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INTENSITY DEPENDENT EFFECTS AT ATF2, KEK

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Abstract

The Accelerator Test Facility 2 (ATF2) at KEK is a prototype for the Final Focus Systems of the future e+e- linear colliders, the International Linear Collider (ILC) and the Compact Linear Collider (CLIC). In this paper both simulation and experimental results are presented with special emphasis on intensity-dependent effects. The importance of these effects is shown using the PLACET code and realistic ATF2 machine simulations (including beam jitter, misalignment, wakefield, Beam Based Alignment (BBA) correction). The latest experimental results are also presented, in particular the impact of the beam intensity on the beam size at the IP.

INTRODUCTION

In future linear colliders, one key parameter is to maximize the luminosity at the Interaction Point (IP). In order to increase the number of collisions, it is beneficial to have the smallest possible transverse beam size. One of the limiting parameter is the intensity (the number of particles in a bunch, here electrons). Electrons traveling through the accelerator interact with the surrounding structure and create an electromagnetic field, the wakefield. This field interacts with electrons inside the same bunch (short-range wakefield) but also with electrons in the following bunches (long-range wakefield). In order to study the intensity-dependent effects in future linear colliders such as CLIC [1] and ILC [2], experimental studies are run at ATF2 at KEK in Japan. The facility is made of an injector, a linac, a Damping Ring (DR), and the ATF2 beamline. The ATF2 beamline consists of 49 quadrupoles, 5 sextupoles, 7 dipoles, 4 skew quadrupoles, 22 correctors (12 in the vertical plane and 10 in the horizontal one), and 38 beam position monitors (BPMs) (13 Stripline BPMs and 25 cavity BPMs). The beamline comprises a 52 m long extraction line (EXT) and a 38 m long Final Focus (FF) and matching section.
The ATF2 beamline was designed and built in order to fulfill two goals:

- Goal 1: Achievement of small beam size (37 nm). Demonstration of the performance of the Final Focus System based on local chromaticity correction;
- Goal 2: Control of the beam position. Demonstration of the performance of the beam orbit's stabilisation with a nanometer precision at the IP.

INTENSITY-DEPENDENT EFFECTS WITH PLACET

PLACET [3] is a code that simulates the dynamics of a beam in a linac in the presence of wakefields, misalignments and other imperfections. It allows one to investigate single- and multi-bunch effects. A number of correction schemes are implemented to test what beam size growth one should expect for given pre-alignment errors. The wakefield kick is calculated assuming that the longitudinal profile of the bunch is Gaussian. The wake used for ATF2 was calculated with Gdfidl [4], an electromagnetic field simulator. The main wakefield sources in the ATF2 beam line are cavity BPMs [5], bellows and flanges. The geometry of the ATF2 C-Band dipole cavity is shown in Fig. 1. The wakepotential is calculated considering a 7 mm long Gaussian bunch traveling through the element with an initial transverse offset of 1 mm. The calculated wakepotential for the ATF2 cavity BPM is show in Fig. 2. In the ATF2 line, cavity BPMs are located at quadrupoles, shown in Fig. 3.

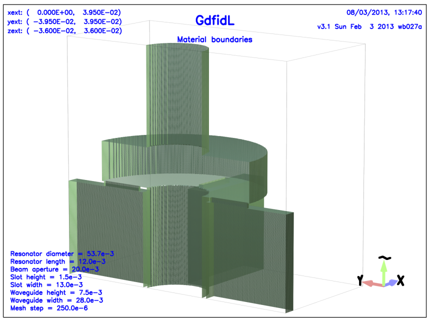

Figure 1: The geometry of the ATF2 C-band dipole cavity used in GdfidL.

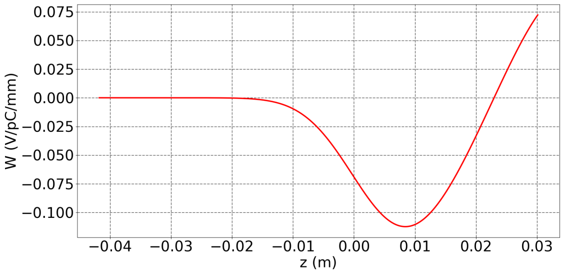

Figure 2: Transverse wakepotential of the ATF2 cavity BPM in V/pC/mm calculated with Gdfidl for a vertical offset of 1 mm, Gaussian bunch length of 7.0 mm and 1 pC charge.

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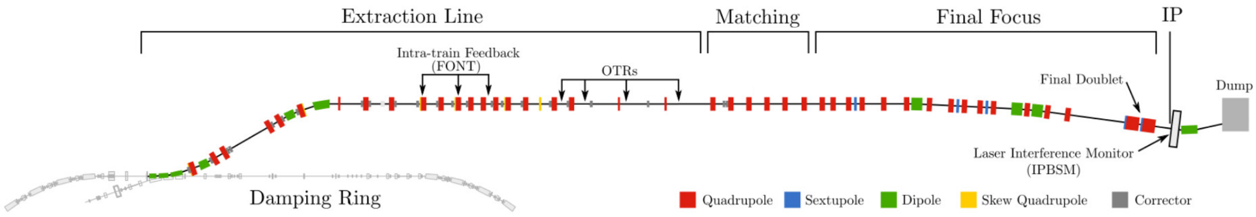

Figure 3: The layout of ATF2.

In order to calculate the effects of dynamic errors, 200 single bunches were injected in the extraction line with an angle/position offset in unit of $\sigma_{y'}/\sigma_y$ and were tracked all the way to the IP. Some realistic imperfections were taken into account in the simulation. We considered the quadrupoles, the cavity BPMs and the sextupoles to be misaligned by 100 µm RMS, to have a magnet roll error of 200 µrad RMS and the quadrupoles and sextupoles to have a magnet strength error of 10^{-3} RMS. These bunches were tracked through 100 different machines, each of them with a different misalignment random seed. A full correction procedure was applied: first a one-to-one correction that steers the beam and minimizes the transverse displacements measured by BPMs. Then Dispersion-Free Steering correction was applied to correct for unwanted dispersion introduced by misaligned quadrupoles. This correction steers the beam through the center of the BPMs and simultaneously minimizes the difference between two beams with different energies. A further correction technique was applied: the Wakefield-Free Steering, which minimizes the difference of orbits between beams with different intensities [6]. As a last tuning step, knobs were applied in order to remove the correlations between the following couples at the IP: $< y,x' >, < y,y' >, < y,E >$ and $< y,x'\times x' >, < y,x'\times y' >< y,x'\times E >$ [7]. The results of the impact of these dynamic effects are summarized in Table 1 and shown in Fig. 4 and Fig. 5.

Table 1: Impact of angle and position jitters at low and high beam intensity on the vertical beam size at the IP.

Case	$\overline{\sigma_y^*}$	**90th percentile**
Angle jitter		
Jitter $0.5\sigma_{y'}$, $1\times10^9 e^-$	43 ± 0.4 nm	51 nm
Jitter $0.5\sigma_{y'}$, $10\times10^9 e^-$	54 ± 7.0 nm	78 nm
Position jitter		
Jitter $0.5\sigma_y$, $1\times10^9 e^-$	47 ± 4.1 nm	57 nm
Jitter $0.5\sigma_y$, $10\times10^9 e^-$	91 ± 46 nm	160 nm

Each point corresponds to the average of 200 consecutive pulses, reproducing the number of pulses the IP Beam Size Monitor (IPBSM) needs to compute one beam size [8]. The simulations show that the effect of the angle/position jitter is significant on the IP beam size. Indeed, with a misalignment of 100 µm and a initial angle jitter of $0.5\sigma_{y'}$ the average vertical beam size at the IP for 100 machines at the nominal beam intensity ($1.0\times10^{10}e^-$) is around 54 nm. Given an initial position jitter of $0.5\sigma_y$, the resulting average vertical beam size at the IP is then more than 91 nm at the nominal beam intensity. Even at low beam intensity ($1.0\times10^9e^-$), the effect of these dynamic errors is significant. 10% of the machines have a vertical IP beam size greater than 51 nm for the incoming angle jitter case and 57 nm for the position jitter. This 90^{th} percentile becomes really large at high intensity ($10\times10^9e^-$). This shows that some machines have particularly bad misalignment seeds and are harder to correct.

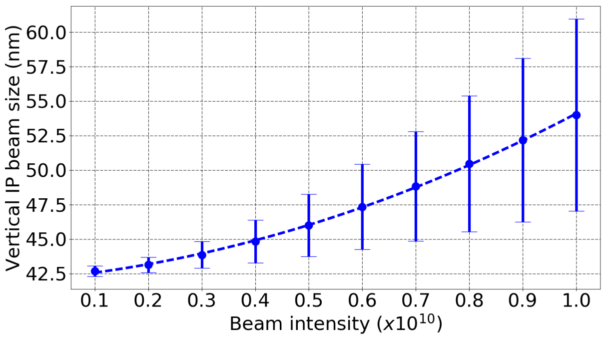

Figure 4: Vertical beam size at the IP considering an initial angle jitter of $0.5\sigma_{y'}$ vs. beam intensity.

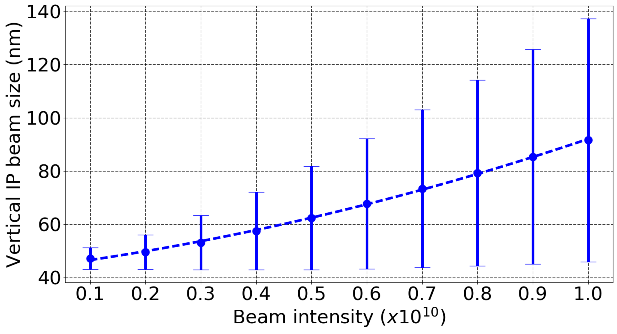

Figure 5: Vertical beam size at the IP considering an initial position jitter of $0.5\sigma_y$ (bottom) vs. beam intensity.

These simulations show that the vertical beam size at the IP evolves quadratically with the beam intensity. These effects have also been measured in the ATF2 machine in single bunch mode, as discussed below.

INTENSITY DEPENDENCE STUDIES USING THE IPBSM

The vertical beam size at the IP is measured with the IPBSM also called the Shintake monitor. This monitor was tested at the Final Focus Test Beam (FFTB) experiment at SLAC. It measured a vertical beam size of around 60 nm [9]. The monitor is made of two laser beams that intersect at the IP with the electron beam. Compton scattered photons are generated when the electron beam passes through the interference pattern of the two laser beams and the signal is recorded by a Compton photon detector. The modulation of the Compton signal is measured. It is expressed as $M = \frac{N_+ - N_-}{N_+ + N_-}$ where N_+ and N_- are the maximum and minimum Compton signal intensities during a beam scan. For a Gaussian beam and for chosen parameters, the modulation (M) can be defined as a function of the beam size at the IP (σ) as:

$$M = |\cos(174°)| \exp\left(\frac{-2\pi^2\sigma^2}{(266.10^{-9})^2}\right) \quad (1)$$

Measurements of the intensity dependent effects on the vertical beam size at the IP were done at ATF2. The modulation is measured at the IP for different beam intensities. The results of a recent scan are shown in Fig. 6 [10]. A higher modulation means a smaller beam size. In this case, a modulation of 0.68 corresponds to a beam size of 110 nm. One can observe the same behavior as shown in the simulations.

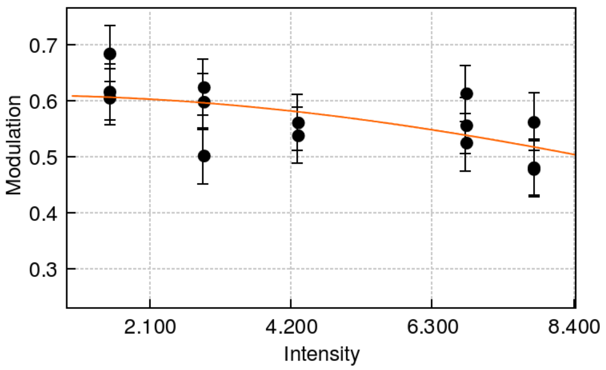

Figure 6: IPBSM modulation vs. intensity ($\times 10^9$ electrons).

In order to compare simulations and measurement, one can define the intensity dependence parameter w as follows:

$$w[\mathrm{nm}/10^9 e^-] = \frac{\sqrt{\sigma_y^2 - \sigma_{y,0}^2}}{N} \quad (2)$$

With σ_y the measured vertical beam size at the IP, $\sigma_{y,0}$ the vertical beam size at the IP considering no wakefield and N the number of electrons per bunch. The simulation taking into account the static and dynamic imperfections and with an initial position jitter of $0.5\sigma_y$ gives $w = 8.73 \pm 2.72$ nm/$10^9 e^-$ and the measurements in 2018 give $w = 8.5 \pm 1.1$ nm/$10^9 e^-$. The PLACET intensity dependence simulations agree well with the measurements made in ATF2.

CONCLUSION

The intensity-dependent effects simulations run with PLACET, with realistic imperfections, showed that the impact of dynamic errors is significant even after full correction. The simulated correction was similar to that used experimentally in the ATF2 beam line, just more effective. For 100 corrected machines, a beam with an incoming angle jitter of $0.5\sigma_{y'}$ leads to an increase of the average IP vertical beam size of 17 nm at nominal intensity ($10 \times 10^9 e^-$) and to an increase of 54 nm for beam with an incoming position jitter of $0.5\sigma_y$. In order to be able to compare the intensity dependent effects more directly, one can use the intensity dependence parameter defined above. Simulations lead to an intensity dependence parameter $w = 8.73 \pm 2.72$ nm/$10^9 e^-$, and recent measurements done in 2018 give an intensity dependence parameter of $w = 8.5 \pm 1.1$ nm/$10^9 e^-$. The agreement between simulations and measurements at ATF2 makes the PLACET simulations on the intensity dependent effects in the future linear colliders ILC and CLIC more reliable.

ACKNOWLEDGEMENTS

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REFERENCES

[1] CLICdp Collaboration,"The Compact Linear Collider (CLIC) 2018 Summary Report", CERN, Geneva, Switzerland, Rep. CERN-2018-005-M, Dec. 2018.

[2] T. Behnke *et al.*, "The International Linear Collider Technical design report", CERN, Geneva, Switzerland, Rep. CERN-ATS-2013-037, Jun. 2013.

[3] D. Schulte *et al.*, "The PLACET project", `http://clicsw.web.cern.ch/clicsw/`

[4] W. Bruns, "The GdfidL Electromagnetic Field Simulator".

[5] J. Snuverink *et al.*, "Measurements and simulations of wakefields at the Accelerator Test Facility 2", *Phys. Rev. Accel. Beams*, vol 19, p. 091002, Sep. 2016.

[6] T.O.Raubenheimer, "A new technique of correcting emittance dilutions in linear colliders", *Nucl. Instr. and Meth.*, vol 306, pp. 61-64, Aug. 1991.

[7] T. Okugi *et al.*, "Linear and second order optics corrections for the KEK Accelerator Test Facility final focus beam line", *Phys. Rev. STAB*, vol 17, p. 023501, Feb. 2014.

[8] T. Shintake, "Proposal of a nanometer beam size monitor for e+e- linear colliders", *Nucl. Instr. Meth.*, vol 311, pp. 453-464, Jan. 1992.

[9] V. Balakin *et al.*, "Focusing of Submicron Beams for TeV-Scale e+e- Linear Colliders", *Phys. Rev. Lett.*, vol 74, p. 2479, Mar. 1995.

[10] P. Korysko, “Intensity-dependent effects in the ATF2, simulations and measurements”, presented at the CLIC Workshop, Meyrin, Switzerland, Jan. 2019. `https://indico.cern.ch/event/753671/`