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UPDATED HIGH HEAT LOAD FRONT-ENDS FOR SLS 2.0

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Abstract

The Swiss Light Source (SLS) at the Paul Scherrer Institute (PSI) in Switzerland undergoes from 2021 to 2024 an upgrade named SLS 2.0 to increase brightness and coherence. This upgrade will have a significant impact on the existing front-ends. Due to the proven reliability and good concept, we plan a refurbishment strategy for all front-end (FE) components where possible. New source points for all beam-lines – resulting in shifts both lateral and tangential, newly developed insertion devices and bending magnets as well as spatial restrictions due to the multi bend achromat (MBA) design challenges this strategy. We demonstrate how we plan to deal with these challenges for the case of high heat load FEs. We discuss the design and thermal analysis of a novel primary aperture and high heat load slits, the adaptions that will be made to the tungsten blade x-ray beam positioning monitors (XBPM) and the modifications on the photon shutter will be discussed

PURPOSE OF A FRONT-END

A front-end delivers a synchrotron radiation beam, through the tunnel wall, to the beamlines and end stations in order to perform experiments using said beam. Another important task of the front-end is to securely shut the radiation to allow people to work in downstream areas even if the rest of the beamlines is in operation mode.

Additionally the front-end performs some first beam conditioning. Most importantly the maximum beam size is defined by a diaphragm (or fixed aperture). This helps to reduce the heat load on all downstream elements. Additionally slits define the beam size according to the need of the beamline and downstream optical elements.

FRONT-END STRATEGY FOR SLS 2.0

The front-ends at SLS have proven to be very reliable and low-maintenance during the last two decades. Therefore we plan to reuse some of the existing components after refurbishment for SLS 2.0. All elements will be updated to state of the art motion control and safety standards [1]. However some FE elements need to be completely redesigned. The primary reason for this is the increased heat load on the exposed elements. For hard x-ray FEs, generally associated with high power loads, the power has increased by a factor of three coming from SLS going to SLS 2.0. This is due to the increase in storage ring energy from 2.4 GeV to 2.7 GeV and more powerful insertion devices.

Due to the new lattice all beamlines shift in lateral and longitudinal direction and available FE floor space has been reduced due to the more round storage ring with MBAs (see Fig. 1).

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Because of these reasons all FEs need to be completely removed from the storage ring tunnel and carefully reassembled in dedicated areas during the SLS 2.0 dark time.

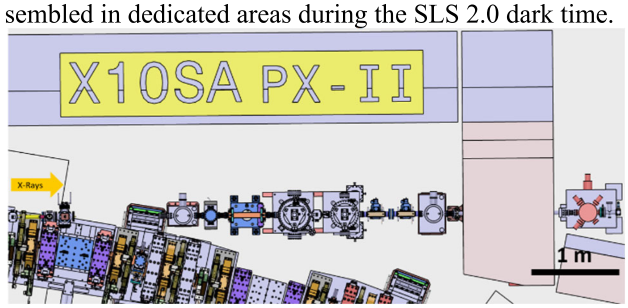

Figure 1: The PX-III front-end in its SLS 2.0 confines.

HIGH HEAT LOAD FRONT END COMPONENTS

The most demanding FEs in terms of thermal management are the hard x-ray FEs (see Fig. 2). In the most extreme case a cryogenically cooled U16 undulator produces up to 10 kW and 56 kW/mrad^2. But also some soft x-ray front ends are equipped with very powerful undulators producing comparable amounts of heat load which needs to be dealt with.

This is why our novel high heat load components are designed for versatility: by adapting only a few computer-aided design (CAD) parameters the same design can be used for different beam sizes to suit the diversity between the different FEs.

Following the most important components of a high heat load FE are outlined.

Tungsten Balde XBPM

Tungsten blade XBPMs (Pos. 1, Fig. 2) will be used to provide a feedback of the beam position to the machine and the beamline. This feedback will be used to optimize the electron-beam stability and serves as a reference for the beamline.

For SLS 2.0 we will reuse the existing tungsten blade monitors (W-XBPM). In order to use the W-XBPMs with the new beam parameters we developed a python script to calculate the response function of tungsten i.e. the probability of a photon emitting an electron from a tungsten blade and thus generating a signal using Eq. (1).

$$Y = \int_{30\,eV}^{30\,keV} F^{'}(E) \cdot BW \cdot \sigma_{ph}(E)\, dE \qquad (1)$$

Where Y is the tungsten response function $F^{'}(E)$ is the flux density per energy [ph/s/mrad^2/0.1BW], BW the band width and σ_{ph}(E) the photoelectric cross section.

The result is then plotted together with the power density and the blades are then manually adjusted in order to maximize the signal and minimize the heat exposure (see Fig. 3). We will then physically adapt the position of each blade for SLS 2.0 according to these findings.

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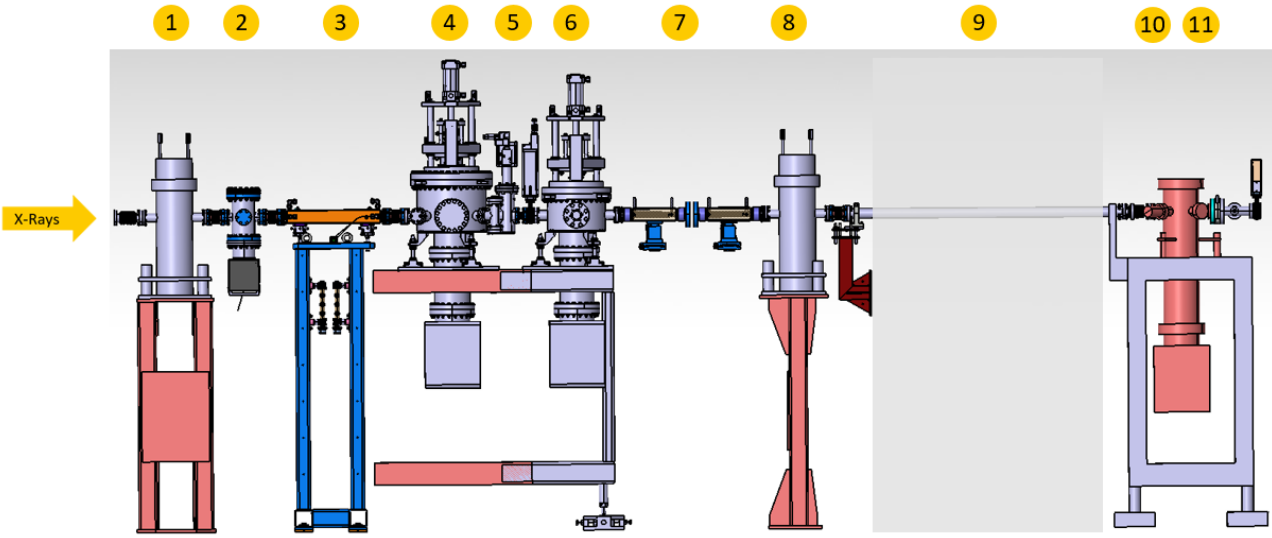

Figure 2: Typical component layout of a hard x-ray front-end at SLS 2.0. Labels: 1. 1st XBPM, 2. pump stand, 3 high-power diaphragm, 4. photon shutter, 5. fast- and gate valve, 6. beam stopper, 7. high power slits, 8. 2nd XBPM, 9. tunnel wall, 10. pump stand, 11. CVD window, arrow labelled X-Rays: propagation direction of the synchrotron radiation.

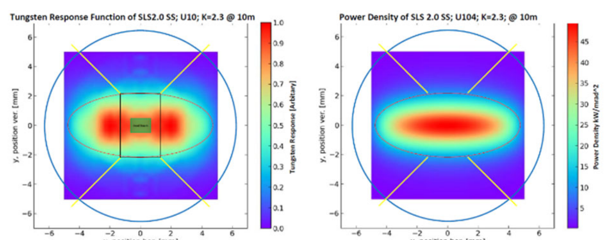

Figure 3: Example of the plots used to adjust the positions of the tungsten blades in the W-XBPMs. Left: tungsten response function plot. Right: power density plot.

New High Power Diaphragm

The new high power diaphragm (Pos. 3, Fig. 2) is a heavily water cooled (18 l/min) beam-defining fixed aperture. It will be completely rebuilt for most beamlines and consist of two copper parts brazed together (see Fig. 4).

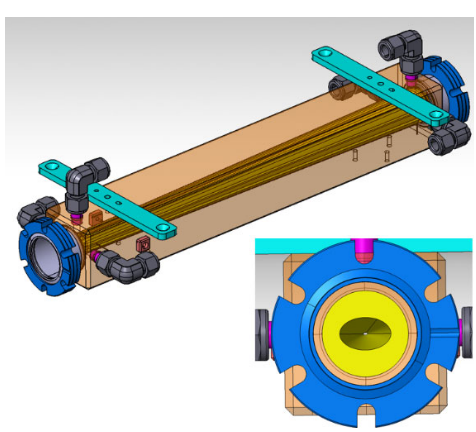

Figure 4: High power diaphragm. Insert bottom: cornerless entrance and exit window.

This innovative design allows us to optimize the cooling to deal with the increased power load of SLS 2.0. The inner part, exposed to the heat load, forms 12 coaxial cooling channels. These cooling channels follow the tapering of the exposed surfaces to minimize the distance between the heat and the water and therefore optimize the heat flow from the exposed surface to the cooling water over the whole length of the device. Additionally the water inlet, with the coolest water, is at the narrowest part of the diaphragm i.e. the part where the most heat is absorbed. The outer part of the diaphragm closes the cooling channels as a sleeve and holds all the connectors, flanges et cetera.

The surface which is directly exposed to the synchrotron beam, formed by wire erosion, is designed in such a way that no corners are directly exposed to the beam in order to avoid corner stresses.

We performed finite element analyses FEA using ANSYS CFX in combination with ANSYS Mechanical and found that we are well below our design criteria even with a safety margin of 40 %.

Photon Shutter and Beam Stopper

The primary safety element in an insertion device FE is a combination of a photon shutter and beam stopper (see Fig. 5). The photon shutter (Pos. 4, Fig. 2) is water cooled and absorbs the synchrotron radiation whereas the beam stopper (Pos. 6, Fig. 2) consist of a 180 mm long Inermet-IT180 block and stops the high power radiation such as the gas Bremsstrahlung.

For SLS 2.0 we plan to reuse the existing components. We will replace the bellows with new ones, the end switches will be replaced with new and certified safety end switches and we will install a fall through protection i.e. if any of the mechanical supports would beak the photon shutter and the beam stopper will remain inside the beam. Additionally we will replace the pneumatic components with the latest versions and we will generally refurbish the devices thoroughly.

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We also performed FEA for the photon shutter and found that we are below our design criteria.

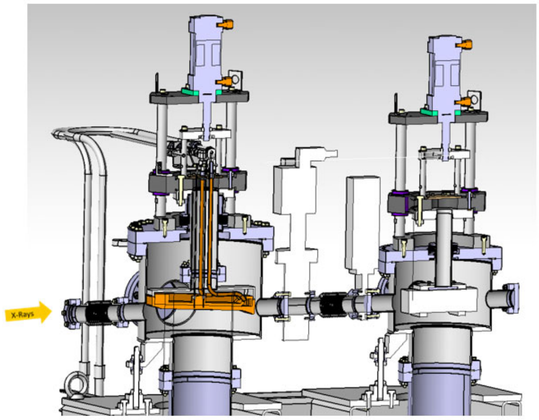

Figure 5: Cut through photon shutter (left) and beam stopper (right) with fast- and gate valve in between.

New High Power Slits

The purpose of the FE slits (Pos. 7, Fig. 2) is to reduce the beam size and to scan the beam with a small aperture to obtain the beam position.

At SLS most slits where built in the blade or shovel style i.e. four different blades where independently moved in and out of the beam. This design requires a vacuum chamber and occupies a lot of floor space. For SLS 2.0 we designed a new set of slits (see Fig. 6) which uses the L-Slit principle where each of the two elements is able to cut the beam in horizontal and vertical direction. The first element cuts the Down and Ring part of the beam while the second element cuts the Up and Wall part.

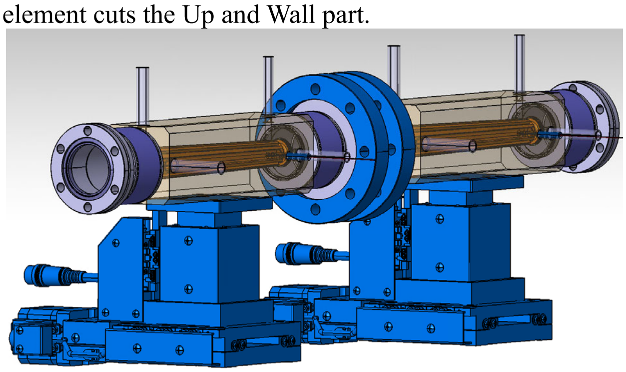

Figure 6: Draft of the new high power slits (design to be finished).

The new design has several advantages over the old blade slits design. Since the vacuum chamber is an integral part of the slits, the design is more compact and occupies less floor space.

In the conventional design the motors where placed outside of the vacuum chamber guiding the motion through a set of bellows and linkages over several dozens of centimetres to the beam cutting surface. This reduces the mechanical stability of the blade. With the new design we can apply the motion more direct and design for stiffness.

In the case of high power slits an additional advantage comes to play: using the design principle of the high power diaphragm we can build slits with small tapering angles at the beam exposed surfaces and with excellent cooling. This allows to deal with the high power and high power densities at SLS 2.0 and improves the thermal stability of the slits.

Tunnel Wall Break Through

Due to the shifts of the source points and the beam lines it will no longer be possible to reuse the existing filler elements of the tunnel wall break through.

We therefore plan to cast the tunnel wall break through in a single concrete block of the same density as the surrounding concrete (4.5 t/m^3) (see Fig. 7).

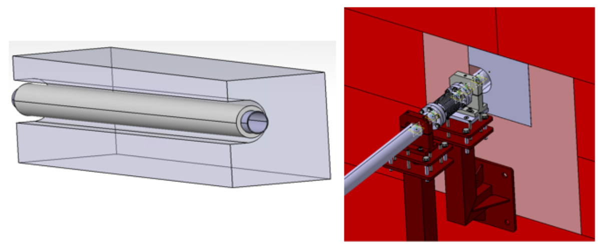

Figure 7: Tunnel wall break through. Left casted mono block concrete filler with beam tube (surrounded with insulation for bake out). Right: Situation.

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REFERENCES

[1] D. M. Just, C. Pradervand, P. Willmott, "Front-Ends", in SLS 2.0 Technical Design Report TDR, to be published.