ISBN: 978-3-95450-207-3 doi:10.18429/JACoW-MEDSI2018-TUPH24

FRONT END OF DUAL IMAGING AND DIFFRACTION BEAMLINE AT DIAMOND LIGHT SOURCE

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Abstract

The Dual Imaging and Diffraction (DIAD) beamline X-ray source is a ten-pole mini wiggler. By locating the mini wiggler in place of an existing sextupole magnet, the DIAD beamline is built at a bending magnet beamline position in Diamond. To accommodate the unusual beam trajectory, a new front end was designed for the DIAD beamline. The particular designs and specifications, including an improved front end slits design, as well as the synchrotron and dipole ray tracing of the front end are presented in this paper. The development process of delivering the front end - the project challenges, approach and activities are also described along with the technical challenges.

INTRODUCTION

All of the original straight sections in the Diamond storage ring are now occupied. After an extensive study at the beginning of the DIAD beamline project, the decision was made that the DIAD beamline would be built at a bending magnet (BM) beamline position by replacing an existing sextupole magnet with a ten-pole permanent magnet wiggler [1]. DIAD X-ray beam radiates in the same direction as the first bend of the double-bend achromat. The schematics of the beam trajectory are shown in Figure 1. The field strength of the mini wiggler is 1.56T, the period length is 117mm and the total power at 500mA is 4.8kW.

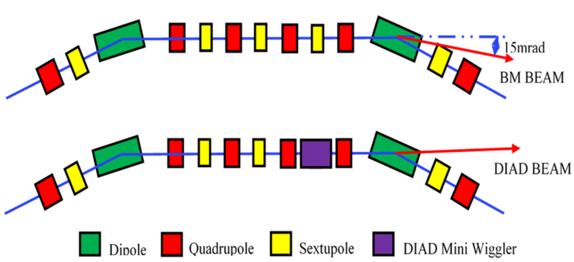

Figure 1: Top: Schematic diagram of the double-bend achromat layout. Bottom: Schematic diagram of the mini-wiggler replacing the sextupole.

This unusual beam trajectory means that the front end will be exposed to the radiation from the dipoles of the double-bend achromat. It will be necessary to shield the uncooled part of the front end from dipole radiation. Further engineering challenges include the front end having to cope with a wide wiggler beam of a fan size of 6 (horizontal) x 0.4 (vertical) mrad. The beamline also requires the front end slits to be the first optics of the beamline. It is important for the front end slits to perform according to the beamline needs.

The delivery of the Front End is on the critical path of the beamline project. A new approach of "Management of the Fuzzy Front End of Innovation" [2] was tried in the concept design stage to manage the technical uncertainties effectively at the early stage of the project. We have gained more understanding of how to be more efficient in the design and development of front ends, which is an innovation process, and deliver the project successfully.

ENGINEERING SOLUTIONS

The DIAD front end design is shown in Figure 2. It consists of Zero Aperture module, 1st Aperture module, Absorber module and fast shutter, Access Pipe module, Slits module, Twin Port Shutter Module and Optics Hutch module. Radiation shielding and modules using DLS generic designs [3] are not part of the discussions in this paper. The more challenging front end ray trace and front end slits will be discussed.

Front End Ray Trace and General Layout

Ray tracing using AutoCAD was employed to study the optical path of the wiggler X ray radiation and dipole radiations and to identify aperture needs. General Layout of the front end was carried out in parallel with the ray tracing to optimise the component sizes and locations of assembly modules. The ray tracing (Figure 3) has the following findings:

- A zero module is necessary to connect the front end to the storage ring (SR) as it is almost 12 meters from the end of the SR vessel to the ratchet wall, while the standard length of an undulator front end at Diamond is around 10.4 meters.
- The crotch absorber in the SR vessel needs to be wider to provide more shielding to prevent radiation from dipole 2 shining on the uncooled zero module vessel.
- A zero aperture, in addition to the wider crotch absorber, is also needed to provide shielding to the uncooled zero module vessel. The zero aperture is also designed to replace the Beam Port Absorber fitted at the end of the SR vessel to make the easy connection of the front end to the storage ring.
- For the benefit of the project timescale and cost, a decision was made at the ray tracing stage that Absorber, Access Pipe, Twin Port Shutter and Optics Hutch module will use DLS generic designs [3]. However, the 6mrad wiggler beam size is too wide for the standard 1st Absorber. The solution was to design the 1st Aperture to trim the wiggler beam to 0.86(H) x 0.34(V) mrad so that the standard 1st Absorber can be used.

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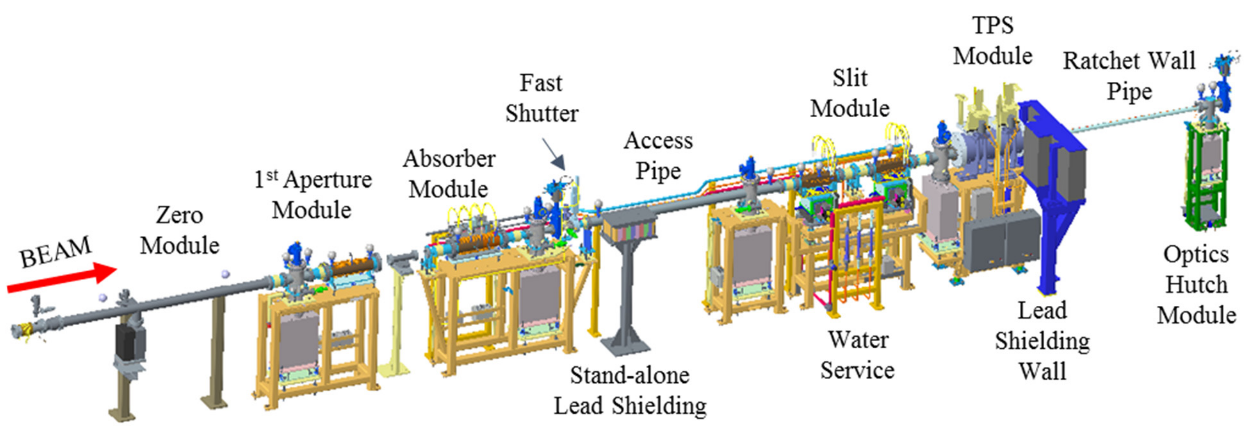

Figure 2: The DIAD Front End (Steel Wall Penetration is not shown). The fabrication design from FMB Berlin [4] is shown.

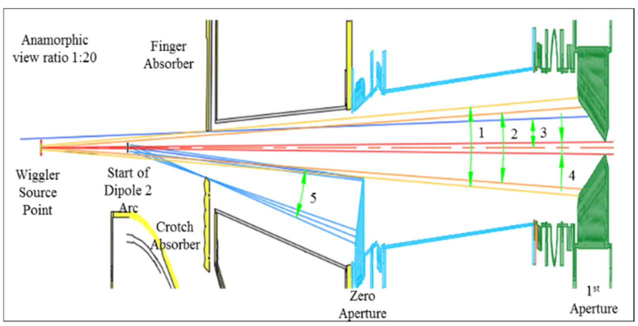

Figure 3: Plan view showing the wiggler and dipole light ray tracing. 1: wiggler fan including mis-steers; 2: 6 mrad wiggler fan nominal position; 3: 5mrad dipole 1 fan; 4: 0.86(H) mrad wiggler light exiting the 1st aperture; 5: dipole 2 light including mis-steers.

Front End Slits – the First Optics of the Beamline

The Slits Module Assembly is shown in Figure 4. Each slit block is mounted on a motorised stage. A middle bellows assembly connects upstream and downstream slits blocks. By clamping down the central section of the middle bellows to the support frame, the bellows forces exerted on the motion stages are more balanced when the slit blocks move, and the slits can have stable motion.

The slit blocks are made from OFHC copper and are designed using DLS Finite Element Analysis criteria [5]. Four independent 3mm thick slit blades made from Tungsten are fixed to the end faces of the copper blocks forming the aperture. The distance between the pair of slit blades is 858 mm.

Slit Blade Alignments The slit blades alignment is critical for the successful operation of the slits. It is required that the upstream and downstream slit blades are parallel and orthogonal to 10µm in operation. A slits alignment protocol was defined and kinematic mounts were designed for the fine adjustment. Firstly the slit blades are aligned parallel to the travel of their own motion stages. Secondly, the upstream slit blades together with its motion

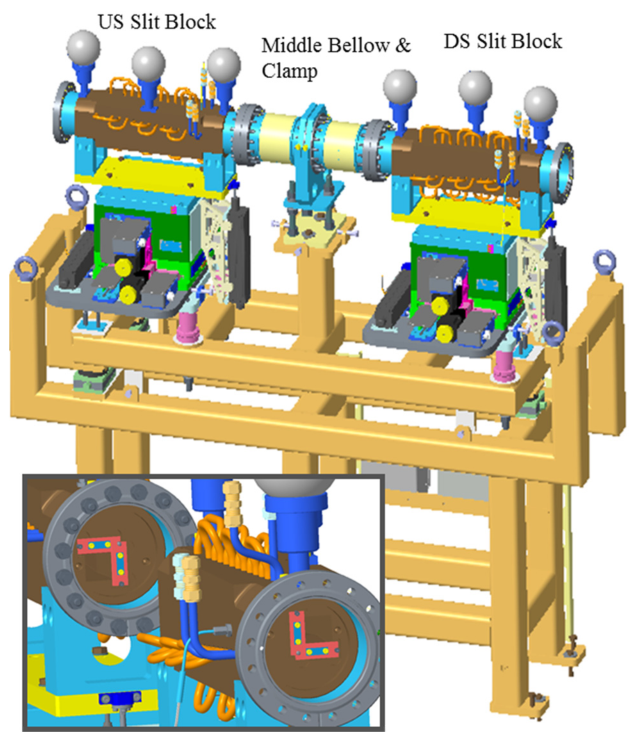

Figure 4: the DIAD front end slits. The detailed view shows the arrangement of the L shaped slit blades. The fabrication design from FMB Berlin [4] is shown here.

stages are aligned parallel to the downstream blades and its motion. It is required to take measurement records of the height between the survey monument and slit blade for the survey reference during the installation in the storage ring.

Slits Motion The motion stage is FMB Berlin YZ Stage 40/40 [4]. DLS traditionally used Renishaw incremental encoders, which demands skilled intervention when resetting is required, often with a significant delay and the risk of introducing inaccuracies. A new linear encoder that has both absolute and incremental outputs is chosen for the slits motion. The encoder is Transformation Measuring Systems (LT-100-PI) from TR Electronic [6]. Its incre-

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mental outputs will be used for normal operation and connected to the Geo Brick LV^{TM} [7] driving the slits motors. The absolute output will be connected to an EPICS IOC supervisory and will be used to update the position record while the stage is static. This allows the monitoring of the absolute position.

Machine Protection There is a need for a machine protection function to prevent slits opening too wide and allowing a damaging amount of radiation into the beamline. This is achieved by fitting Linear Variable Differential Transformers (LVDTs). LVDTs monitor the position independently of the control system and report motion stage position to a PLC that has values set to represent the limits of illumination of downstream equipment with the synchrotron light.

PROJECT CHALLENGES

The front end was identified on the critical path. Successfully delivering the DIAD front end is vital for delivering the beamline project on time. The core challenge was to quickly transform ideas, inputs and previous build experiences into the designs that meet the scientific needs. An understanding of the front end design process will help us to apply methods and tools to manage the project effectively and efficiently.

The DIAD Front End Design and Development is an Innovation Process

The beamline scientists, who are the customers of the project, envisaged to put the first pair of slits for the beamline in the front end. This idea initiated the concept of the DIAD front end. Driven by this scientific requirement and the advancement of technologies, the design and development of the DIAD front end is an innovation process.

The Fuzzy Front End of the Front End Design

In the innovation management literature, Fuzzy Front End ranges from the generation of an idea to either its approval for development or its termination. It has the highest impact on the whole project. In Fuzzy Front End, the degree of freedom in design and influence on project outcomes are high, whereas costs for changes are low [8]. With this understanding, the focus of DIAD front end design process was on managing the Fuzzy Front End phase. Figure 5 illustrates the DIAD front end design process.

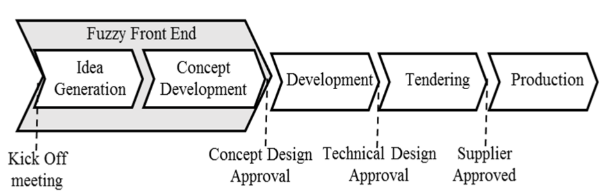

Figure 5: The DIAD front end design process.

Identifying customer needs is a key challenge in the Fuzzy Front End [2]. Focus was aimed at designing a slits module that would become a customer-specified instrument. Beamline scientists were asked about their needs of alignment, commissioning and motion control during operation, and beamline equipment protection. Another important source of input to the concept design is the multi-functional team. The team's past experience and knowledge generate good ideas of a better building of the front end. The needs were then transformed into technical specifications and concept designs were developed. At the end of the concept phase, the DIAD front end had a fully developed General Layout. Core Technical Specifications were defined for the scientific and technical needs. The need to run a separate project for the zero module to decouple tasks was also identified. There wasn't any design change in the development stage of the design process and the project timescales were kept.

CONCLUSION

The DIAD front end design and development is an innovation process. The stage-gate approach with a focus on managing the Fuzzy Front End at initial stage of the process has proved to be successful in managing the DIAD front end project. All the project mile stones in the development stage were met. The front end will be installed in November 2018 and the slits module will be tested after the beamline commissioning in 2019.

ACKNOWLEDGEMENTS

We thank valuable inputs from DLS mechanical team members: M. Small, J. Margerum, A. Martin and B. Greening. Your feedback helps us to design better products.

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