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Detection of Ground Motion effects on the beam trajectory at ATF2

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Abstract

The ATF2 experiment is currently demonstrating the feasibility of the beam delivery system for the future linear collider. The orbit feedback is very critical to obtain the nanometer vertical beam size at the interaction point and in the case of CLIC, ground motion effects on the beam must be corrected. In this respect, as a proof of principle of a ground motion feed forward, the ground motion effects on the beam trajectory are extracted from the beam position monitor readings.

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The ATF2 experiment is currently demonstrating the feasibility of the beam delivery system for the future linear collider. The orbit feedback is very critical to obtain the nanometer vertical beam size at the interaction point and in the case of CLIC, ground motion effects on the beam must be corrected. In this respect, as a proof of principle of a ground motion feed forward, the ground motion effects on the beam trajectory are extracted from the beam position monitor readings.

INTRODUCTION

The Accelerator Test Facility (ATF) successfully creates beam with almost the emittances required by the ILC [1]. The ATF2 facility [2] uses the beam extracted from the ATF damping ring. It was built to demonstrate the feasibility of the Beam Delivery System of a future linear collider, to implement and test the instrumentation and tuning procedures involved to obtain the nanometer scale transverse beam size required for a high luminosity.

In the final focus section (see figure 1), the large β functions magnify incoming beam jitter up to several microns displacement. Thanks to precise cavity BPMs [3] with $\simeq 100nm$ resolution, the pulse to pulse beam trajectory fluctuation can be reconstructed with a sub micrometer resolution.

As the effect of the magnets vibrations on the pulse to pulse trajectory variations are of $1-6$ μm in the FF, these trajectory variations are measurable.

This paper describes the algorithm developed to predict the pulse to pulse trajectory fluctuations as a function of the magnet displacement measurements and show simulated correlation with the BPM readings for 15 sensors (installation planned this year) and 30 sensors (possible upgrade).

After a brief description of the ATF2 ground motion, a method to select the best elements where the vibration sensors has to be placed is presented. The last sections describe a method to predict the trajectory fluctuations from these sensor measurements and how to remove incoming beam jitter effects.

DETERMINATION OF THE SENSOR POSITIONS

Quadrupole displacements deflect the beam trajectory proportionally to its integrated strength KL and to the displacement δY.The trajectory displacement at a BPM induced by this kick is described by the transfer matrix between the displaced quadrupole and that BPM.

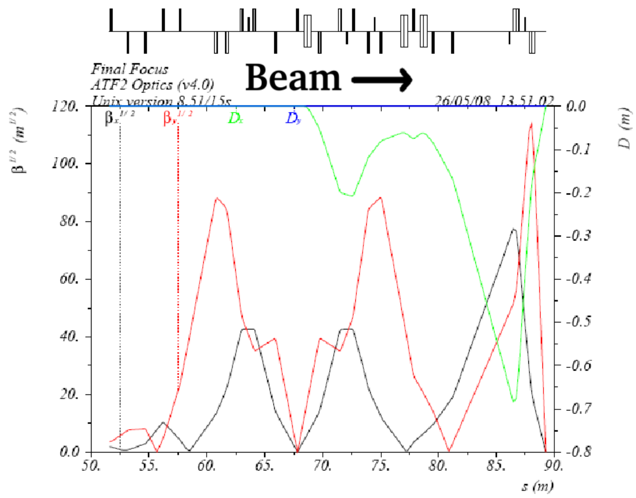

Figure 1: Nominal ATF2 final focus optics.

Ideally the position variation of all the quadrupoles has to be measured to estimate the effect at each BPM. However, the number of sensors is limited,so they have to be located carefully to optimize the results.

The measured displacement of the beam at a BPM i normalized by the displacement of the quadrupole ($\frac{\Delta X_i}{\delta X}$) has been computed for all BPMs and quadrupoles.

The quadrupoles inducing the largest effect on all the BPMs (in vertical and horizontal plane) will be chosen to have sensors on them (as well as the first and last quadrupoles to avoid extrapolation).

The highest influence is obtained for elements in the extraction line ($s < 50$m) and BPMs in the Final Focus ($s > 50$m). That is due to the large magnification ($\simeq 100$) between these two sections.

ESTIMATION OF THE TRAJECTORY FLUCTUATIONS DRIVEN BY GROUND MOTION

Element Vibrations from Measurements

To take the effects of the vibrations of the quadrupoles without sensor into account, their positions must be estimated. The estimation of the displacement δY_i of a quadrupole i is done linearly with the distance between the two closest sensor surrounding it. A ground motion model fitted on measurements at ATF2[4] has been used to generate the positions of all the elements for 100 pulses at 1.5 Hz. The measurement of the quadrupoles motion takes into account the transfer function of ground motion sensors which will be installed.

The amplitude of the displacements relative to the first element compared to the error introduced by the estimation for all the elements using 15 or 30 sensors is shown in figure 2. As most of the sensors are located in the extraction

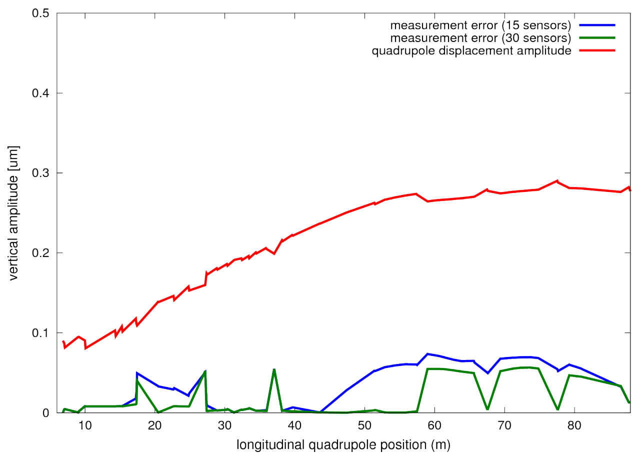

Figure 2: Amplitude of pulse to pulse element displacements and error on the estimation of these displacements using 15 and 30 sensors.

line, the errors on the element displacements introduced by the linear estimation are small in that area. In spite of the fact there are only few sensors at the final focus, the error is about $50nm$, demonstrating the validity of the linear estimation.

Estimation of Trajectory Fluctuations

Once the displacements of all the elements along the line have been estimated, the trajectory fluctuation at a BPM ΔX can be computed summing all the influences of all the element displacements δX_i:

$$\Delta Y \quad = \sum_i R_{34}(elem_i \rightarrow BPM) \times K_i L_i \times \delta Y_i \tag{1}$$

The trajectory fluctuations are computed with the tracking code PLACET using the displacements of all the elements given by the ground motion model predictions. The amplitude of the pulse to pulse BPM readings is shown in figure 3 (blue line). The difference between the estimation of the trajectory variation and its simulation is shown in figure 3 using 15 vibration sensors (red line) and using 30 vibration sensors (green line).

The errors are significantly smaller than the amplitude of the trajectory variations induced by the ground motion.

RECONSTRUCTION OF THE TRAJECTORY FLUCTUATIONS DRIVEN BY INCOMING BEAM JITTER

It is absolutely necessary to correct for beam jitter effect as it is about 100 times higher the the ground motion effect accordingly to latest available measurements (see figure 4).

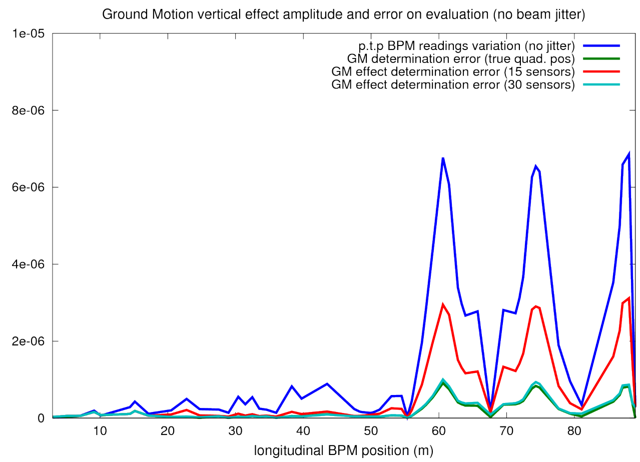

Figure 3: Amplitude of the GM induced pulse to pulse trajectory variations at 1.5 Hz and error on the estimation of these variations using 15 or 30 sensors.

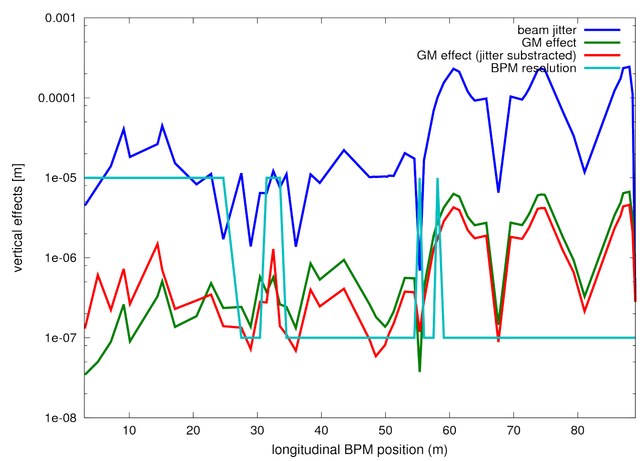

Figure 4: Comparison of the beam jitter amplitude induced by the incoming beam jitter and by the ground motion. BPM resolutions are shown in cyan.

As, in ATF2, the longitudinal position has no influence on transverse position, the jitter induced pulse to pulse variations of BPM readings is function of only fives parameters (X, X', Y, Y' and $\frac{\Delta E}{E}$), in the linear lattice approximation.

Jitter is removed using a generalized least square method:

$$R = \left(I - T\left(T'C^{-1}T\right)T'C^{-1}\right)\Delta B \tag{2}$$

where I is the identity matrix, R is the residual of the jitter subtraction on the BPM readings, T is composed by the transfer matrix between the start of the beam line and the BPMs and C is the covariance of the errors, it correspond to the sum of a diagonal matrix with the squared BPM resolutions and the GM covariance matrix. ΔB is the pulse to pulse BPM readings variation.

As the precision needed is higher than the model precision, the jitter subtraction is done using the first 5 SVD modes of the pulse to pulse BPM readings instead of using the transfer matrices obtained from the model. T^* is used instead of T : $T^* = U^*\Sigma^*$ with U^* the first 5 left singular vectors and Σ^* the diagonal matrix of the first 5 singular values of the SVD decomposition of BPM readings.

The first estimation of the ground motion effect is the residual R_1 of the jitter subtraction on the BPM readings B:

$$R_1 = \left(I - T^* \left(T^{*\prime}C^{-1}T^*\right) T^{*\prime}C^{-1}\right) \Delta B \qquad (3)$$

The second estimation R_2 is the prediction of the displacement from the GM sensors. However, as the GM effects measured by the BPMs have been corrected for jitter, we do as well jitter subtraction to the prevision from the GM sensors:

$$R_2 = \left(I - T^* \left(T^{*\prime}C^{-1}T^*\right) T^{*\prime}C^{-1}\right) \Delta Y \qquad (4)$$

To estimate how the GM effect has been detected in the BPM p is constructed as:

$$p = \frac{||R_1 - R_2||_2}{||R_1 + R_2||_2} \qquad (5)$$

If R_1 and R_2 are independent $p = 1$, and if $R_1 = R_2$ we have $p = 0$. p lower than 1 proves detection of the GM effect in BPM readings, the lowest the best the detection is.

The results from simulation are shown figures 5 and 6 deducing the ground motion effect with 15 (red line) and 30 sensors (green line) and compared to the case where the quadrupole displacements is perfectly known (blue line). The case without beam jitter is also shown (cyan line).

Figure 5 shows p as defined in eq. 5 for a lattice with the expected experimental errors ($100um$ initial misalignment for quadrupoles, 10^{-4} relative error strength on quadrupoles and 1% scale error on BPMs).

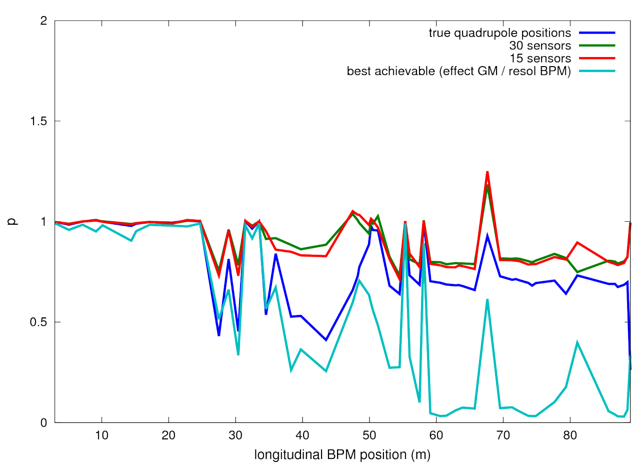

Figure 5: p with expected experimental errors.

With 15 or 30 sensors, p is about 0.8 on good resolution BPM (the BPM resolution is shown in cyan figure 4). It is higher than 1 for some BPMs at low β_y due to the sensitivity to errors on the transfer matrices. There is a large difference with the case where there is no jitter showing the difficulty to remove all the jitter without affecting the GM effects.

Figure 6 shows p for the same lattice but with precise BPMs everywhere (100 nm resolution).

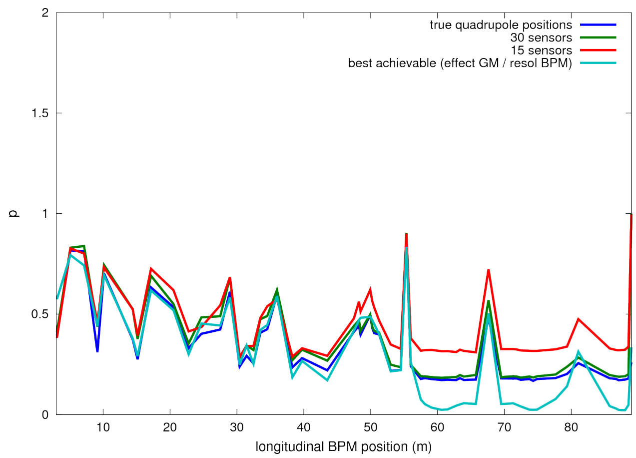

Figure 6: p for a lattice with 100nm resolution on all BPMs.

High precision BPMs at the beginning of the line allow a better differentiation between the GM effect and the incoming jitter and p about 0.3 can be obtained with 15 sensors. p is higher at the beginning of the line due to smaller GM effects.

CONCLUSION AND PROSPECTS

We saw how to estimate the pulse to pulse beam trajectory fluctuations from the measurements of the vibrations of a limited set of magnets, with a criteria for the sensors position. Despite the incoming beam jitter has an effect 100 times larger, the effect of the ground motion can still be detected with the presently available BPMs at ATF2 with 15 ground motion sensors.

This detection is however very difficult with the current lattice, however with the replacement of the BPMs in the extraction line, it become much easier. Also to test the CLIC BDS at ATF2, even larger magnification between the extraction line and the final focus will be used which should further improve the results.

REFERENCES

[1] Y. Honda et al. Achievement of ultra-low emittance beam in the ATF damping ring. *Phys. Rev. Lett.*, 92:054802, 2004.

[2] Boris Ivanovich Grishanov et al. ATF2 proposal. SLAC-R-771.

[3] Y. I. Kim et al. Cavity beam position monitor system for the accelerator test facility 2. *Phys. Rev. ST Accel. Beams*, 15:042801, Apr 2012.

[4] B. Bolzon, A. Jeremie, A. Seryi, P. Bambade, and Y. Renier. Linear collider test facility: ATF2 final focus active stabilisation pertinence. In *Proceedings of the 23rd Particle Accelerator Conference 23rd Particle Accelerator Conference "PAC09"*, page TH5RFP086, 2009. LAL/RT 09-09.