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P. Bambade, Y. Renier

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P. Bambade, Y. Renier
LAL, Univ Paris-Sud, IN2P3/CNRS, Orsay, France

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U.M.R
de
l'Université Paris-Sud

Institut National de
Physique Nucléaire et de
Physique des Particules du CNRS

LAL ~ Bât. 200 ~ B.P. 34 ~ 91898 Orsay Cedex ~ France

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Study of time-dependent corrections in the ATF2 beam-line

Philip Bambade, Yves Renier[*]

LAL, Univ Paris-Sud, IN2P3/CNRS, Orsay, France

Abstract

Goals of ATF2 will be to provide beams with a few tens of nanometers and stability at the nanometer level. To achieve this, ground motion should be measured and the effects of element displacement on the beam at the Interaction Point (IP) should be well understood. Feedback systems should also be simulated with a ground motion generator which includes spatial coherence for effects to be computed realistically.

1 Introduction

The goal is to understand and simulate the effects of ground motion on the ATF2 beam, in order to design and implement suitable feedback. Effects from displacing each magnet on the beam position and size at the IP are first computed and interpreted. Feedback requirements are then analysed given measured ground motion properties and results from simulating an initial version are shown. Finally, some conclusions and prospects are given.

2 Effects of magnet displacements on the beam at the IP

Displacing a dipole magnet with constant field has no effect. For a quadrupole, it will however cause deflection since a dipole term appears from the linear field. Similarly, a displaced sextupole changes both the focusing and (slightly) the steering, through quadrupole and dipole terms. The beam offset and size changes at the IP depend both on the displaced magnet strengths and on the optical transport to the IP.

The result of displacing each ATF2 magnet on IP beam position and size is shown in Figure 1. The tightest tolerance for the beam position is for QD0 which is the strongest quadrupole. Displacing another quadrupole, QD2A causes the largest size increase due to the long drift to the next magnet group, which includes two strong sextupoles then traversed off-axis.

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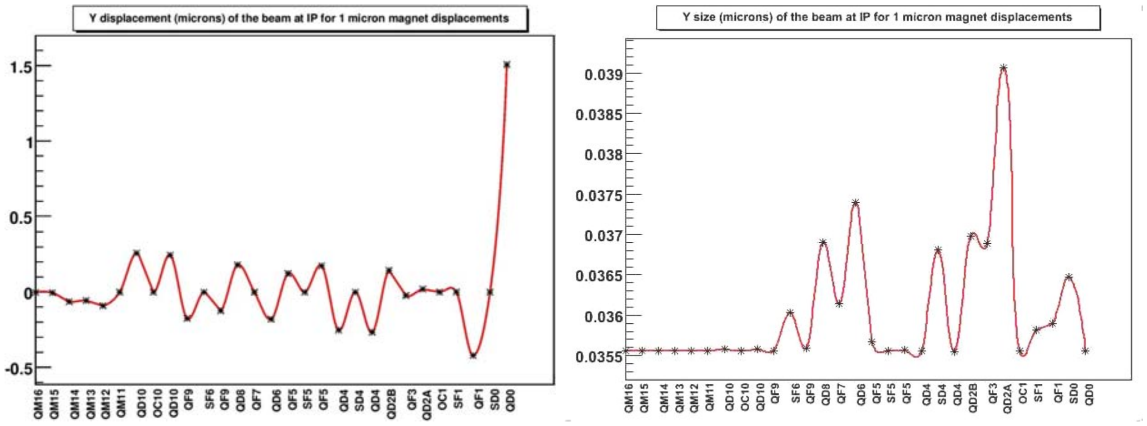

Figure 1: Displacement and size at IP for magnet displacements of 1 micron.

3 Effect of ground motion on the beam at the IP

3.1 Measurement of ground motion at the ATF site

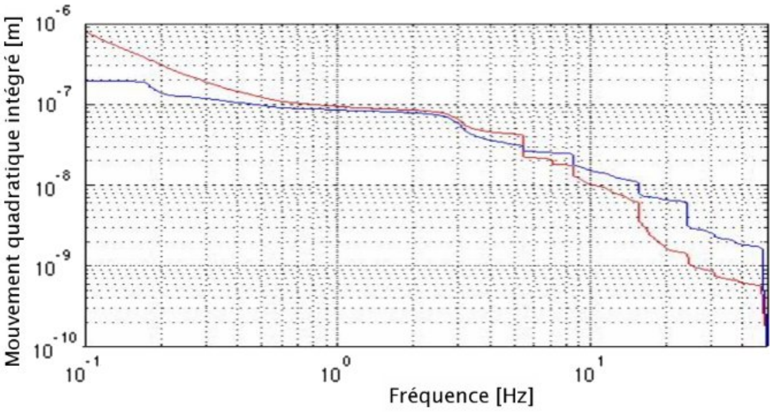

Figure 2: Integrated RMS displacement

Figure 2 shows the integrated RMS vertical displacement measured at KEK (courtesy of R. Sugahara), computed integrating from 50 Hz to each frequency on the abscissa.
For a 1 Hz bunch repetition rate, feedback can only be expected to work up to $\frac{1}{6}$ Hz. At that frequency, the ground motion amplitude is about 0.2 micron. For such amplitudes, the beam position and size at the IP would be affected at the level of 0.2 micron and 10%, respectively, given the sensitivities to QD0 and QD2A displacements in Figure 1. This would be even for perfect feedback and would definitely not allow reaching ATF2 objectives. Fortunately, as QD0 is just about 1 m from the IP, there is very good coherence up to a few Hz. If mechanical structures supporting this magnet and the IP instrumentation are rigidly mounted to the floor, both will vibrate in phase and relative motion should be small and produce negligible effects at the IP.
However for about 10 other quadrupoles farther from the IP, 0.2 micron motions can still cause about 0.04 micron beam displacements. The global effect expected at the IP for fully incoherent motions of these other magnets is about $\sqrt{10} \times 0.04 = 0.125$ micron. Even with perfect feedback, for a repetition rate of 1 Hz, achieving stability at the level of the beam size must thus rely on some degree of coherence beyond just a few meters.

3.2 Simulation of the effects on the beam

The simulation process starts with a ground motion simulator, developed in MATLAB to recreate the Fourier spectra of the measured vibration and some of its coherence properties [?]. Data files are created as input to PLACET, a code which tracks particle distributions along the ATF2 beam line

including magnet misalignments. Analysis is done in ROOT.
Figure 3 (right) shows the vertical size and displacement obtained at the IP in the first 100 seconds. The size enhancement is small in this short time span (< 10%), but displacements without feedback (dotted line) are 0.1 microns, which exceed the goal by an order of magnitude.

4 Feedback implementation

Position feedback according to the scheme shown in Figure 3 (left) was simulated with PLACET, with 5 nanometer errors for the BPMs used to measure the beam positions near the IP. The most efficient controller tried was the PID one, using Takahashi's method to choose the coefficients [1]. The corrector dipole is placed after the final doublet to avoid offsetting the beam in the last sextupoles.
This feedback improves the beam stability by a factor 3 and doesn't affect the beam size during the 100 seconds considered, see Figure 3 (right, plain line). Although a significant improvement, the vertical position beam stability obtained is not sufficient to avoid affecting the beam size measurement. This may be explained in part by the ground motion generator used, which underestimates the coherence and is hence pessimistic [?].

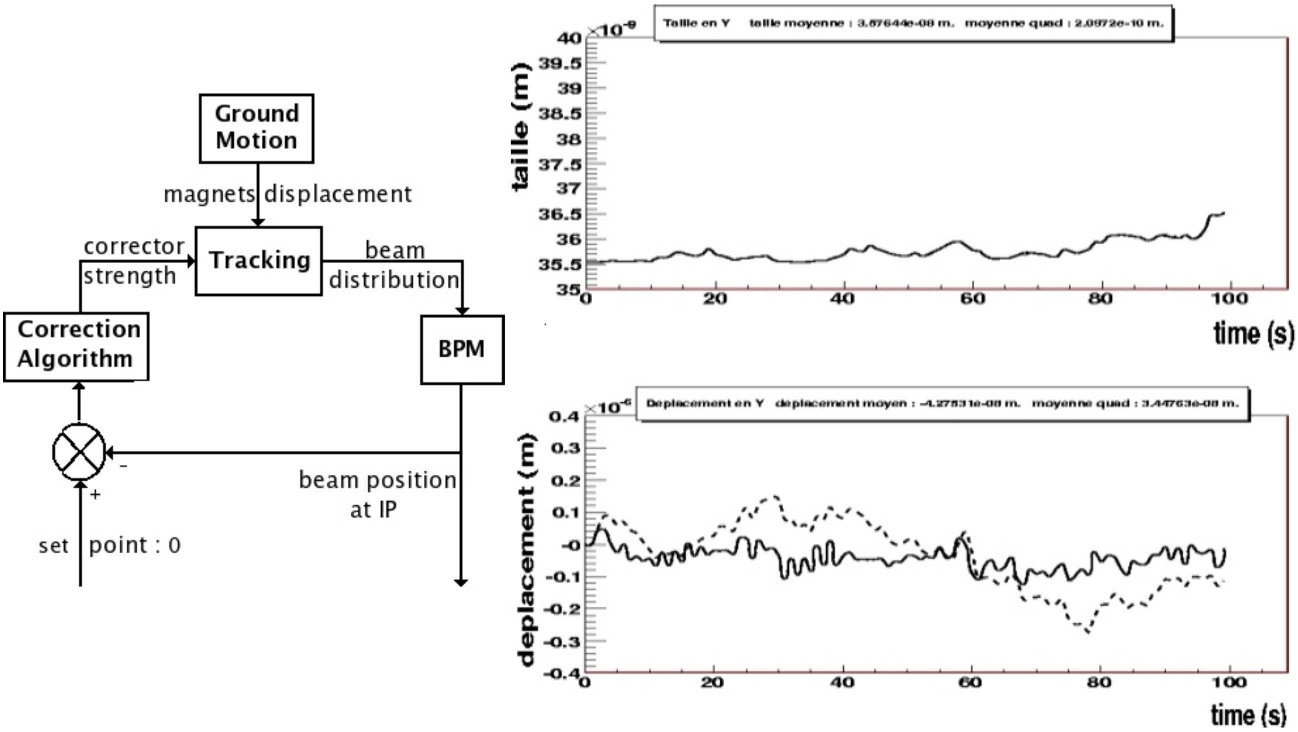

Figure 3: Left : Scheme of the feedback. Right : Size and displacement as function of time without/with feedback (dotted/plain).

5 Conclusion and prospects

The sensitivity of the ATF2 beam to ground motion has been studied. Simulating a correction feedback loop using a PID controller, improvements in stability by a factor 3 were obtained. This however remains about a factor 3 above specifications.
An improved generator representing coherence properties more reliably should be developed and other PID coefficients may need to be tried to reach the goals.

6 Acknowledgements

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[1] Slides: first presented at LCWS, second presented in a KEK weekly meeting
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