OBSERVATION AND IMPROVEMENT OF THE LONG TERM BEAM STABILITY USING X-RAY BEAM POSITION MONITORS AT DLS

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Abstract

We present our observations of the medium term and long term stability of the photon beams at Diamond Light Source. Drift of the Electron Beam Position Monitors results in real X-ray beam movements, observed by both Front End X-ray Beam Position Monitors and beamline scintillator screens on some beamlines. We discuss how we are using these diagnostics tools to measure and characterise the drift. Medium term movements related to top-up cycles are seen, believed to be caused by changes to single bunch charge, and the long term drift of the electron beam position over several days and weeks is examined. A slow feedback system using X-ray Beam Position Monitors has been shown to successfully correct this drift. The results of these trials are presented.

INTRODUCTION

The stability of the X-ray beam is fundamental to the ability to perform high quality synchrotron light experiments. Changes to the pointing angle and source point of the electron beam cause the X-ray beam to change, both in intensity and in spectra. Many experiments consist of scans which take hours to perform and it is vital that the beam is as stable as possible for this long period. To help stabilise the electron beam against high frequency effects the Fast Orbit Feedback (FOFB) operates at 10kHz [1]. This system is able to damp beam vibrations to within a fraction of a μm in the 1-100Hz bandwidth, however longer term drift of greater than 10% of beamsize has also been obverved over 24 hour periods.

There are various diagnostics methods used to monitor this drift including X-ray Beam Position Monitors (XBPMs), beamline slit drain currents, and beamline imaging screens. Tungsten vane XBPMs are used in the Front Ends of all in-vacuum undulator beamlines, and so are the the most well understood and consistently implemented diagnostics apparatus in use.

The following sections discuss the work carried out in order to characterise these devices, comparing their measurements to other beamline diagnostics, and to quantify the stability of several Diamond beamlines.

STABILITY MEASUREMENTS

Tungsten vane XBPMs are capable of making submicron precision measurements of the centre of mass of the X-ray beam. Details of their operation and calibration can be found elsewhere [2] [3].

To verify their accuracy, and to determine their limits, a range of tests has been performed, observing other beamline diagnostics in order to corroborate the XBPM measurements. Presented below (figures 1 and 2) are measurements taken on the I24 Macromolecular Crystallography beamline using a black diamond fluorescent screen, inserted into the beam at an angle and observed with a Point Grey Flea2 CCD camera.

The image from the screen is processed in real time using MatLab, and a 2D Gaussian fitting routine is used in order to calculate the beam position, beam size, and beam rotation to sub pixel resolution.

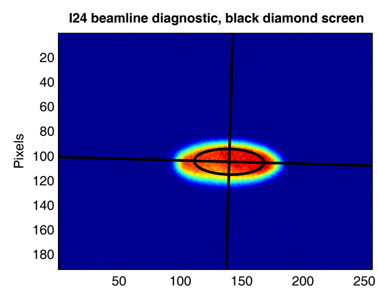

Figure 1: Monitoring of the X-ray beam position on I24.

A standard test has been performed on multiple beamlines, using a 60μm parallel bump applied to the electron beam through the Insertion Device (ID). A series of 20μm steps are taken in both the horizontal and vertical planes, and the XBPM response is compared to other beamline diagnostics.

Data from the I24 beamline is presented in figure 2. A screen inserted into the X-ray beam and observed with a camera at an angle of 45 degrees would produce an image with a $\sqrt{2} = 1.41$ elongation of the beam in one dimension. Indeed, this is what is seen. Horizontally a peak to peak variation of the screen image is measured to be 1.6 pixels, whilst vertically the peak to peak measurement is 1.1 pixels.

For static ID gaps the XBPMs produce reliable and accurate results across most beamlines, however, the use of Elliptically Polarizing Undulators presents problems due to unusual beam shapes. Other problems occur once the ID gaps are changed, and comparisons of the X-ray beam position using the XBPMs become more difficult [4]. All measurements presented in this paper are at constant ID gap. Methods to maintain the X-ray beam position even during ID gap movements are discussed in the last section.

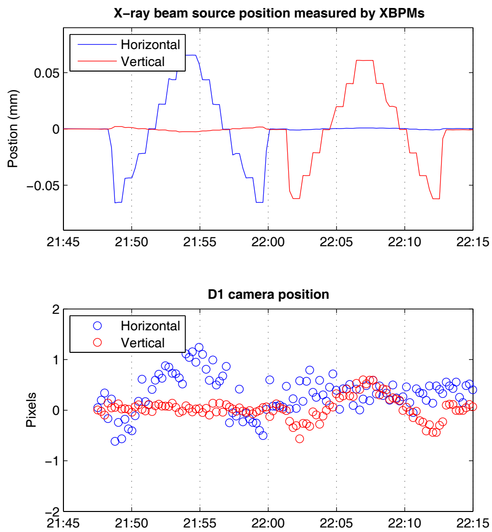

Figure 2: Correlation between Front End XBPMs and beamline diagnostics on I24.

MEDIUM TERM DRIFT AND THE INTRODUCTION OF TOP-UP OPERATION

While the FOFB is able to damp fast vibrations, slower movements due to thermal effects are observed. Top-up operation has been the standard mode of operation at Diamond since October 2008 [5], and this has significantly improved the stability of the X-ray beam pointing angle.

Figure 3 shows the pointing angle of the I19 beam for three days before Top-up operation was initiated, and for three days afterwards (the blank period in the middle is a Machine Development shift). Clearly significant improvements can be seen as the machine becomes more thermally stable. The major variations that occured after reinjections

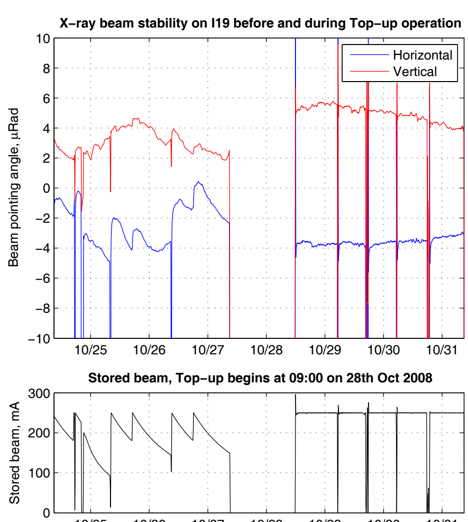

Figure 3: The pointing angle stability of I19 before and after Top-up operation was implemented.

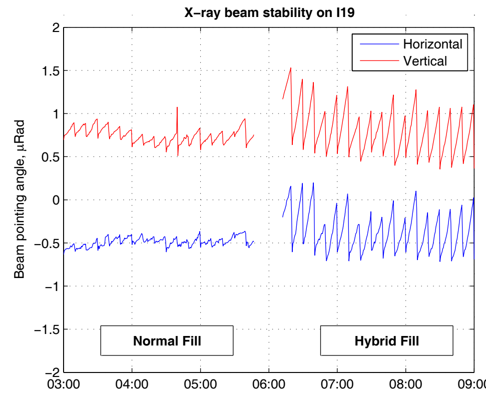

Figure 4: The left of the graph shows the changes to the beam pointing angle during Top-up operation with normal fill. The right shows the change in beam pointing angle during hybrid mode fill.

completely disappear, however, even during the 10 minute Top-up interval there are still noticeable thermal effects.

The type of machine fill is also seen to have an effect on the beam stability. Generally speaking there are two types of user operation at Diamond, 'normal fill' mode and 'hybrid fill' mode. Normal fill consists of between 686 and 936 buckets uniformly filled. Hybrid mode sees 686 buckets uniformly filled, and one bucket filled with an order of magnitude more charge for time sensitive experiments.

Figure 4 shows a period where the standard fill was dumped and replaced with hybrid fill at 06:00. An immediate difference in stability is observed, the peak to peak variations caused by the decay of the stored beam increases from 0.2µRad during normal fill to 0.8µRad during hybrid fill.

LONG TERM DRIFT AND SUCCESSFUL CORRECTION

Over longer timescales, many days, there are also drifts. These have been measured to be >> 10% of beamsize, and are presenting problems to some beamlines. In particular, investigations have focused on the I19 Small Molecule Diffraction beamline, where during microfocus operation scans are taken over several hours and at constant gap. Without any correction the drift of the X-ray beam is too large and produces too great a variation in beam intensity, reducing the quality of long time scale datasets.

A simple geometrical calculation uses data from the two Front End XBPMs, located at 12.2m and 16.5m from the source, to extrapolate the X-ray beam pointing angle and source position at the ID. A slow XBPM based correction system makes minute adjustments to the demand values of the FOFB at a rate of 0.5Hz, asking for orbit changes of the order 10nm to 100nm. This system has been in test operation on the I19 beamline since November 2009.

In figure 5 it can be seen that all of the diagnostics on the beamline are in agreement regarding the beam movements seen on I19. Without this improved stability the drift

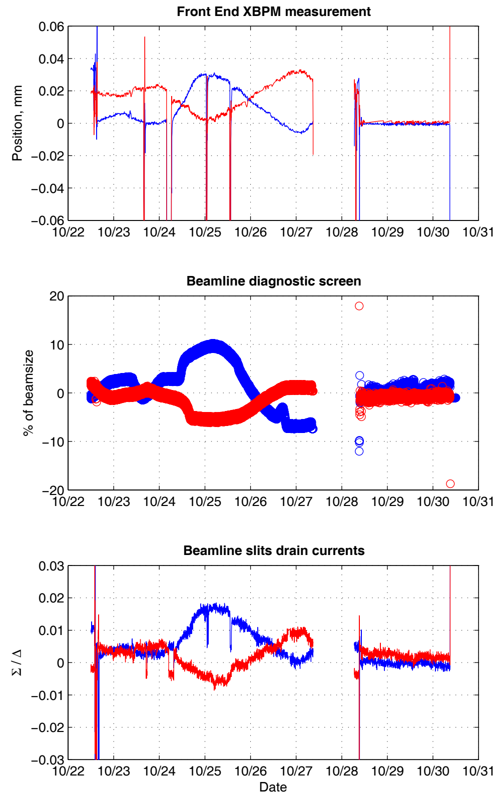

Figure 5: Improvement of X-ray beam stability using XBPM feedback on I19. Feedback is switched on for the first time on the 28th October, 2009.

over several days means that the beam would drift from the sample point, and the beamline would need to realign every 24 hours. The beamline now sees stability in the order of $\pm 3\%$ of beamsize over the course of a week.

The overall changes to the electron beam orbits are generally very small. Figure 6 illustrates the typical demand that the slow XBPM feedback places on the electron beam over the course of a week, a few 10s of microns.

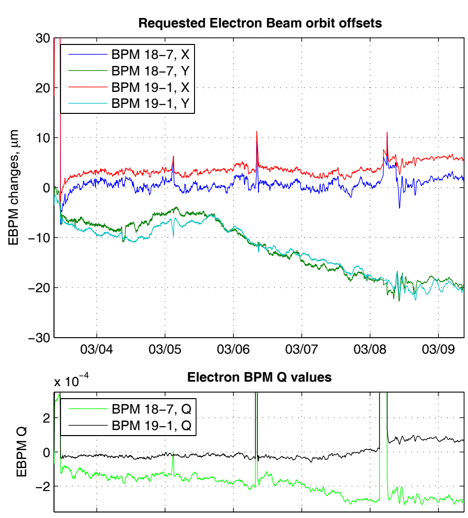

Figure 6: Requested electron beam offsets rarely exceed 20µm over the course of a week.

CONCLUSIONS

Significant improvements have been made to the X-ray beam stability over long time periods. Feedback has been shown to successfully stabilise the beam position for a test period of three consecutive weeks. However, work is still ongoing to tackle the original source of the drift. It is believed to be due to a variation in the coupling of the machine, causing a rotation of the electron beam through the Electron Beam Position Monitors (EBPMs). Channel to channel coupling in the EBPM electronics causes this rotation to be interpreted as a positional change, and this is fed into the FOFB to produce a beam position offset. One easy way to see this is to calculate the EBPM Q value, the difference over sum of the *diagonal* EBPM buttons. It can be seen in figure 6 how the changes to EBPM Q are reflected in the changes asked of the electron beam orbit by the feedback.

This feedback has proved invaluable for the scientists on I19, however, it is not without problems. The feedback presently struggles to correct the X-ray beam source for changing ID gaps due to the inherently difficult nature of using XBPMs to provide reliable readings across a very large range of gaps. As the ID gap moves, the changes to beam shape and beam energy change the calibration of the XBPMs, thus altering the measured beam position.

Presently at Diamond the method employed to tackle this problem is to only allow the slow XBPM feedback to operate for static ID gaps. It is hoped that through a combination of feed-forward tables and more intelligent XBPM calibration it may be possible in the future to run this feedback, even for a wide range of gaps.

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