ISBN: 978-3-95450-188-5 doi:10.18429/JACoW-MEDSI2016-WEPE05

INNOVATIVE DESIGN OF RADIATION SHIELDING FOR SYNCHROTRON LIGHT SOURCES

M. G. Breitfeller, Brookhaven National Laboratory, Upton, N.Y., USA
S. L. Kramer, Operations and Accelerator Design Consulting, Ridge, N.Y., USA

Abstract

Over the course of decades, the shape of the bulk shielding walls for synchrotron light sources has developed into a standard configuration, including a ratchet shape of the outer storage ring wall, to accommodate the clearance needs for front end and first optical enclosure assemblies. New state of the art light sources will have low emittance, high energy beams, which will give potential for higher beam losses. These losses will yield higher radiation dose rates at the downstream wall and stricter safety requirements in the first optical enclosure. Throughout the installation of local shields at NSLS-II, verification dose rate studies of various shielding configurations were performed. Analysis of these studies revealed that a circular outer bulk shield wall could greatly reduce the dose rate to the users who work near the front end optical components. This presentation discusses the benefits of this circular bulk shield wall verses the challenges of component installation near the wall and ways to mitigate them.

INTRODUCTION

The bulk shield wall is the first line of defense from harmful radiation for human health safety, which is the highest of all priorities. A well designed outer storage ring wall attenuates the radiation field to acceptably low level dose rates for people near the wall. A wall with circular geometry presents a large arcing radius, relative to the beam path, that naturally maximizes wall thickness and attenuation. The challenge for engineers is to adapt new methods for interfacing the front ends to the beamline components through the much thicker concrete wall and it's curved outer surfaces.

BENEFITS AND PLANNING FOR THE CIRCULAR WALL

The safety benefits of the circular wall are numerous. The bulk wall shield is the first line of defense for radiation safety, a passive system, and once it is built it requires no additional attention. Other than the penetrations themselves, costly radiation analysis of complex wall geometry is simplified, and fewer local shields are required for hot spots. Next generation light sources will require thicker downstream walls, because higher dose rates will exist in the First Optical Enclosures (F.O.E.) resulting from abnormal losses caused by mis-steering. These higher dose rates can occur even when the safety shutters are actuated to block the X-ray beam path. More details on the advantages of the circular shield wall are given in Ref [1]. Also, cost savings may be significant. The circular wall will require less labor to build forms, less cement to pour, and less lead, needed for strengthening an inferior ratchet shield design.

At NSLS-II, the shape of the existing ratchet wall makes it convenient to connect the front end's gate valve to the first component of the F.O.E. The outer ratchet wall's orthogonal shape allows F.O.E. girders to position close to wall, and their hutches use the bulk wall as the backbone for its boxed shape (see Fig. 1). The downstream wall thickness is 1.5 m, so relatively little layout space is lost by feeding a drift tube through the wall to connect the two systems. To accommodate the new circular wall design, engineering methods must be considered to create penetrations in the thick wall that will gain access to components where needed.

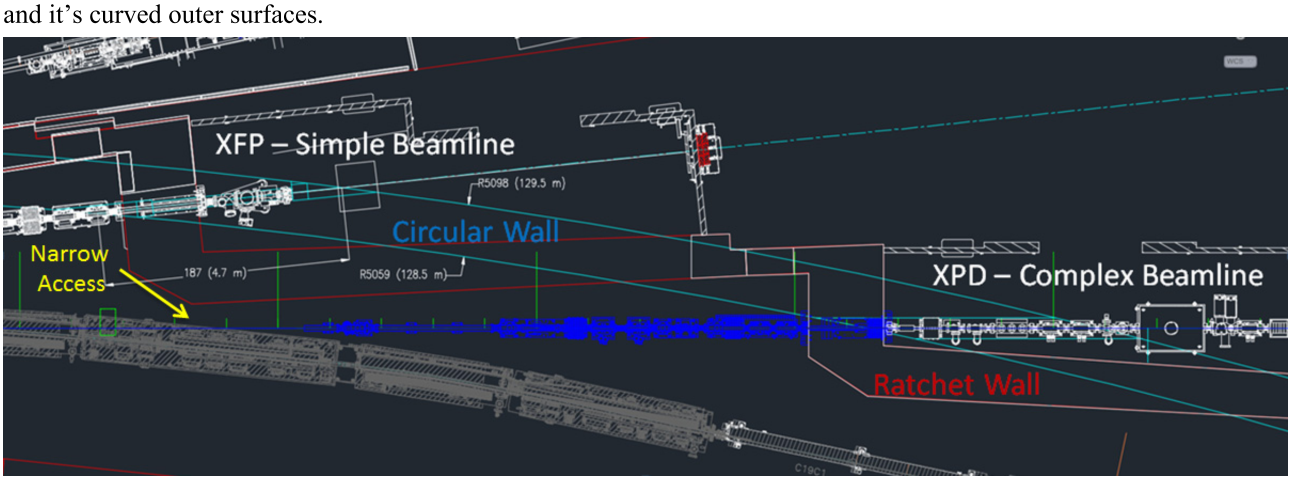

Figure 1: Existing adjacent beamlines at NSLS-II, with ideal circular wall outline overlay.

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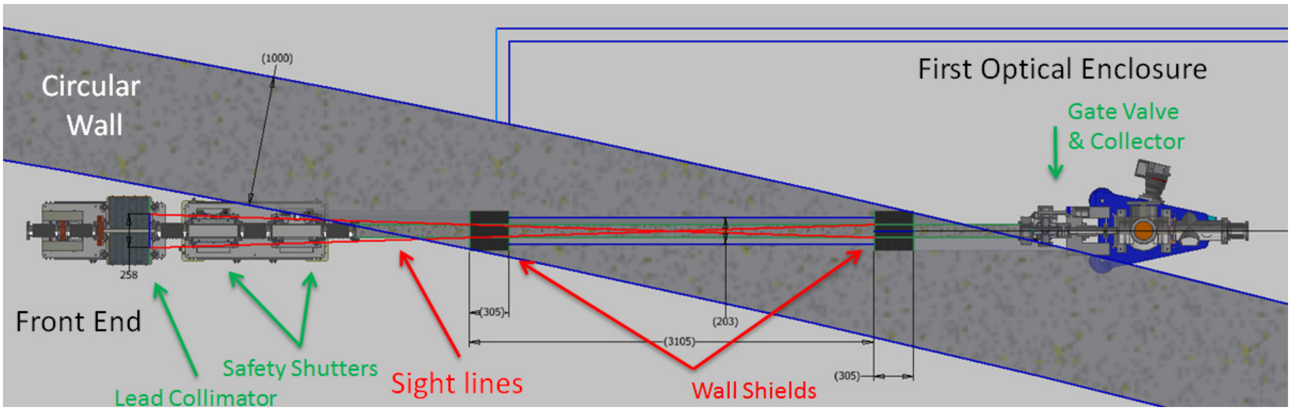

Figure 2: Simple beam line cut wall view from top.

MITIGATION

Two example adaptations, that detail engineering requirements to create penetrations through thick circular walls, will be compared. The details are illustrated by referring to two adjacent NSLS-II beamlines and are described in Fig. 1. The first is X-Ray Footprinting (XFP), a simple beamline, typical for BM sources, with few components and plenty of floor space in the F.O.E. hutch. The second is X-ray Powder Diffraction (XPD), a complex beamline, typical for ID sources, with many tightly spaced components and limited floor space.

A simple beamline adaptation is illustrated in Fig. 2. A long drift tube is the only component that would need to be installed. The example beamline included a toroidal mirror in the front end, which gives the synchrotron fan a rising pitch of .007 radians. Given the existing lattice geometry, the centerline hole length through the circular wall is 4.7 m, and projecting the rising pitch through the wall, the ends of the penetration would have a height difference of 40 mm. At NSLS-II, many simple beamlines were designed after the ratchet wall penetrations were formed with sleeves, and with mirrors causing beam path variations, it seems the practical approach to facilitate installation of the long drift tube would be to core drill, rather than pre-install a sleeve.

The actual breakout core cutting distance would be 5.7 m, but this should not be a problem as companies specializing in core drilling are equipped with a large supply of long tube core bits, as well as a host of drill motors and mast configurations to accommodate concrete thicknesses in excess of 18 m. In preparation for core drilling, the wall's penetration area should be free of rebar. Unreinforced concrete is easier and faster to drill. To minimize the effect of angular error of drilling, it would be ideal to drill from each side.

Rectangular tube lengths are available up to 7.3 m long, so a seamless 100 mm x 50 mm tube, with standard 150 mm welded Conflat flanges can be manufactured and would slide completely through a 200 mm diameter core. The cored hole should be counter bored to 300 mm diameter at each end, to allow for the shielding material to install and overlap the full length thru-wall seams. When installed, the tube would sag under its own weight, so length long ribs could be welded to the tube and shimmed supports could be installed in the middle to minimize deflection. After the tube flanges are surveyed, machined steel rounds are inserted in the counter bore, around the tube, and become the wall collimating shields.

As can be seen in the illustration, an added benefit is that the extended distance between the wall shields is more than double that of the ratchet wall configuration. With the line of sight through the wall shields narrowed, size of the Front End's collimator shield can be reduced to ½ of its existing size, and the need for additional front end scatter shields is eliminated.

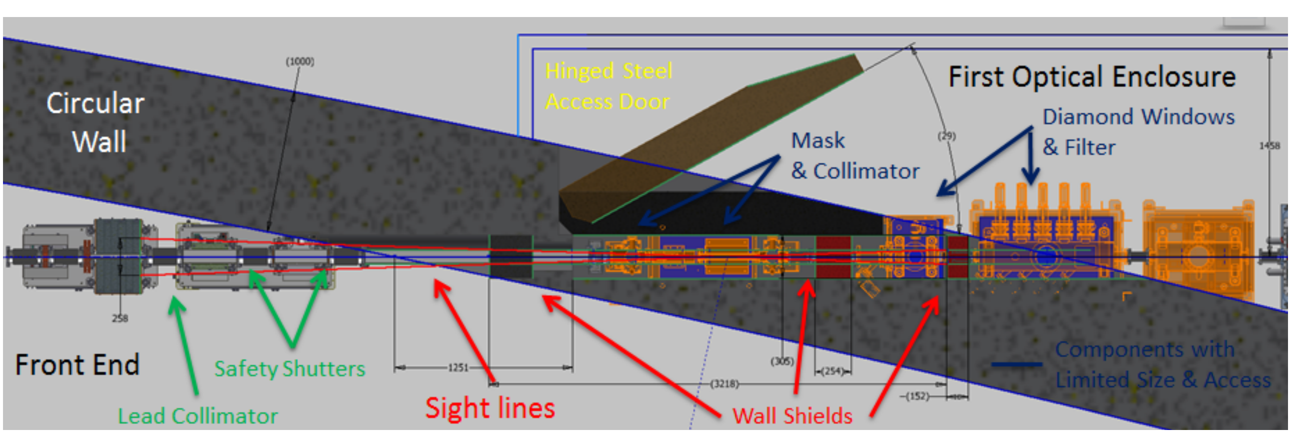

Figure 3: Complex beam line cut wall view from top.

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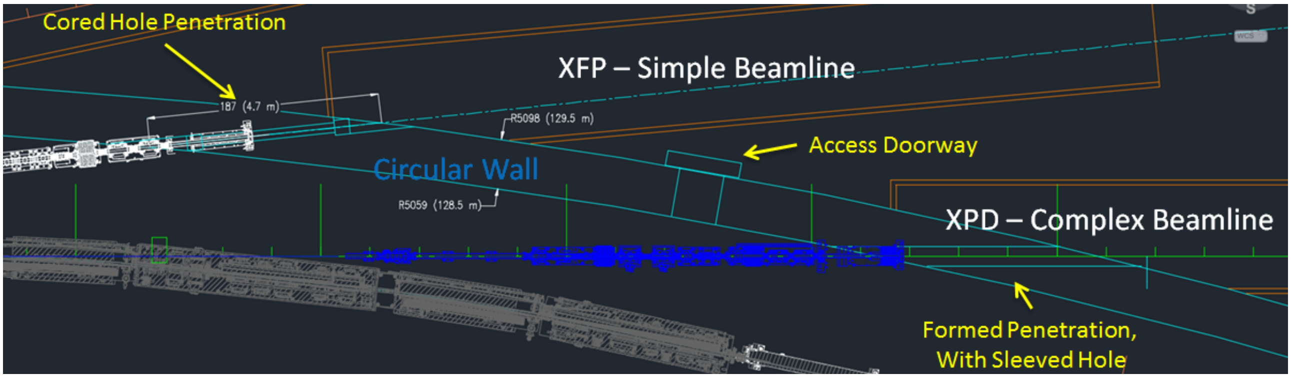

Figure 4: View of access with new circular wall layout.

A complex beamline adaptation is illustrated in Fig. 3. At NSLS-II, complex beamlines do not include mirrors in the front end, so designed penetration sleeves can be located in forms and surveyed to position. With the concrete properly formed, their surfaces can act as supporting structures for components. For the front end side of the wall, the cored-hole method, with a small diameter hole, would leave the circular surface of the shielding wall intact, for a depth of 1.25 m, enabling it to absorb the forward radiation shower. To minimize voids and maintain the ideal wall thickness of 1 meter, the upstream, near wall, beamline components would be mounted in a section of the circular wall that would be shaped with a steel sleeve. The steel sleeve would form a rectangular access window on the FOE side of the wall. The window would provide access to components, such as gate valves, masks and collimators, and allow enough room for installation, survey and service. An additional step in the forming sleeve would create a pocket that would house a steel plate shield. The steel plate would fit in the sleeve pocket, so the steel can overlap the full length thru-wall seams. The steel to concrete attenuation ratio is 4:1, so a 30 cm thick plate would adequately substitute for the concrete removed from the circular wall shape and would serve as an access door. The proposed access door would weigh close to 4 tons, but mounted on a frame with pins and thrust bearings, it could easily swing open. A 30 cm wide x 50 cm high mounting area would be large enough to facilitate most of the upstream beamline components. Larger beamline components, such as monochromatic mirrors must be located clear and downstream of the wall. Some planning would be needed for beamline layouts, to ensure that components in the wall would be size limited and facilitated for full supply and service. Additional blind sleeves could be installed in the wall to provide utilities to the components. After the components are installed, lead stacks would be assembled in between the components to shield any forward radiation through the penetration to the F.O.E.

FINAL LAYOUT

With the circular wall beamline penetrations defined, adjustments to the F.O.E. hutches and access doors can be made. Although existing ratchet wall F.O.E. hutches typically use the orthogonal wall as a backbone, hutches located out on the experimental floor are free standing. The new F.O.E. hutches would be similar to these designs, only needing supports to fasten the hutch wall ends to the circular wall. The hutches would be aligned parallel to the beamline to maximize floor space (see Fig. 4).

As seen in the illustration, and comparing to Fig. 1, much floor space has been gained on the storage ring side of the wall. The narrow access area between front ends has expanded to 1.5 meters. By eliminating the narrow access area, half of the access doorways can be removed from the circular wall, as one doorway can adequately service adjacent front ends. With limited time available for building after storage ring commissioning and ongoing construction of new front ends and insertion devices only during shutdowns, the open space is a great resource which enables movement of pre-assembled girders and gives easy access to all areas.

CONCLUSION

The need for the circular wall from a radiation perspective is compelling and additional benefits have been discovered while finding ways to mitigate the challenges of adapting to the proposed wall. Although detailed preparation and planning is required to ensure that all beamlines can be installed in a timely and cost effective manner, these efforts are balanced by the many cost and time saving benefits discussed.

ACKNOWLEDGEMENT

Sushil Sharma contributed insightful knowledge and guidance towards ideas for this paper from his vast experiences from working on Synchrotron Accelerators for many years.

REFERENCES

[1] S. L. Kramer *et al.*, “Shielding Synchrotron Light Sources: Advantages of Circular Shield Walls Tunnels”, *Nuclear Instruments and Methods in Physics Research*, **A827** (2016) p.24–31.