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RE-EVALUATION OF THE NSLS-II ACTIVE INTERLOCK WINDOW*

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Abstract

The NSLS-II Active Interlock is the system which protects the NSLS-II Storage Ring vacuum chamber from damage due to synchrotron radiation. The Active Interlock measures the beam position and angle at all insertion devices and issues a beam dump if the beam is outside of the pre-defined window. The window is determined by thermal analysis of vacuum apertures and considers the effects of local magnets such as canting magnets, etc. Recently, it was realized that the insertion device correction coils where not considered in the initial evaluation of the envelope. The purpose of these coils is to correct for the orbit deviations caused by imperfections in the insertion devices that steer the beam. The usual effect is to negate any angle induced by the device, however, if the coil is not set properly the beam may have a larger angle than permitted by the Active Interlock even though the angle calculation does not show it. In this paper we discuss the effect of the insertion device coils on the electron beam and the steps taken to account for this effect in the Active Interlock.

INTRODUCTION

The NSLS-II Active Interlock System (AI) protects the NSLS-II Storage Ring vacuum chamber from damage caused by mis-steered synchrotron radiation. The ring vacuum chamber, absorber apertures and possibly front end components may be damaged by errant steering of the x-ray beam[1]. Part of the AI is to measure the beam position and angle within the insertion devices to ensure that the beam is appropriately located, that is to say it is within the AI envelope. When the beam is outside of the envelope the AI trips the RF system.

All of the insertion devices have correction coils that are used to correct for steering induced by the devices as the gap is closed. The appropriate strength of these coils as a function of gap is measured and subsequently controlled via feedforward tables. It was realized that the influence of these coils was not considered in the analysis of synchrotron radiation protection and the active interlock system. Even though the purpose of the coils of to correct for steering induced by the insertion device, for whatever reason these coils may not have the proper current and therefore the beam may have additional steering. If the beam is measured to be close to the edge of the envelope, the beam may exceed it, and cause damage to the vacuum chamber.

In this paper we recall the requisite functionality of the AI System, and the previous analysis that was performed. Then we discuss the strategy for including the correction coils in the analysis and then the results of the analysis and its incorporation in the AI system.

AI SYSTEM BASICS

The AI system protects the storage ring vacuum chamber from synchrotron radiation damage by controlling the electron beam location and angle through the insertion device. In insertions with one or two uncanted devices, two beam position monitors (BPMs) are used. In canted insertions, three or four BPMs are used. Figure 1 shows a typical canted insertion. The data from the BPMs is sent through a dedicated link to a FPGA which calculates the beam position and angle within the insertion. This result is compared to the AI envelope, if the position or angle is outside of this envelope, then the AI delivers a beam dump signal to the RF system.

The AI envelope is determined by calculations of where the synchrotron radiation strikes various objects in the storage ring (vacuum chambers, flanges, RF fingers, absorbers, etc.) and what the temperature rise is for various missteerings of the beam. This sets ultimately sets the safe limits of the electron beam and angle at the center of the insertion device [2]. The most stringent limits come from the dipole chamber immediately downstream of the insertion device. As with most synchrotron light source chambers, the vertical aperture is very small and the horizontal aperture is large, especially when the antechamber for pumping is included.

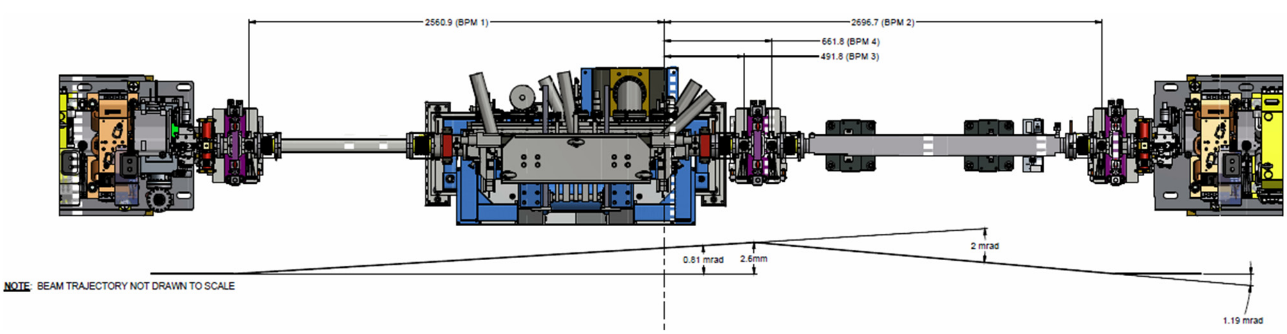

Figure 1: Layout of the 19 ID Straight section. This is a typical canted beamline with one undulator. Taken from [3].

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The beam position and angle calculation assume that the distance between the BPMs is a drift. The one exception is a three BPM canted beamline which takes into account the

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canting magnet (also monitored in hardware by the AI system). The correction coils for the insertion devices reside between the BPMs. If the coils do not have the proper current for the insertion device, the space between the BPMs will not look like a drift. The AI system does not account for these coils and does not have a readback of the current. Figure 2 illustrates the problem. The black dotted line is the extrapolated trajectory in a drift, while the solid black line is the trajectory with the effect of the correctors. At the center of the insertion the extrapolated angle and position are different than the actual.

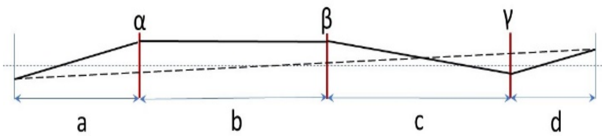

Figure 2: Diagram of Effect of ID correctors (red) on the position and angle reading of the beam.

The concern is that these coils may not have the correct current and impart an angle. This would give an incorrect interpolation of the beam position and angle at the ID center, which may mask an out of envelope condition requiring a beam dump. Typical size of the AI envelope are 500 µm in position and 250 µrad in angle, though it is customized for particular insertion devices as needed. The maximum strength of the coils can be several 10's µrad per coil so this is not negligible.

It was determined that incorporating readback on all of the correction coils was too costly, therefore the problem would be accounted for by reducing the AI envelope size and limiting the maximum current of the power supplies. This would ensure that if all of the coils were set incorrectly in the worst case that the beam would not be in an unsafe state as long as the interpolation was inside the new AI envelope.

REANALYSIS

The AI envelope initially as defined as a ±500 µm x ±250 µrad box at the center of the ID straight. This defined a "No Touch Envelope" where the beam could be anywhere within the box and the synchrotron beam would not touch any apertures [4]. Ray tracing is performed from both ends of the insertion device to ensure that the beam from any point in the insertion device does not strike the apertures. This envelope was used for all insertions, as it was the maximum envelope that could be used for all insertions and provided input used for Front End design.

Figure 3 shows the analysis of the Damping Wiggler insertion. The black box is the ±500 µm x ±250 µrad horizontal "No Touch Envelope" at the center of the straight. The red, blue, and green lines are three of the downstream apertures that cannot be hit with beam from the damping wiggler. The black box does not intercept any of the apertures. However, the upper right and lower left corners of the box are close to intercepting some of the apertures, which in this case is a bellows and a flange absorber. This highlights that it is important to account to errors introduced by the coils.

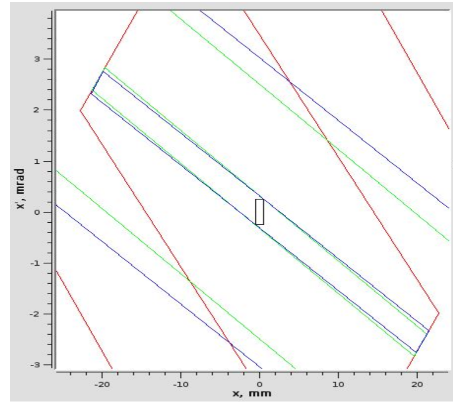

Figure 3: Horizontal No Touch Envelope for the Damping Wigglers. The black box is the envelope, while the other boxes represent other apertures projected to the center of the wigglers.

Analysis was also performed to show the maximum angle of the radiation coming from an ID which would not cause a temperature rise to more than 100C° on the dipole chamber. This is shown in Table 1. There are several hundred µrad of angle between the No-Touch Envelope and the maximum safe angle in all cases except for the Elliptically Polarizing Undulators.

Table 1: Maximum Safe Angle for Insertion Devices

Type	Maximum Vertical Angle
Damping Wiggler	375 µrad
In Vacuum Undulator	500 µrad
Elliptically Polarizing Undulator – Linear Mode	375 µrad
Elliptically Polarizing Undulator – Helical Mode	250 µrad

The strategy is as follows. First, if the beamline is canted, the No Touch Envelope is defined for each insertion device and not just for the center of the straight. The maximum possible angle caused by the correction coils is determined for each device. If the No Touch Envelope angle and the angle from the coils is greater than the maximum safe angle, than the steps are taken to assure this maximum safe angle is not exceeded. Current limits are imposed on the power supplies to limit the max current while still allowing for correction of the insertion device. Power supplies that are not used are disabled. If this does not ensure that the maximum angle is less than the maximum safe angle, then the AI envelope is reduced. Reducing the AI envelope is a last resort as it can lead to increased trips if the beam excursion gets too large.

Following Table 1, we break the analysis down by class of insertion device.

DAMPING WIGGLERS

The NSLS-II has three pairs of damping wigglers. They are unique in the ring not only because of their high power, but their larger horizontal divergence. Each device has

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three pairs of coils. The maximum vertical kick is 11 µrad for each pair of devices, and the nominal envelope does not need modification. The maximum horizontal kick per wiggler pair is 385 µrad. Figure 4 shows the backward tracking that includes the maximum possible angle from the corrector coils. It shows that the flange absorber located at the end of the insertion is being intercepted by the beam with the standard No Touch Envelope. This absorber was never analysed for intercepting beam. The reasons for this are not known.

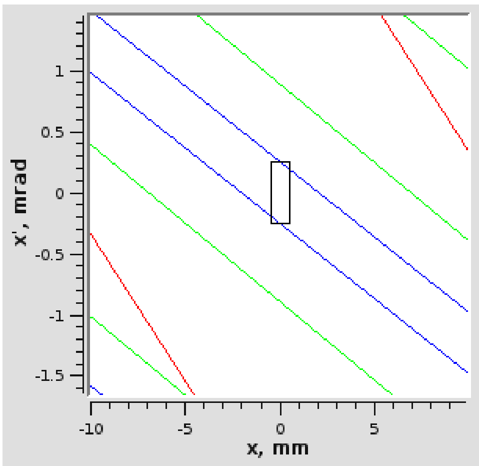

Figure 4: Horizontal No Touch Envelope for the Damping Wigglers with the correction coils added. The black box is the envelope, while the other boxes represent other apertures projected to the center of the wigglers.

Because of the uncertainty about the temperature rise of the absorber, a conservative approach is taken to ensure that the coil kicks will not cause the beam to strike the absorber. The middle coils for each device are not used for correction and therefore are disabled. This reduces the possible kick to 154 µrad. Furthermore, the AI envelope is reduced to ±360 µm x ±150 µrad. This will ensure the No Touch Envelope is maintained.

IN VACUUM UNDULATORS

In Vacuum Undulators (IVUs) comprise the bulk of the undulators in NSLS-II and except for two have a standard construction of three pairs of coils, 2 upstream coils, 2 middle coils, and 2 downstream coils – one for each plane. The other two IVUs do not have the middle correction coils. In all cases the maximum kick angle with all of the coils powered at maximum current is 152 µrad per IVU. The No Touch Envelope had a maximum angle of 250 µrad. Adding the additional angle gives a maximum angle of 402 µrad, which is less than the 500 µrad maximum safe angle. Therefore no modification is necessary for any IVU.

One insertion device is an out of vacuum undulator that is not a damping wiggler or EPU and goes by the name U42. The maximum safe angle for this undulator is 500 µrad. There are two pairs on correction coils. The vertical coils produce a total maximum angle of 248 µrad if both power supplies are at the maximum current of 10 A. Adding this to the 250 µrad active interlock window brings the beam right to the maximum safe angle. Therefore, a current limits of 9 A is imposed on the vertical coils. The horizontal coils produce a total maximum angle of 130 µrad and therefore no limits are placed on these coils. The AI Envelope is unchanged.

ELLIPTICALLY POLARIZED UNDULATORS

There are six EPUs installed in NSLS-II. As Table 1 shows there are two maximum safe angles for EPUs. The fan in helical mode is taller than in linear mode, and the maximum safe angle is already at the edge of the AI Envelope. Therefore, there is no for room errors in the coils. Additionally, each EPU is constructed differently with coils whose strength varies with the gap. All EPUs have their vertical AI Envelope reduced to at most ±500 µm x ±125 µrad. Five of the six EPUs have the maximum strength of their coils reduced. This reduction in maximum strength does not have an impact on the ability to correct for errors in the EPUs. Details can be found in [5].

Also noted in this category is one straight section that has two uncanted EPUs. This analysis shows that these EPUs cannot close their gaps simultaneously. The straight section has only BPMs at either end. The coils from both EPUs need to be added for this analysis. That would shrink the AI Envelope to nothing. Therefore, this beamline is limited to operating with only one of the two EPUs closed until such time as a BPM is placed in between them. Then each EPU can be analysed separately.

CONCLUSIONS

The Active Interlock System is a critical equipment protection system for NSLS-II. Previous analysis of the required AI Envelope neglected the effect of the correction coils mis-steering the electron beam inside the devices. The analysis of the required envelope has been modified to include this effect and the AI Envelopes have been modified where necessary to ensure that vulnerable components do not get damaged. This has been implemented and tested in the AI System.

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