GROUND MOTION COMPENSATION USING FEED-FORWARD CONTROL AT ATF2

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Abstract

Ground motion compensation using feed-forward control is a novel technique being developed to combat beam imperfections resulting from the vibration-induced misalignment of beamline components. The method is being evaluated experimentally at the KEK Accelerator Test Facility 2 (ATF2). It has already been demonstrated that the beam position is correlated with the readings from a set of seismometers located along the beamline. To compensate for this contribution to the beam position jitter, the fully operational system will use real-time measurement and processing in order to calculate a feed-forward correction from the seismometer readings and apply it on a useful time scale. The progress towards a working system is presented in this paper.

INTRODUCTION

In order to achieve the design luminosity for a future linear lepton collider, compensating dynamic misalignments of the quadrupole magnets caused by the natural motion of the ground will be essential [1]. Several techniques are envisioned for this purpose including active stabilization of the magnets [2] and intra-train beam position feedback at the interaction point (IP) [3]. Both of these existing techniques have their limitations; active stabilization systems are bulky and expensive and are thus best suited for use with a few critical components, while intra-train feedback is very effective at removing the beam-beam offset at the IP but as a local system is unable to prevent luminosity loss resulting from the accumulation of misalignment errors along the length of the entire machine.

To address this, a novel technique of ground motion compensation using feed-forward control has been proposed [4]. Traditional beam orbit feedback systems use beam position monitors (BPMs) to detect deviations of the beam from the ideal orbit and then one or more kickers to remove these unwanted excursions. Such systems are capable of correcting effects at frequencies much lower than the beam repetition rate (3.12 Hz at ATF2). The proposed ground motion feed-forward system operates along similar lines, but the BPMs are replaced by seismometers (Figure 1) so that the deviations in orbit are effectively predicted from the positions of the quadrupoles themselves. This allows orbit distortions caused by vibrations higher than the beam repetition rate to be compensated for.
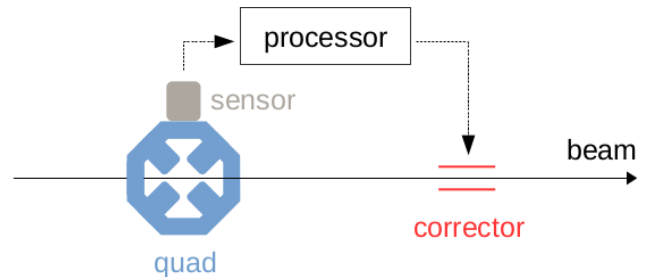

Figure 1: Schematic illustrating the principle of ground motion compensation using feed-forward control.

GROUND MOTION MEASUREMENTS

A system has been deployed at ATF2 to quantify the effect the motion of the quadrupoles has on the orbit of the beam. This section will describe the system and the main conclusions of the results it has generated so far.

Hardware

A total of 14 Güralp CMG-6T seismometers are distributed along the ATF2 extraction line (Figure 2). These sensors produce an output proportional to their velocity in both planes perpendicular to the direction of beam travel and respond to frequencies in the range 0.2 Hz up to 100 Hz. Their location was determined by simulation [5] and they are optimally located on top of the quadrupoles (Figure 3).

The outputs of the sensors are digitized and logged using a National Instruments PXI system consisting of a PXI-1042 chassis containing a PXI-8108 controller along with two PXI-6289 multi-function DAQ modules. An additional signal functioning as a beam presence indicator is also recorded for synchronization purposes.

To measure the beam orbit the ATF2 extraction line contains 46 BPMs in total which are a mixture of stripline BPMs (in the upstream region just after extraction) and higher resolution cavity BPMs (throughout the Final Focus line).

Data Acquisition

The data acquisition software for the PXI system was developed in LabVIEW and uses a sample rate of 1024 Hz to digitize the seismometer outputs. Beam position and charge data is generated at the machine rate of 3.12 Hz and is made available in real time using the Experimental Physics and Industrial Control System (EPICS) to publish the data over the local network.

In order to determine the effect of the motion of the quadrupoles on the beam, it is critical that the two data sets are in phase. This is ensured by turning the beam off
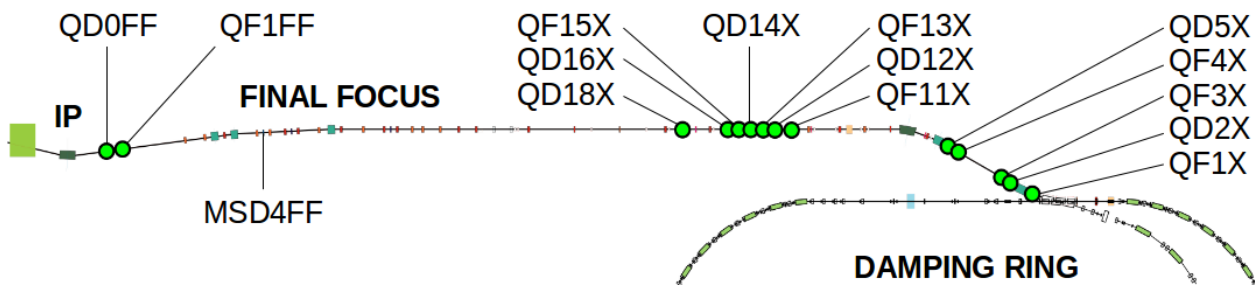
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Figure 2: Location of the seismometers along the ATF2 extraction line.

Figure 3: Photograph of the seismometer on QF4X.

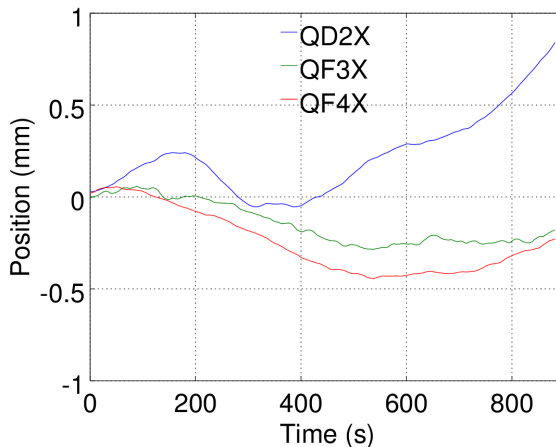Figure 4: Motion of the seismometers on the quadrupoles QD2X, QF3X and QF4X.

before data acquisition is started for both the seismometers and the BPMs. The beam is then turned on almost immediately to create a reference point in time that is visible in both data sets. A second reference point is created by turning the beam off again just before 15 minutes has elapsed. The synchronization signal from the PXI system can then be correlated with the charge data from the BPMs to select the samples from the seismometer data set that were coincident with the passage of the beam.

Results

For illustration, Figure 4 shows the motion of the seismometers placed on the quadrupoles QD2X, QF3X and QF4X. Figure 5 shows the position reported by BPM MSD4FF as well as the linear combination of the data from the 12 upstream seismometers that best fits the BPM data. The purpose of the feed-forward system is to reduce the jitter of the beam by removing that component of the beam posi-

tion that is correlated with the motion of the quadrupoles. The reduction in jitter that can be achieved is:

$$\frac{\sigma_f}{\sigma_i} = \sqrt{1 - \rho^2} \tag{1}$$

where σ_i is the original jitter, σ_f is the jitter after subtracting the fit and ρ is the correlation between fit and measurement. For the data in Figure 5 a value of $\rho = 0.29$ is observed and thus a reduction in jitter of 4% could be achieved.

Figure 5 shows that the fit (the best projection of the seismometer data onto the BPM data) accurately describes the mean position of the beam but fails to reproduce variations occurring on the pulse-to-pulse time scale. Figure 6 shows the effect that removing frequencies below a cut-off of 0.25 Hz has on the quality of the fit. The sensors are known to be non-reliable in this region of the frequency spectrum and so the result is to increase the correlation to $\rho = 0.58$, which implies a possible reduction in jitter of 18%.

FEED-FORWARD

As the data has shown that the motion of the quadrupoles contributes to the beam position jitter measured at ATF2, the next step is the practical demonstration of the technique of ground motion compensation using feed-forward control.

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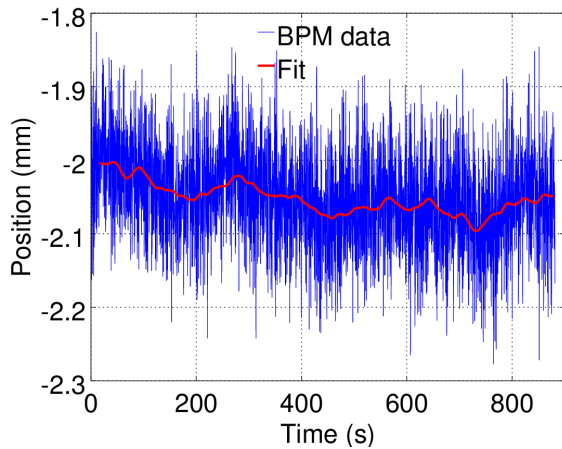
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Figure 5: Data from BPM MSD4FF along with the best projection to this data constructed from a linear combination of the 12 upstream seismometers.
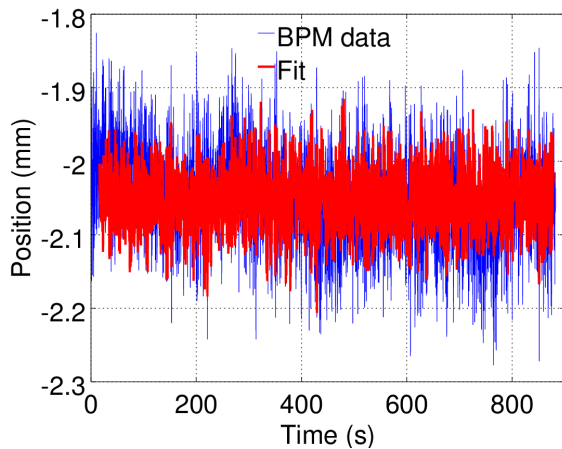

Figure 6: Data from BPM MSD4FF along with the best projection to this data constructed from a linear combination of the 12 upstream seismometers. The seismometer data has been run through a high-pass filter with a cut-off frequency of 0.25 Hz to remove unreliable frequencies of the sensors.

Hardware

Figure 1 shows that the feed-forward system consists of three components: sensor, processor and corrector. The sensor component is the same Güralp seismometers used for the initial ground motion measurements. As the PXI system is not suitable for real-time control applications, the processing will be performed by a National Instruments CompactRIO system. This FPGA-based solution consists of a cRIO-9064 controller with cRIO-9205 and cRIO-9263 modules for analogue input and output respectively. The corrector is a stripline kicker which is already instrumented in the ATF2 extraction line as part of the FONT intra-train feedback system. The latency of the system is expected to be on the order of several milliseconds, most of which is due to the seismometers.

CONCLUSION

The potential for beam stabilization using the technique of ground motion feed-forward has been shown using ground motion and beam position measurements from ATF2. The correlation between the actual beam position and the beam position projected from the seismometer readings is ~0.3. This can be increased up to ~0.6 by first filtering out low frequency noise from the seismometer data. Work is ongoing to demonstrate a reduction in the beam position jitter at ATF2 through the application of a correction based on the seismometer readings.

ACKNOWLEDGMENT

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