a highlight of modern beam instrumentation. Similar monitor systems can now be deployed at FLCs and linac-based synchrotron light sources.

REFERENCES

[1] P. Bambade *et al.*, Phys. Rev. ST-AB **13** (2010) 042801.

[2] M. Ross *et al.*, SLAC-PUB-9280, July 2002.

[3] J. Alabau-Gonzalvo *et al.*, Proc. of IPAC2010, MOPE050.

[4] J. Alabau-Gonzalvo *et al.*, Proc. of IPAC2011, TUPC127.

[5] A. Aryshev *et al.*, Proc. of IPAC2011, "Sub-micrometer Resolution Transverse Electron Beam Size Measurement system based on OTR".

[6] Nelder, J. A. and Mead, R., Computer Journal vol.7, (1965), "A Simplex Method for Function Minimization".

[7] J. Alabau-Gonzalvo *et al.*, Proc. of IPAC2012, MOPPR044.

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