THE STRAIGHTNESS MONITOR SYSTEM AT ATF2*

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Abstract

The demonstration of absolute stability of the position of the focused beam is the primary goal of the ATF2 commissioning effort. We have installed a laser interferometer system that will eventually correct the measurement of high-precision Beam Position Monitors used in the ATF2Final Focus Steering Feedback for mechanical motion or vibrations. Here, we describe the installed system and present preliminary data on the short- and long-term mechanical stability of the BPM system.

INTRODUCTION

Much of the physics of the future e^+e^- Linear Collider will depend on a precise measurementof the center-of-mass energy, the differential dependence of luminosity on energy, and the relationship between these two quantities and the energy of a single beam (E_b). Studies estimating the precision of future measurements of the top mass[1] and the higgs mass[2] indicate that a measurement of the absolute beam energy scale of 50 MeV for a 250 GeV beam ($\delta E_b / E_b \sim 1\text{-}2\times10^{-4}$) will be necessary to avoid dominating the statistical and systematic errors on these masses. If precision electroweak measurements become necessary, the requirements on the beam energy measurement are even more stringent[3]. Provisions must be made in the overall accelerator design to provide adequate beamline space for the devices which will provide these energy measurements.

A primary candidate to provide these precise energy measurements is a BPM-based spectrometer similar to that constructed in the LEP tunnel for energy measurements at LEP2[4]. An active test-beam program has been underway since 2005 to provide proof-of-principle tests for similar techniques with performance parameters commensurate with the ILC requirements, which are approximately an order of magnitude more stringent. Nominally, 100nm resolution, including all systematic and stability effects, is a resolution goal for these tests. The straightness monitor installation at ATF2 is the latest in this series of experiments aimed at understanding the tools necessary to monitor the electronic and mechanical stability of BPM-based spectrometer systems.

THE STRAIGHTNESS MONITOR

The straightness monitor for ATF2 is designed to provide sub-10-nm resolution on the vertical position of two BPMs used in the Final Focus stabilization steering feedback. The BPMs are installed in a quadrupole string in the initial telescope of the ATF2 final focus optics, as shown in Figure 1. For the ultimate steering leading toward the achievement of the smallest spot sizes, BPM MFB2 will be required to produce stable, single measurement resolution of 40 nm or better. The long-term stability of the mechanical support must be monitored and verified. Any significant vibration or motion of the support structures must be subtracted in order to obtain an accurate steering correction.

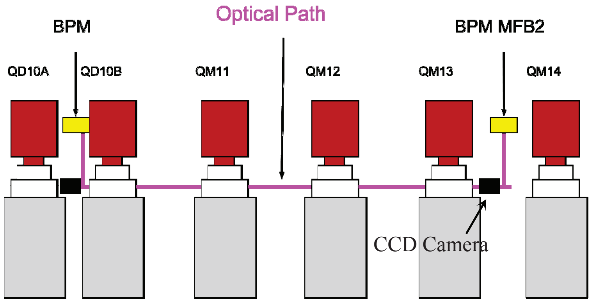

Figure 1: Layout of the Straightness Monitor installation in ATF2, showing the optical connections.

The Zygo Displacement Interferometer System

The interferometer system is built around a pair of Zygo displacement interferometers, each of which is used to measure the vertical displacement of the BPMs relative to the laser beam linking the two BPM stations. The laser source is a heterodyne 5 mW HeNe laser that produces two wavelengths of light, λ_1 = 632.991501 nm and λ_2 = 632.991528 nm with perpendicular linear polarizations. A polarized beam splitter directs one wavelength to the reference arm of the interferometer and the other to the target retroreflector. The reflected waves are recombined at the input to an optical fiber which channels the light from each interferometer head to a VME-based data acquisition card. Here, a 37-bit ADC running at 33 MHz measures the phase difference between the two frequency signals and the relative Doppler shift in order to determine change in position and in instantaneous velocity[5]. The dynamic range of the electronics is impressive: a single-bit precision of 0.31nm/count can be attained with target velocities up to 5.1 m/s and over distance changes of 21.2 m.

The Zygo information is acquired via an EPICs client for every ATF2 pulse. Four separate readings of the BPM positions taken 1 ms apart are recorded for each ATF2 pulse. This is to allow the time delay between the ATF2 kicker pre-fire clock pulse and the Zygo data acquisition

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to be measured by minimizing the resolution of the system. Bench-top measurements demonstrate a single-measurement system resolution of ~ 7nm over a 1 meter optical path length in air.

CCD Cameras

Two Basler Scout 2MP CCD cameras mounted directly to the support blocks measure the vertical and horizontal positions of the laser profile in order to constrain relative vertical movements between the two blocks. Camera information is collected via a dedicated frame-grabbing video card at a rate of approximately 1 Hz. Camera readings are averaged and the positions are updated every 30 seconds over a separate EPICs client. Single-measurement precision for the 30-second average is over order 150 nm in air. A photograph of the installation around quadropole QD10B can be seen in Figure 2.

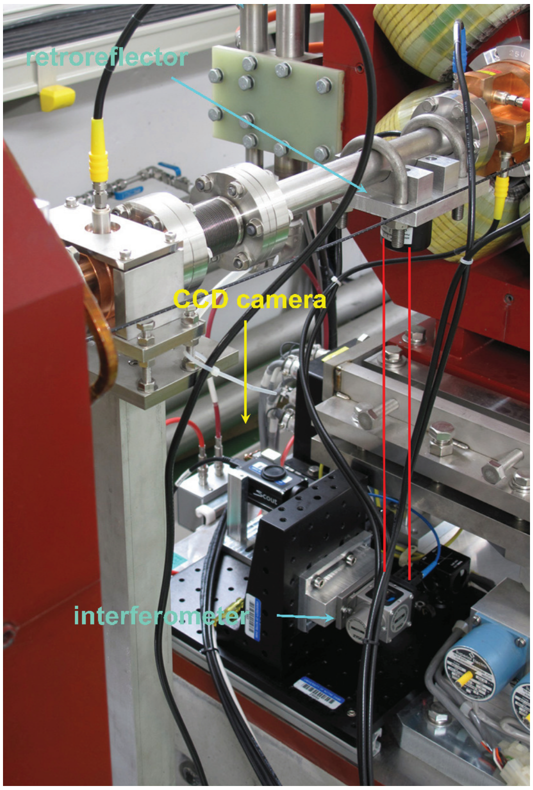

Figure 2: Photograph of the straightness monitor hardware installed on quadropole QD10B.

SYSTEM PERFORMANCE

Resolution

In-situ vibration measurements were made of the BPMs using a data acquisition mode where the system was read-out continuously at 1kHz. Results for BPM QD10B are shown in Figure 3. The rms motion is approximately 35nm; the oscillatory motion can clearly be seen in the Zygo data. An FFT of the data shows peaks at approximately 25 and 50 Hz.

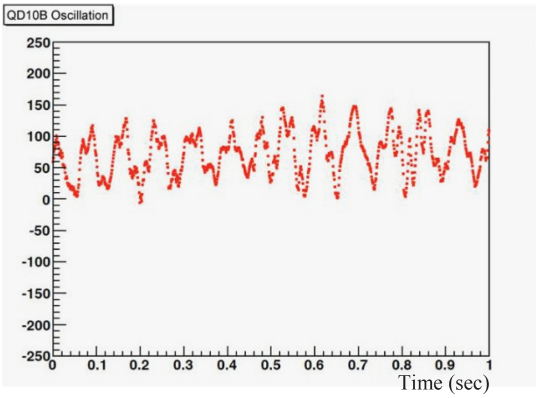

Figure 3: Oscillation measurement of BPM QD10B. Measurements were taken at 1kHz.

Figure 4 shows the position difference measured by the CCD cameras in the horizontal and vertical planes over approximately an hour. Overall linear shifts have not been subtracted to yield a resolution determination; the measured values are consistent with bench-top calibrations. The best value obtained is in the horizontal plance, at an rms of 150nm, corresponding to a single-camera resolution of approximately 110nm.

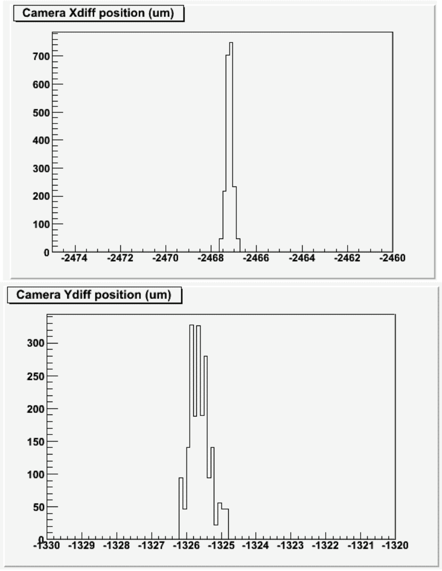

Figure 4: Differences in horizontal and vertical position of the laser path as measured by the CCD cameras.

The local resolution of the Zygo system can be determined by comparing the relative position measurements during the 4ms "burst" of data-acquisition around the arrival time of each ATF pulse. The difference between the first and the subsequent position measurements gives the convolution of the system resolution and any oscillation that may be present. The values determined for this installation are 8.4nm for BPM QD10B and 5.1nm for BPM MFB2. These figures imply that the BPM mounts are sufficiently stable that no oscillation correction is necessary. This is in stark contrast to the results obtained in the End Station A test beam at SLAC[6], where similar measurements yielded oscillations exceeding 1 micron in amplitude.

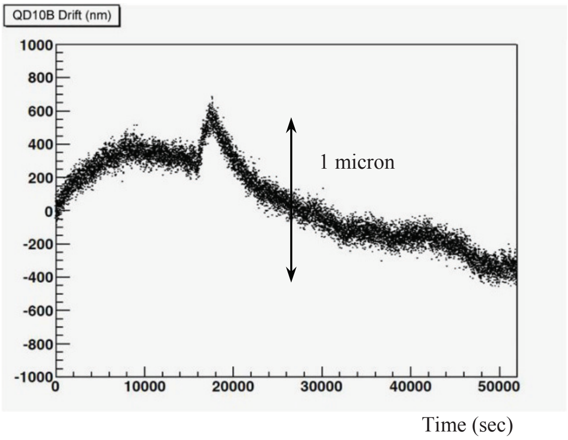

Figure 5: Long-term drift measurement of QD10B.

Stability

Long-term measurements of position drift have also been recorded. Figure 5 shows one such measurement, a 36-hour monitoring of the vertical position of BPM QD10B. The vertical bar on the figure indicates 1 micron of total motion. This measurement was taken outside of stable ATF running, but it was made on the beamline in the temperature-controlled enclosure. Hence, it does indicate the range of motions possible. Stability on one-hour timescales, however, is quite good, even in these non-optimal conditions.

Figure 6 shows some interesting behaviour observed during ATF running. At the beginning of each calibration run, the magnet mover under the quadrupole for BPM QD10B or under the BPM itself in the case of BPM MFB2 is moved by 50 microns. This provides a physical calibration with a known shift, and is readily seen in both the Zygo and BPM data. Figure 7 shows an expanded view of the Zygo measurement after the 50 micron shift has finished. What appears to be a mechanical relaxation is seen, with relatively large (500nm) amplitude. This is seen on both QD10B and MFB2 after the large calibration motions. Recently, the BPM systems have reached sufficient accuracy to cross-check motion against the Zygo system. These shifts are under investigation to see if they correspond to physical motion of the BPMs.

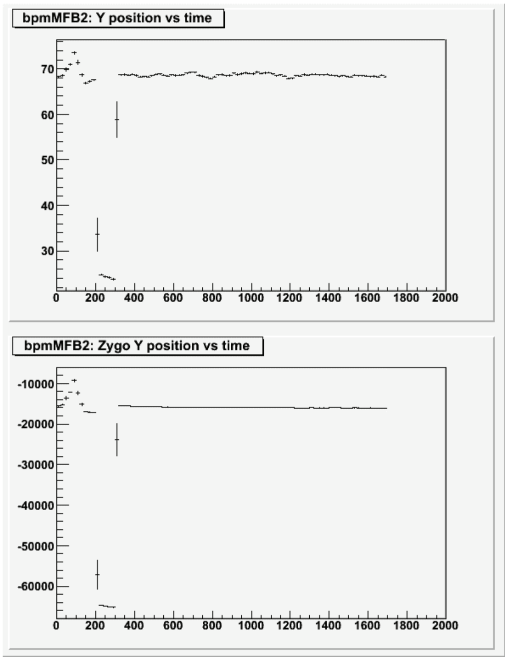

Figure 6: Calibration step of 50 microns clearly seen in BPM MFB2 measurements (top) and Zygo readings (bottom).

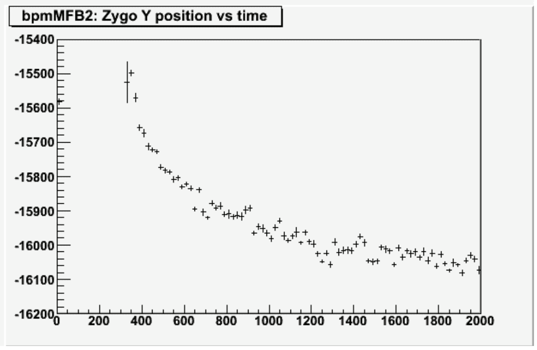

Figure 7: Measurement of the vertical position of BPM MFB2 after the calibration step. Vertical scale in nm.

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