OPERATION OF DIAMOND LIGHT SOURCE XBPMS WITH ZERO BIAS

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Abstract

Tungsten blade X-ray Beam Position Monitors (XBPMs) have been used at Diamond Light Source since 2007, however a long-standing problem with these devices has been the growth of leakage current through the ceramic insulation within the XBPMs over time, often becoming greater than 10 % of the signal current after a few years of operation. The growth of these leakage currents has been found to be exacerbated by the application of a negative bias (-70 V) to the tungsten blades, a bias suggested for optimum position sensitivity. This bias is applied in order to accelerate free electrons away from the surface of the blades and to prevent cross-talk, however, we have found that the operation of the XBPMs without bias has negligible impact on our measurements. Removal of the bias has been found to prevent the growth of leakage currents over time, and can also significantly reduce the cost of our signal acquisition by removing the need for a low-current amplifier with a bias supply.

INTRODUCTION

A critical requirement of synchrotron users is a stable X-ray beam. In order to help achieve this at Diamond Light Source (DLS) most beamlines have two tungsten-blade XBPMs located in their front ends. These devices are most commonly used to monitor for medium- to long-term (weeks, months) angular movement of the X-ray beam. When monitoring for longer time periods then problems with the electrical leakage within the XBPMs had been found to influence the calculated beam position. This paper discusses the cause of this problem, and the steps taken to counter it.

The XBPMs operate on the principal of photoionisation: incident X-ray photons strike the surface of the tungsten blades and eject electrons. This loss of electrons from the blade material is measured by a sensitive ammeter. Ceramic insulation electrically isolates the blade material from the copper 'blade holder' and the XBPM assembly. This basic principal has been used for some decades as the basis for photon beam monitoring [1][2][3][4].

As the signal currents measured are typically low, ~ µA, the integrity of the insulation used to isolate the blades from the XBPM chamber is vital. A degradation of this insulation will lead to current leakage, leading to position measurement inaccuracies. Figure 1 illustrates the principal behind the XBPM operation, and Fig. 2 shows how the tungsten blades are fixed within the XBPM assembly.

Commonly, an electrical bias is applied within the XBPM to either: repel ejected electrons away from the XBPM blades [1]; to attract these electrons to some 'collection electrode'; to attempt to discriminate against photons of a certain energy (usually background light from optical elements); or a combination of all of these [2]. This biasing is designed to improve the signal/noise ratio, and to reduce cross-talk between the four blades, thus improving the linearity of the XBPM response.

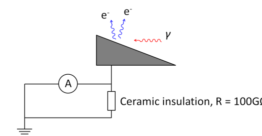

Figure 1: An illustration outlining the principal of operation behind the XBPMs. The ceramic insulation that is used to hold the XBPM blades in place, and to electrically isolate them from the rest of the XBPM chamber, is indicated by the resistor.

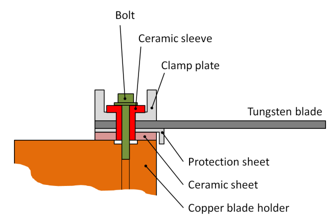

Figure 2: A schematic showing the insulation, and how the tungsten blade is fixed to the copper blade holder.

MEASUREMENTS OF LONG-TERM ELECTRICAL DRIFT IN OUR XBPMS

Over many years of operation at DLS it has been observed that the insulation between the copper blade holder and the tungsten blades within our XBPMs has been degrading. On the worst affected XBPMs after three years the insulation resistance had fallen from ~ 100 GΩ to ~ 10 MΩ. Figure 3 shows the effects on two XBPMs over this period of time. Data is sampled only during shutdown periods (i.e. when there is no beam illuminating the blades). What is seen here is the 'leakage current' through the ceramic insulation, driven by the -70 V blade bias. Starting with ~ 1 pA leakage currents seen during XBPM commissioning in 2007, this leakage current is seen to have increased by 7 orders of magnitude by 2011. The photoionisation currents seen with beam on these XBPMs are ~ 100 µA, so the leakage current represents > 10 % of this normal signal, and while easily measurable, it contributes towards an uncertainty in the XBPM measurement.

Figure 3 also illustrates that the increases in leakage

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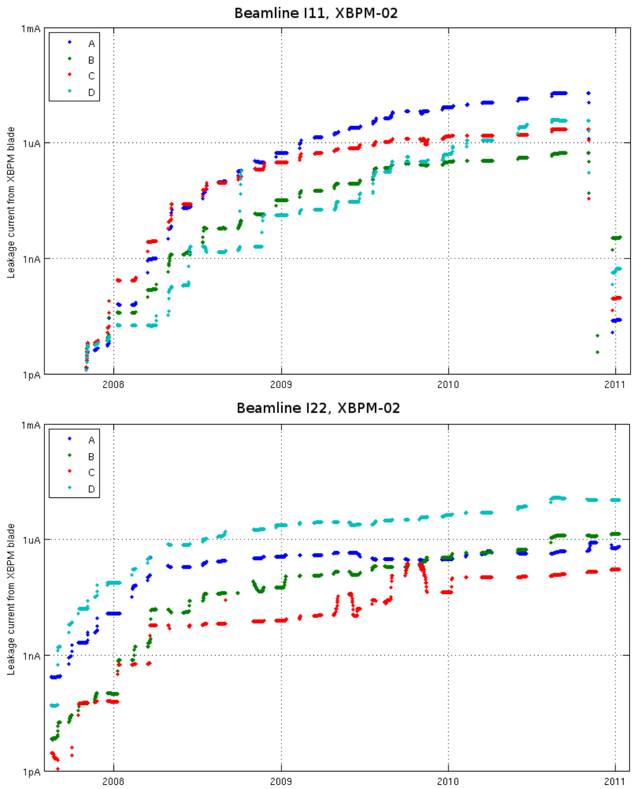

Figure 3: Blade currents (blade A, B, C, D) for XBPM-02 on the I11 beamline, top, and XBPM-02 on the I22 beamline, bottom. These two XBPMs exhibited the largest leakage currents seen at DLS. In November 2010 the ceramic insulation was replaced in the I11 XBPM, reducing, but not eliminating, the leakage current.

current were not uniform over time: it varies by XBPM, and by blade. 'Jumps' in current are measured, sometimes seen across all four blades on an XBPM, sometimes on just one blade. There was no obvious correlation found at DLS between the XBPMs with the highest leakage current and those that saw the most flux, or those with a certain blade geometry, or those of a particular Insertion Device (ID) type. The only consistency found was that in the affected XBPMs all four blades were always found to have significant leakage current.

In November 2010 the XBPM-02 on I11 was removed in order to examine it and attempt to determine the cause of the leakage current. New ceramic insulation components were installed, and these succeeded in reducing the leakage current significantly, but they did not return to their 2007 levels. The removed ceramics were found to be discoloured: a dark-coloured deposit had formed on the surface of the ceramics where they had been in contact with the blade holder clamp plate. Figure 4 shows the ceramic insulation sleeves removed from I11, while Fig. 2 shows their location within the XBPM.

This leakage current is not unique to DLS, and has been reported at other light sources [5]. A similar black residue has also been found in XBPMs at other synchrotrons, and

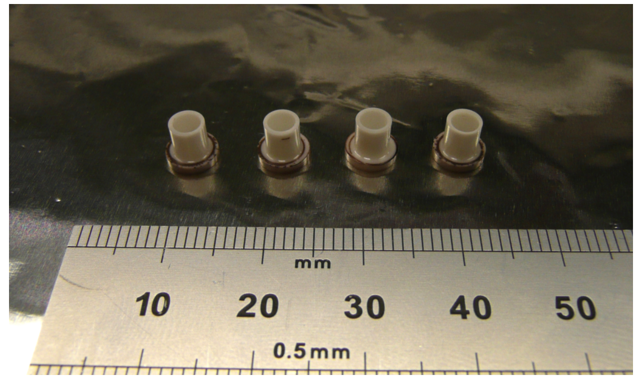

Figure 4: The ceramic sleeves that electrically isolate the XBPM blades from the XBPM vessel. Dark-coloured deposits are visible on the white ceramic surface.

an analysis of the dark deposits on the ceramics found the presence of various metals[1], but no tungsten.

THE USE OF A BIAS VOLTAGE

During XBPM commissioning at DLS it was found that increasing the bias applied to the tungsten blades, up to -70 V, had the effect of increasing the measured signal current, see Fig. 5. The increased signal current also improved the signal/noise ratio. These improvements were seen to taper off beyond -70 V, so there was little need to increase the bias further.

The XBPMs at Diamond also have an HV collection electrode, a copper aperture located close to the blades. It is possible to bias this up to +1000 V in order to attract the electrons ejected from the surface of the XBPM blades. This is designed to help prevent the ejected electrons from colliding with neighbouring blades and causing cross-talk. However, it has been found that biasing this HV electrode makes negligible difference in either reducing cross-talk, or improving the signal/noise ratio of the XBPM signals. The sensitivity of the XBPM, as measured during stepper motor scans, was found to be unchanged. Figure 6 shows the effect that this positive bias has on the XBPM blade response during normal operation: there is no change in the signal seen.

Experiments at the DLS Test Beamline, B16, demonstrated that the -70 V blade bias preferentially 'selects' soft X-rays, the bias amplifying the photoionization effect for photons of ~5 keV, discriminating against photons of > 6 keV. These results can be seen in Fig. 7. At other light sources, XBPMs that utilize a large negative bias have been developed that discriminate against low energy photons, < 1 keV [2], however for our B16 test the X-ray window we had available limited us to a minimum photon energy of 4 keV, so we were unable to confirm the effectiveness of this technique.

When we analysed these empirical results during initial XBPM commissioning in 2008 at Diamond we reached

[1] Metals found included C, Fe, Ne, Al, Cu, Ni, Si, Cr, Zr, Y, K, and Ca!

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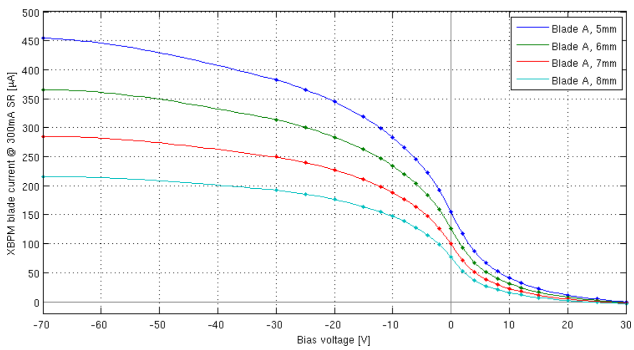

Figure 5: Measured XBPM blade response for varying ID gaps on I11. As one increases the bias voltage from 0 V to -70 V the signal increases, improving signal/noise.

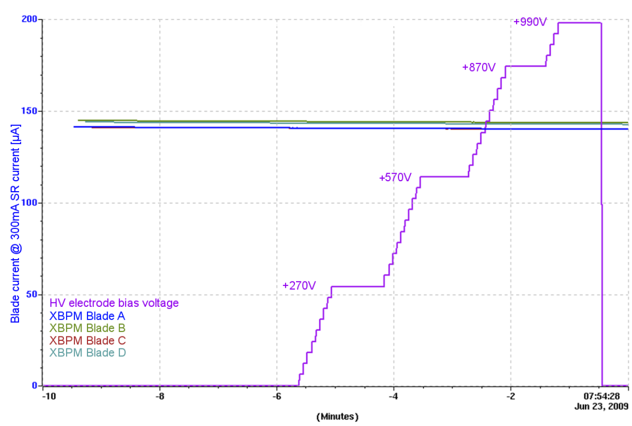

Figure 6: Results from I16, XBPM-01. As the HV electrode was ramped up to +1000V under nominal conditions (300 mA stored beam current, ID at 7.0 mm gap) the XBPM blade response was recorded. Negligible difference was seen to either the overall currents, or the signal/noise ratio.

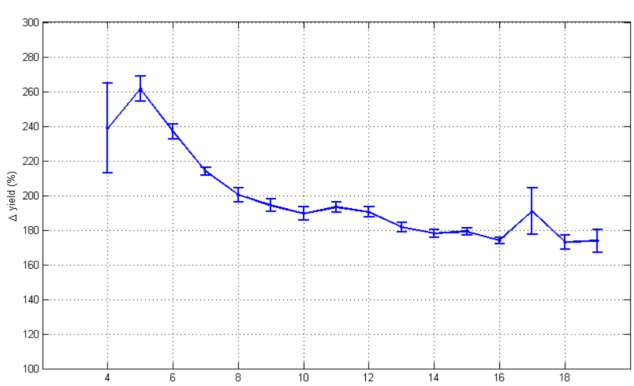

Figure 7: Experimental results showing the % increase in XBPM signal that a -70 V bias causes (compared to no bias), for various X-ray energies. The -70 V bias has a tendency to preferentially select soft X-rays. These results were obtained using dedicated beam time on the B16 Test Beamline at Diamond.

the conclusion that, for our DLS IDs with tungsten-blade XBPMs, a blade bias of -70 V produced a satisfactory ratio of signal/noise, and a higher bias than this provided no benefit. For our Dipole beamlines with copper-blade XBPMs the same empirical techniques suggested a suitable blade bias to be -20 V. In both cases we found that the HV electrode biasing had no effect. Anecdotal evidence from other third generation light sources corroborated our results.

THE EFFECTS OF LEAKAGE CURRENTS AND EFFORTS TO PREVENT THEIR FUTURE GROWTH

When the -70 V bias is present, a leakage current of some μAs is always present, however this leakage current is not constant and varies over time. This introduces an error into the position measurement. As of 2011, the leakage currents represented a significant fraction (1 %-10 %) of the signal seen on the majority of beamlines at DLS.

One XBPM (on beamline I06) was returned to the manufacturer, where it had the insulating ceramics removed and upgraded. An in-house effort to remedy the degradation of the insulation was made on beamline I11, where XBPM-02 was removed from the storage ring to have its insulating ceramics replaced. This turned out to be a time-consuming procedure though. To remove the XBPMs a vacuum intervention is required on the beamline front end, exposing the machine to some degree of risk. The procedure also did not remedy the problem as well as had been hoped, and relatively high leakage currents remained (see Fig. 3).

After some consideration, a better solution was found to be to turn *off* the XBPM blade bias. This does not 'fix' the insulation, however it does eliminate the variable offset seen in the signal current due to leakage.

By eliminating the -70 V blade bias the only signal seen at our ammeter is the loss of electrons via the photoionization process. (There is still *some* leakage current that flows through the ceramic. However the internal resistance of the ammeter is tiny, measured to be in the region of 1 kΩ, compared to the 10 MΩ resistance of our residue-coated ceramic. The amount of current flowing through the ceramic becomes totally negligible.) By 2010 it had been noted elsewhere that the bias was not absolutely required for operation, and that satisfactory signal/noise ratios and linear response could both be achieved without it [6][5].

XBPM MEASUREMENTS USING ZERO BIAS

In January 2011 we turned off the bias for XBPMs on all beamlines following successful test results. Figures 8 and 9 show the measured XBPM response without bias. The position measurement remains good at 0 V bias, and even across a wide range of beam positions (±1.0 mm) there is no noticable increase in cross-talk between the blades.

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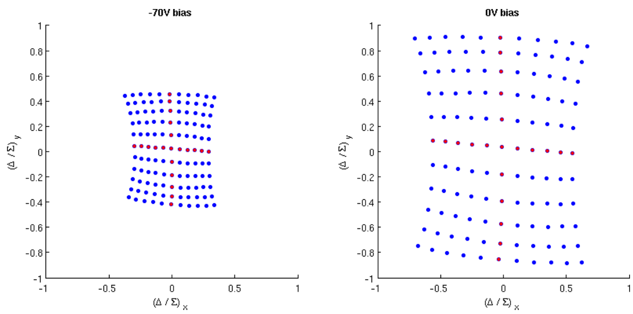

Figure 8: Results from a 2D stepper motor scan of the I24 XBPM-01 with, and without bias. The recorded Δ/Σ position measurements are shown, with points evenly spaced: each represents a 200 µm stepper motor movement.

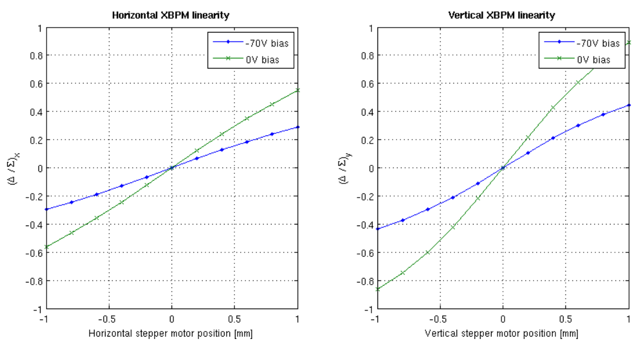

Figure 9: The linearity of the XBPM measurements for horizontal and vertical stepper motor displacements.

It was found that the linearity of the XBPM position measurements remained, and that the scale factors were improved by the removal of the bias. This has the unanticipated effect of making the position measurement more sensitive. Without bias we still achieve 100 nm resolution at kHz bandwidths, as measured by acquiring XBPM data synchronously with electron BPM data from directly either side of the X-ray source. The two sets of data correlate extremely well, and are able to give us a value for the resolution of the XBPMs.

THE SCOPE FOR NEW ELECTRONICS

The option of running without any form of bias on the XBPMs has opened up the possibility of simplifying our acquisition electronics chain. Previously, for each XBPM (two per beamline) we purchased a 4-channel low current amplifier with a built-in bias source. However, generally speaking, on our XBPMs for dipole sources and for standard in-vacuum IDs we measure signal currents on each blade of >10 µA and >100 µA respectively. At these currents, the requirement for a ‘low current amplifier’ is relaxed: one can even measure these currents with a standard 0-10 V ADC, by measuring the voltage drop seen across a resistor in series with the signal cable.

For IDs there is the difficulty that if a beamline operates at a wide range of ID gaps then a single resistor may not produce a suitable voltage drop for all conditions.

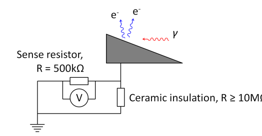

Figure 10: A sense resistor can be substituted for the ammeter, so long as the $I_{sense} >> I_{leakage}$.

However, for dipole sources the signal current from the XBPMs remains within a very narrow band for virtually all machine conditions (whilst top-up is running). In this case four thermally-stable resistors and a 4-channel 16-bit 0-10 V ADC offer the same resolution as a specialised ‘low current amplifier’, but at a fraction of the cost. Figure 10 shows the schematic for such a measurement circuit.

Our tests have shown that we can still operate with sub-micron position resolution using this method, and we plan to use this system on the upcoming B24 beamline.

CONCLUSIONS

A bias voltage is unnecessary for the operation of XBPMs at DLS. The addition of the bias voltage was introduced at earlier synchrotrons where beam currents were smaller and flux was reduced: boosting the signal/noise ratio was of great importance in order to improve XBPM position resolution. We speculate that significantly lower flux seen in the past may be the reason for older facilities not seeing the same degradation of the insulating ceramics seen by modern light sources (or seeing these effects at a much slowed rate).

At DLS there is sufficient flux that the use of a bias on the XBPM blades, or on an HV electrode, to increase the signal/noise is not necessary. In any case, running with slightly reduced signal/noise is certainly a better alternative to dealing in the long-term with growing leakage currents. Without bias we still measure 100 nm resolution at kHz bandwidths when using a low current amplifier.

The option to simplify the acquisition chain on some future beamlines by using a 0-10 V ADC rather than a low current amplifier should help to reduce costs. The long term performance of this system will be tested over the coming months.

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