SHORT RANGE WAKEFIELD MEASUREMENTS OF HIGH RESOLUTION RF CAVITY BEAM POSITION MONITORS AT ATF2

J. Snuverink, S. T. Boogert, F. J. Cullinan, A. Lyapin,
John Adams Institute at Royal Holloway, University of London, Surrey, UK
Y. I. Kim, John Adams Institute at University of Oxford, Oxford, UK
K. Kubo, T. Okugi, T. Tauchi, N. Terunuma, J. Urakawa, KEK, Ibaraki, Japan
G. White, SLAC, Menlo Park, California, USA

Abstract

Cavity beam position monitors (CBPM) have been used in several accelerator facilities and are planned to be used in future accelerators and light sources. High position resolution up to tens of nanometres has been achieved, but short range wakefields are a concern, especially for small beam emittances. This paper presents the wakefield calculations as well as the first measurements of the CBPM generated short range wakefields performed at the Accelerator Test Facility (ATF2).

INTRODUCTION

ATF2 Mission

The ATF2 [1] is a scaled demonstrator for Raimondi-Seryi final focus systems [2], which are planned for future linear colliders (LC). The aim of the ATF2 is two fold, firstly to obtain and verify a vertical focus size of 37 nm, secondly to hold the focus stable to within a few nanometres. The ATF2 collaboration has recently achieved its intermediate goal of a sub-100 nm vertical beam size, measured using an interference pattern Compton scattering beam size diagnostic (Shintake monitor) although only at relatively modest bunch charges of 0.1×10^{10} electrons per bunch [3].

Wakefields

Achieving sub-100 nm vertical beam size required lowering the bunch charge from the nominal 1×10^{10} electrons by a factor of 10. Although this had a positive side effect of reducing the Compton signal background of several beam diagnostics, small beam sizes need to be demonstrated at the nominal bunch charge, close to the values required for future LCs to achieve their design luminosity. One of the main contributors to the beam size growth is thought to be the effect of wakefields. The extracted bunch length at ATF is relatively large: 7-9 mm, resulting in the wakefields excited by the head of the bunch producing a kick acting on the particles in the tail. Hence, the particles in the tail arrive at the interaction point (IP), where the beam size is measured, with a small offset with respect to the head, which is perceived as a beam size increase.

The initial design of the ATF2 beamline did not include a thorough study of the wakefield effects of all the elements. This is normally justified for a single-pass beamline such as ATF2, where collective beam effects do not accumulate. The ATF2 beamline includes a number of high impedance elements, such as CBPMs, unshielded bellows, vacuum ports, step transitions, etc. A study began to identify the major contributors, understand the effect on the beam size, and measure the produced kicks.

Cavity Beam Position Monitor System

To achieve the challenging goals of ATF2 there are a total of 39 position sensitive dipole cavities: 35 C-band 20 mm aperture CBPMs for the extraction, matching and final focus sections, 2 S-band 40 mm aperture cavities used in the final focusing doublet (where a larger aperture is required due to the large beam size) and 2 small aperture (10 mm and 6 mm in x and y respectively) cavities at the IP (IPBPMs). The C and S-band CBPMs are rigidly located in a quadrupole, the first 10 BPMs are mounted in fixed quadrupoles, whilst the next 25 are mounted in quadrupoles which are moved by three axis movers and the 4 IP region BPMs (2 normal C-band and 2 IPBPMs) are rigidly fixed, but not in magnets. The beamline also includes several reference cavities providing an independent charge and phase reference for the position measurement. The majority of CBPMs are operated at a resolution of 200 nm in a ±1 mm range with 20 dB front-end attenuation, with several providing 30 nm without attenuation [4].

WAKEFIELD SIMULATION

A number of ATF2 beamline elements have been investigated. The wake potential produced by various geometries was simulated using electromagnetic (EM) simulator GdfidL [5]. GdfidL runs a finite difference loop to numerically propagate the EM fields on a cubic mesh, while the beam is represented by a linear charge with a Gaussian distribution along the z-axis, and offsets from the beam axis can be specified in both x and y.

Wakefield kick measurements and compensation described in the next section have been performed using C-band reference cavities. Their geometry is shown in Fig. 2 and the transverse wake potential in Fig. 3.

Table 1 summarises the peak wake potential $\mathbf{W}_{max}$ for most of the components that have been studied so far in the order they are most likely to affect the beam taking into account their quantities (although, strictly speaking, their position in the beamline and average misalignment need to

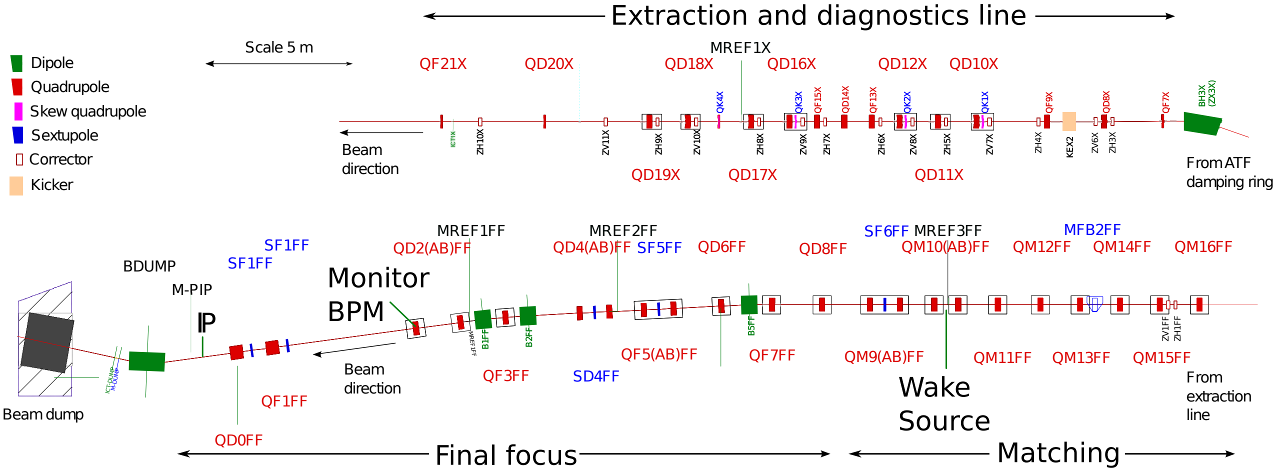

Figure 1: Layout of the ATF2, with the quadrupoles containing cavity BPMs indicated, taken from [4].

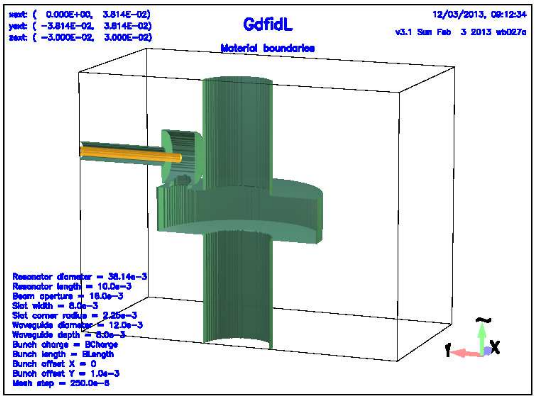

Figure 2: C-band reference cavity model (sliced at the symmetry plane).

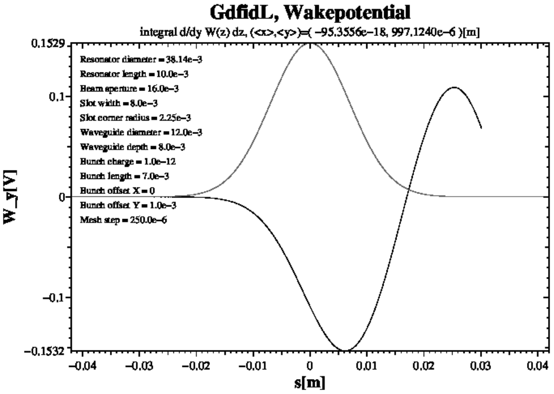

Figure 3: Wake potential produced by a 1 pC, 7 mm long bunch traveling with a 1 mm offset in y in the C-band reference cavity. The centred Gaussian shape shows the charge distribution.

be considered). The simulations indicate that shields must be used for the vacuum bellows as their wakefields may reach the level of wakes produced in CBPMs at the same offset, but the alignment is typically much poorer for them. Lower wakes can also be achieved by better alignment of CBPMs to their respective quadrupole magnets. However, this is complicated since the assemblies are already in the beamline. Other possible low cost improvements are the removal of unnecessary beampipe aperture transitions and tapering to avoid sudden aperture steps.

Table 1: Peak Wake Potentials for ATF2 Components

Component	W_{max}, V/pC/mm	Quantity
Bellows	0.1	100
C-band position	0.11	40
24-20 mm transitions	0.008	100
C-band reference	0.15	4
Vacuum port (X)	0.07	6

MEASUREMENTS

To study the beam distortion induced by the wakefields in the ATF2 beamline and to compensate it, a setup of two C-band reference cavities has been installed on a two axis mover system with a range of ±4.5 mm in a high betatron location in between QD10BFF and QD10AFF, see Fig. 4. Note that moving the setup will also move the bellows connecting the cavities with the rest of the beamline. Assuming that the bellows move by about half of the setup move, the expected peak wakefield potential of the whole setup is about 0.4 $\mathrm{V/pC/mm}$

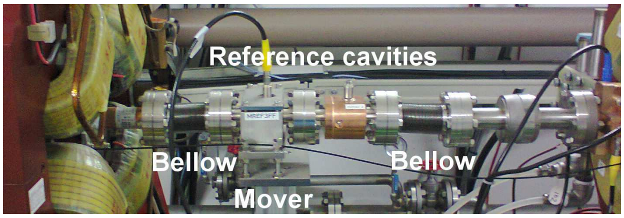

Figure 4: Reference cavity setup with two reference cavities.

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Since the setup produces a considerable wakefield, by tuning its position it is possible to partially cancel out the wakefield induced beam distortion. This wakefield cancellation scheme appeared crucial in the recent measurement of the sub-100 nm vertical beam size.

Analysis

With several high resolution CBPMs both upstream and downstream of the setup, it is ideally placed to study the orbit change downstream from its wakefield with a high precision. Since the betatron function is higher in the vertical direction in the downstream beamline, typically a vertical position scan was performed recording about 100-200 pulses for several mover positions.

To analyse the orbit change due to the reference cavity setup, the pulse to pulse orbit jitter, which is up to tens of μm depending on the beamline location, needs to be subtracted. The correlation matrix **X** of the n_1 upstream BPMs with the n_2 downstream BPMs is defined as:

$$\mathbf{A\ X = B} \qquad (1)$$

with matrix **A** (**B**) the upstream (downstream) average subtracted BPM readings for all m recorded pulses. The matrix **X** is then determined in a least-square sense by inverting matrix **A** with the SVD method. The remaining residuals **R** ($n_2 \times m$) are then:

$$\mathbf{R = AX - B} \qquad (2)$$

After the jitter subtraction, the residuals **R** are averaged over the number of pulses for each mover position. In Fig. 5 the residuals can be seen with respect to the mover position for the most sensitive CBPM at quadrupole QD2AFF.

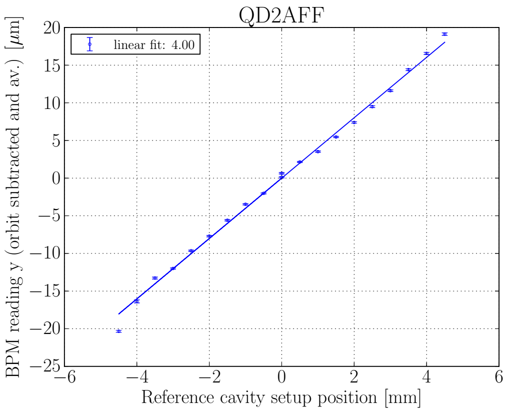

Figure 5: The orbit change after pulse averaging and jitter subtraction of the BPM readings in the vertical direction for the most sensitive location, near quadrupole QD2AFF, with respect to the mover position.

A clear dependence can be seen. The statistical error on each point is about 200 nm. A linear fit is performed showing about 4.0 μm orbit change per mm reference setup move. A third order effect is also tentatively present, which needs more investigation.

The bunch length for these data was monitored with a streak camera located in the ATF damping ring [6]. The bunch length in the turn before extraction was determined to be about 9 mm while the average bunch charge was about 0.75×10^{10} particles.

In order to support the measurement and determine the wakefield potential of the setup from the measurement of the beam displacement, a tracking simulation has been performed with PLACET [7]. Especially for this study realistic geometric wakefield descriptions have been added to the code. The simulation shows a good agreement with the observed orbit change. The measured offsets seem to correspond to a reference cavity setup wakefield potential of about 0.8 $\mathrm{V/pC/mm}$, and further work is underway to understand the factor of 2 compared to the estimate based on numerical calculations.

CONCLUSIONS

Recently the ATF2 collaboration has achieved its intermediate goal of a sub-100 nm vertical beam size for a relatively low charge. It is thought that wakefields are a contributing factor to the beam size growth, especially for higher charges. Wakefields produced by various elements in the beam line are being investigated, and the first analysis of the wakefield measurements shows a clear orbit change due to the wakefield kick. Comparing the measurements to tracking simulations, the observed orbit change agrees well, but the corresponding wakefield potential of the experimental setup is about twice as large as the numerical prediction. This discrepancy is under investigation and a longer more detailed publication is planned, which will include charge and bunch length variations. Also measurements were performed with different experimental setups, with one single reference cavity, and with three bellows. The wakefield potential of a single reference cavity is expected to be determined from these measurements.

ACKNOWLEDGMENTS

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