Report

Specifications

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Technical Specification PDF Beamline Beam Transport System at NSLS II

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Revisions/History

rev.	Sec./Abschnitt	Changes/Änderungen	Date Datum	Sign Kürzel
0	all	1st issue	29.11.2016	cve
1		Changes resulting from PDR included Removed PDR Open Issues List Section 2: - added hutch wall positions provided by BSA - added surveyed floor heights provided by BSA - added section 2.1 listing PDR modifications Section 3 - added section 3.4 listing PDR modifications Section 4 - - added addition 2nd "circle axes to table 4.1 - added section 4.8 listing PDR modifications Section 5 - added section 5.8 listing PDR modifications Section 6 - added section 6.8 listing PDR modifications	22.12.2016	cve
2	all	Updated specifications based on final design Implemented all PDR changes	03.01.2017	cve
3	all	Added modifications needed to be implemented after the FDR	20.03.2017	cve
4	4.7 5.1	Changed telescoping pipe wall thickness to 3 mm Updated design of the bridge to include modifications implemented during in the fabrication drawings	25.07.2017	cve

Content

1 Introduction

This document details the design and specifications of the components of the Beam Transport System (BTS) of the 28-ID-1 PDF beamline at NSLS2. In addition to outlining the overall component setup details of each sub-system and relevant specifications are presented.

The scope of supply of the BTS includes the following subcomponents:

A-hutch: Beam transport including pipes, bellows, crosses, valves and support stands starting at (but not including) the downstream flange of the white beam stop to the upstream entrance flange of the PDF VFM vacuum chamber.

A-hutch: Beam transport including pipes, bellows, crosses, pumps, gauges, valves and support stands starting at the downstream exit flange of the PDF VFM vacuum chamber to the Beam Diagnostic Module (BDM)

A-hutch The BDM including a 4-blade monochromatic slit system and a visualization screen housed in crosses and mounted on a rigid support

A-hutch: Beam transport including pipes, bellows and valves starting at the downstream flange of the BDM to the upstream entrance flange of the photon shutter vacuum chamber.

A-B hutch transport: Bellows, gate valve and lead shielded pipe and supports to transport the beam from the A hutch to the B hutch

B hutch: Beam transport including pipes, bellows, crosses, pumps, gauges, valves starting at the downstream flange of the lead shielded pipe to the Be window on the Optics Conditioning Module (OCM)

B hutch: The OCM comprising of a fast shutter and 4-blade monochromatic slit assembly housed in crosses, a laser/monitor system (LSR/MON) for aligning and monitoring the beam intensity, an Energy Calibration System (ECS) interchangeable with a retractable He-filled flight path. The OCM sits on a 3-axis table to position the components at the two different beam modes (unreflected and reflected beam).

B-hutch: A “Bridge” which will carry stages to be used to position two area detectors (not included) and a sample environment along the beam at distances of ~300 to ~4200 mm from the sample positions (48000 mm from source).

This document provides the design, specification and scope of supply details of the above subcomponents.

As details of the design and specifications are changed following discussions with BSA, new revisions of this document will be issued with the changes documented in the revision table provided at the start of this document.

Several appendices are also provided to this document for additional reference.

2 Beamline setup

The beamline setup provides the positions and lengths of the components included in the scope of supply.

The information is provided as a separate document Rp-2145-1020-2 (beamline setup table).

Furthermore components specific details are given such as type of support, vacuum section, flange size, and height of beam at the components center (for both cases, mirror in (reflected) and mirror out (unreflected). Also included are the pump and gauge types.

To determine the positions and lengths of the beam pipes, the following positions are taken as fixed. These values have been provided by BNL. Changes to these positions will affect changes to the beam transport components and cause delays and potentially incur additional cost.

table 2.1 – Listing of the fixed positions provided by BSA

Component positions and lengths

Fixed point	Distance from source along XPD [mm]	Component flange-to-flange distance [mm]
Middle of SBM reflecting surface	35688.9	
Downstream CF-63 flange of the WB stop	37103.0	
Middle of VFM reflecting surface	38800.4	1850
Middle of photon shutter	43368.9	300
Distance between ECS center wrt sample position at 48000 mm		~800

The interface to the upstream XPD components is at the downstream CF63 flange of the white beam stop (WBS) at 37103.0 mm. BNL has requested that the first pumping cross after the WBS be a CF100 cross, therefore prior to this cross an CF63-CF100 adapter is mounted,

As the BTS components between the PDF VFM mirror and the OCM are not moveable in vertical direction, the flange size and thus the free ID of the components is CF100 (ID of 100 mm). That leaves sufficient clearance for the beam to the pipe walls when changing between mirror in and mirror out. The BDM components (slits and diagnostics) have sufficient vertical stroke to let pass the undeflected as well as the deflected beam from the mirror system.

Please refer to the geometric ray tracings provided together with the 3D model and drawings.

In the next sections, details are provided on the BTS sections 1 to 3, BDM, OCM, and bridge. A final section provides the details on the interconnecting vacuum components and shielded beam pipe.

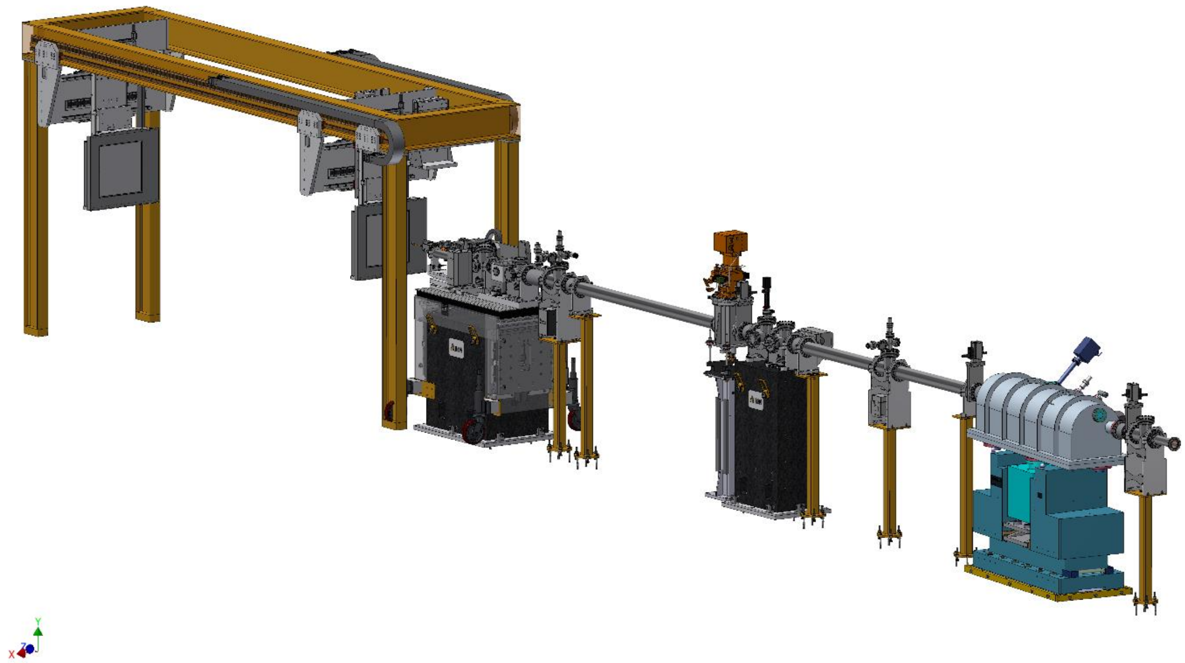


Figure 2.1 – View on the final layout of PDF BTS components

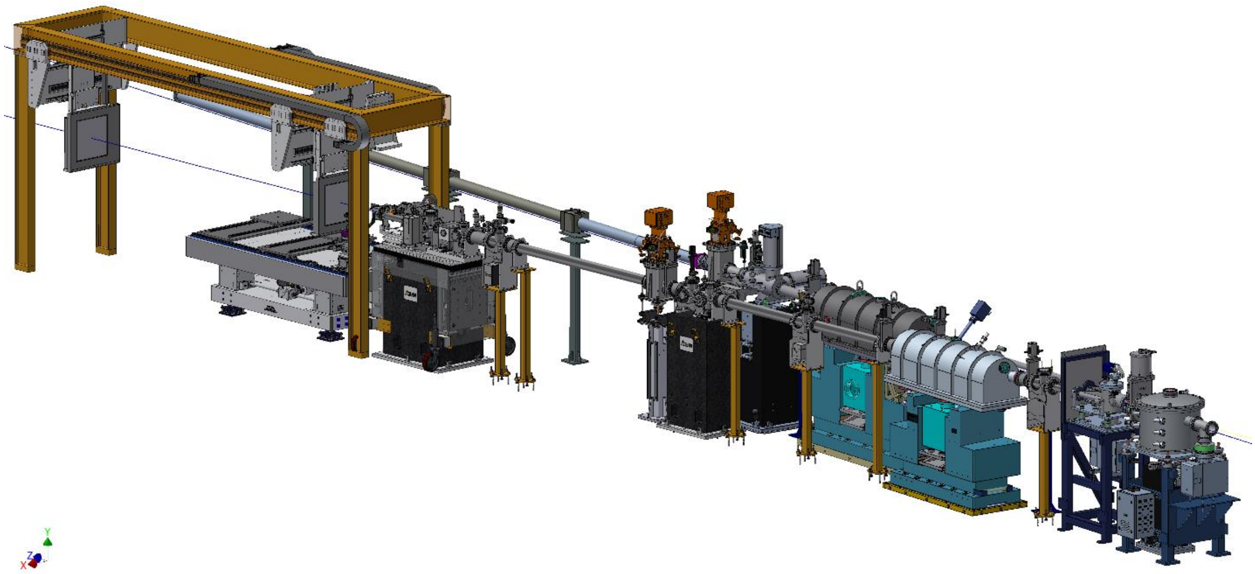


Figure 2.2 – View on the final layout of PDF BTS components together with the PDF components

2.1 General issues FDR modifications

1) Switch the positions of the bellows and the gate valve in vacuum section BTS2 section between the BDM and the PS. ☒, see Rp-2145-1020-2

3 Beam Diagnostic Module (BDM)

The BDM is being supported by a monolithic granite support structure. It is built up from the main sub-assembly groups being described in detail in the following paragraphs:

- granite support structure with manual adjustments
- 4-blade monochromatic slit system
- Diagnostic module with retractable visualization screen

The weight of the BDM is < 900 kg so that it can also be installed using the hutch crane. The granite will also be provided with the mounting interface for standard casters.

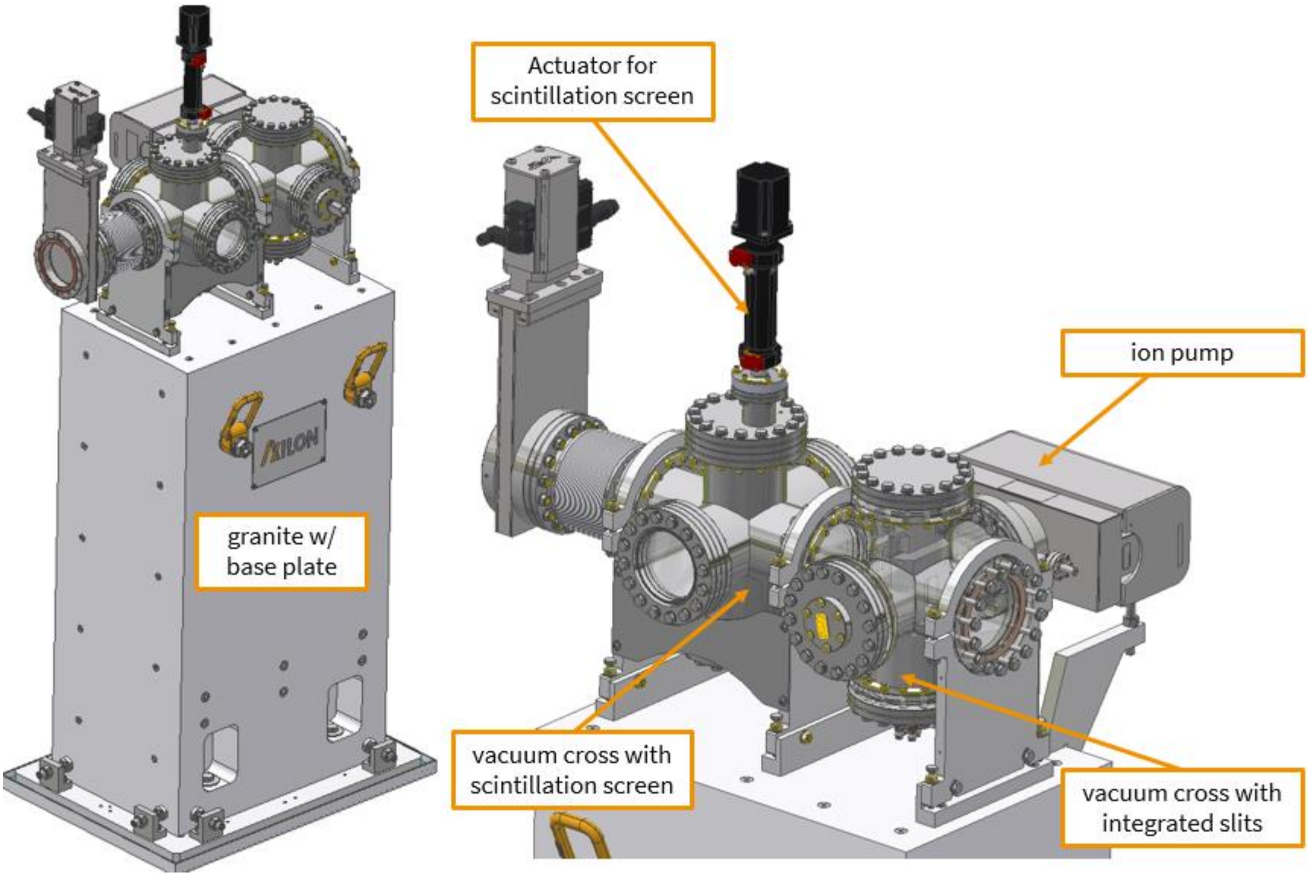


Figure 3.1 – Schematic view of entire BDM.

The motion parameters of slits and diagnostic module are summarized in the following table.

table 3.1 – Summary of all BDM adjustment units (manual and motorized):

axis	type	stroke	mech. resolution[1]	mech. repeatability (uni-dir.)	encoded
adjustments of support *(for accurate pre-alignment positioning of mechanics)*					
horizontal **x, z**	manual	± 10 mm	0.05 mm	n/a	no
vertical **y**	manual	± 10 mm[2]	0.05 mm	n/a	no
tilt (**roll, pitch, yaw**)	manual	± 1°	0.01°	n/a	no
slit system					
inboard blade	piezo	± 11 mm	n/a	< 0.5 µm	yes / 1 nm
outboard blade	piezo	± 11 mm	n/a	< 0.5 µm	yes / 1 nm
top blade	piezo	± 21 mm	n/a	< 0.5 µm	yes / 1 nm
bottom blade	piezo	± 21 mm	n/a	< 0.5 µm	yes / 1 nm
res. slit opening (h x v)		-0.5 x -0.5 to 21 x 41 mm²			
diagnostic module					
YAG + reflective foil holder	stepper	± 50 mm	< 5 µm	< 10 µm	no

3.1 Support Table

The BDM mechanics, i.e. slits and diagnostics, are supported by a monolithic natural granite. In order to provide sufficient stability the dimensions of the granite are slightly larger than the footprint of the two vacuum crosses for the slits and the diagnostics. Furthermore, no weakening large cut-outs are introduced, i.e. the granite is basically a large monolithic cuboid with simplified shape reducing possible amplifications of ground excitations to the BDM mechanics.

The granite itself is rigidly fixed to a base plate acting as accurate and flat reference surface for the granite. The base plate is aligned with reference to the nominal beam height (fiducial points, Ø6^{H7} holes, are integrated to the base plates for precise alignment with a laser tracker) and then grouted to the floor compensating height deviations and waviness of the floor of up to ±12.5 mm over 1 m² (refer to the Interface Document Rp-2144-1020-1). Pushers attached on all sides allow accurate adjustment of the entire granite support in x, z, and yaw direction.

The CF100 crosses are supported with rigid 16 mm thick stands which are additionally stiffened in the in-beam direction with 2mm thick cross plates.

[1] typically assuming full step resolution
[2] Should be precisely set via the grouted base plate

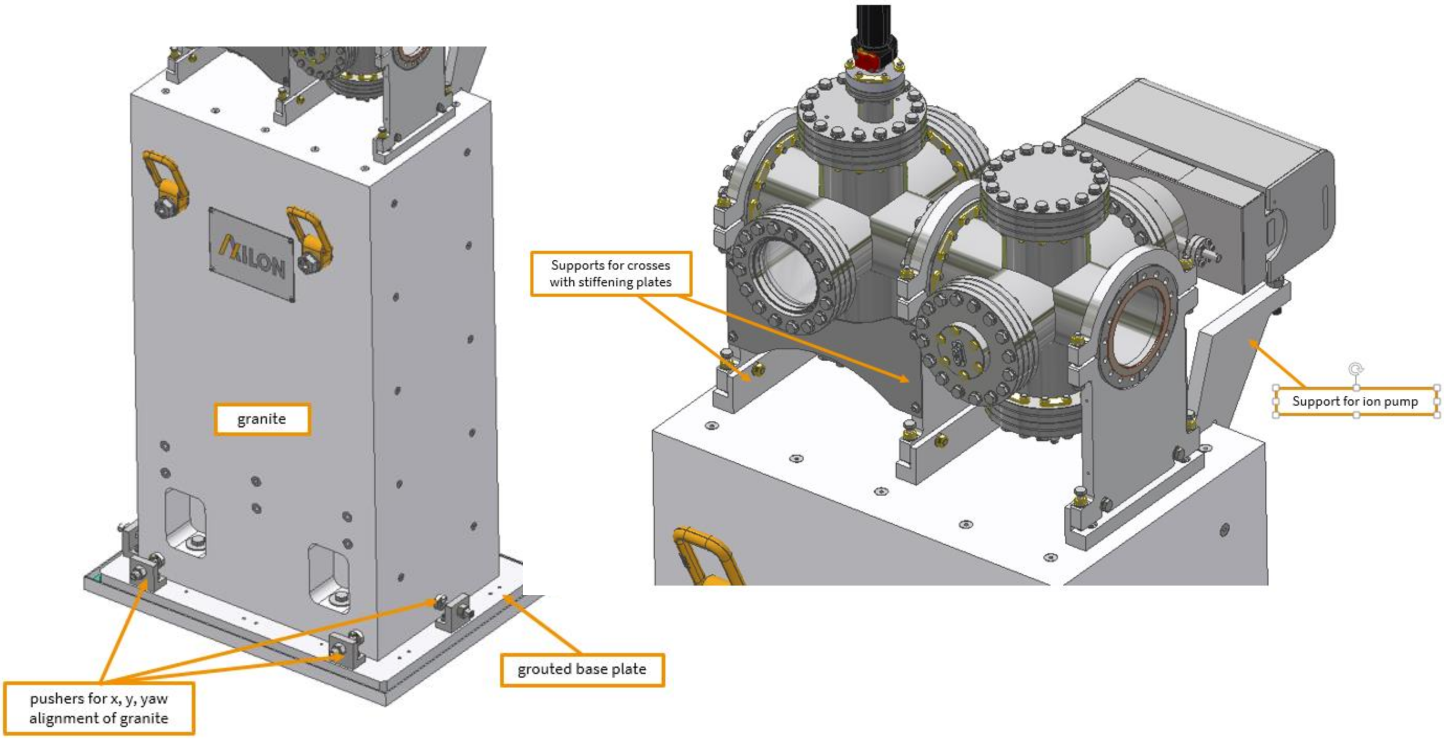


Figure 3.2 Left: BDM granite support table. Right: supports for the crosses and pump

3.2 Slit System

Part of the BDM is a UHV in-vacuum high precision slit system to define the size of the monochromatic beam. The entire mechanics are mounted to a standard CF100 / 6" vacuum cross, thus the design of the slits is extremely compact and does not interfere with the inboard components of the XPD beamline. The electrical connections are provided at feedthroughs at the bottom (connections to the SmarAct controller and sensor modules) and the outboard side (photocurrents).

3.2.1 In-vacuum mechanics of the slit units

The slit assembly comprises a monolithic Al support base, directly mounted to the bottom CF100/6" flange of the cross and carrying both the vertical and the horizontal blade mechanics.

Piezo crawler stages from SmarAct with suitable travel ranges are mounted to this Al support base as shown above. The Al support provides an aperture with sufficient clearance to let pass through the maximum monochromatic beam for all operating modes. This also considers the mirror reflected and unreflected modes where a vertical shift of the beam applies according to the specified deflection angle of the mirror of 2.1 mrad. The stroke of the vertical slits is extended accordingly. A 1 mm tungsten plate mounted to the upstream side of the Al support shields the slit mechanics against damage from the high energy x-rays.

Each individual slit sub-assembly as well as the entire unit is designed in such a way, that the blades can overlap and do not run into each other on their knife edges. With that a fully closed slit is achieved with an overlap of > 0.5 mm for all blades.

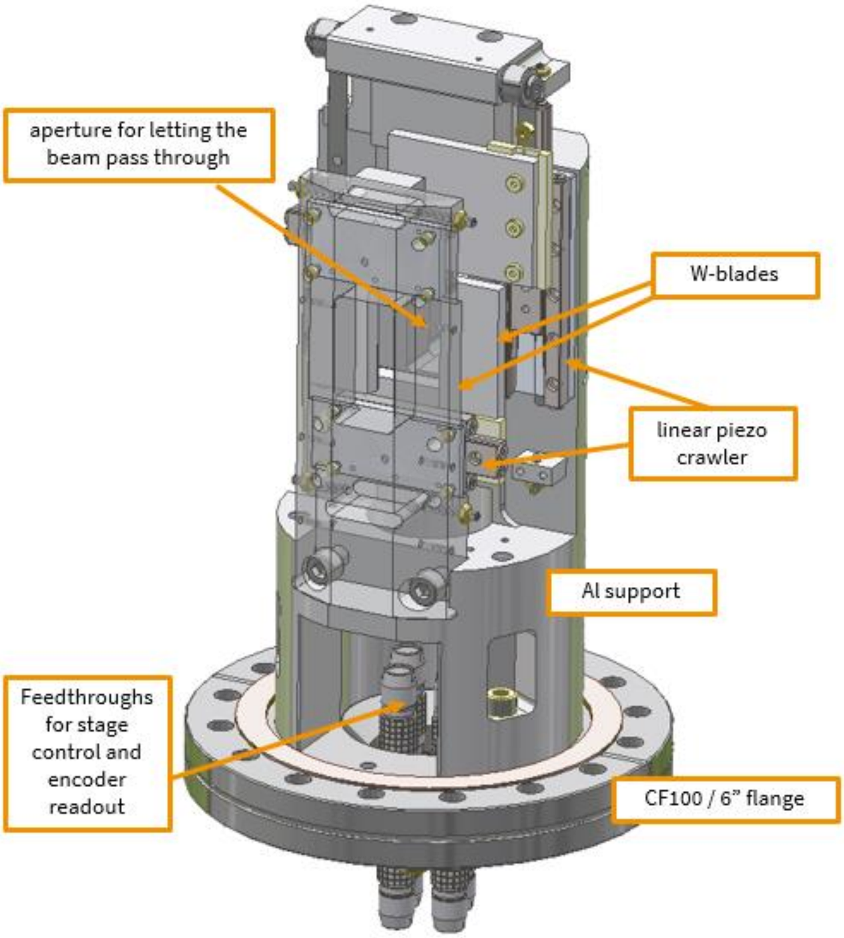


Figure 3.3 – Schematic view of the slit system which is mounted directly to the bottom flange of the cross (the vacuum cross is not shown)

The 5 mm thick tungsten blades are dimensioned to fully intercept and block the beam at all working conditions. Each blade is specially machined and polished on the beam defining side to give a knife edge. During mounting all four blades are aligned to each other to ensure perpendicularity as well as parallelism. To compensate for the weight of the tungsten slit blades, constant force springs are mounted which support the movement of vertical stages.

The slit system also provides the capability of monitoring the induced photo current when the beam hits the blades. Hence, each blade is electrically isolated from the mechanics by using PEEK (or similar) as material for the holder between piezo crawler and blade itself. The blade is wired and the cable is routed to a subD9 connector on the outboard CF100 / 6" flange and ends in. Read-out of the photo current can be realized with a 4-channel high resolution current amplifier from Caenels, type TetrAMM[3], being part of the scope.

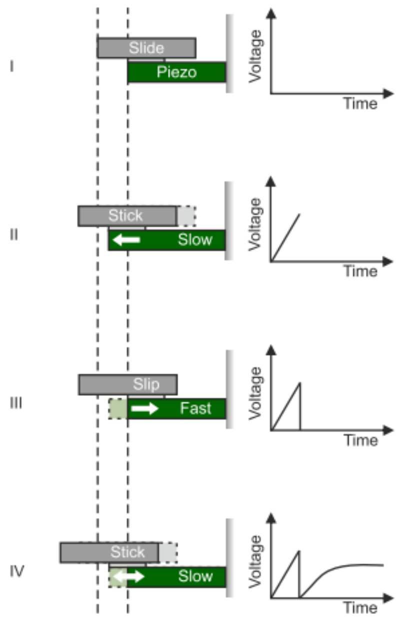
table 3.2 – Monochromatic slit parameters

	Parameter
Blade material	Tungsten
Blade thickness	5 mm
Blade geometry	0.2 to 0.5 deg knife-edge without flat surface
Slit opening dimensions	-0.5 x -0.5 to 21 x 41 mm^2
Vertical actuators	Smaract SLC2475
Horizontal stages	Smaract SLC2445
Stage controllers	Smaract MCS-6CC-ETHA-TAB
Controller connectors (FOE system: ~17 m B-hutch system: ~ 3 m cables from feedthrough to the controllers are provided)	4x Lemo 1B-FGJ-14
Photocurrent readout	Caenels TetrAMM-CI (4-channel)
Photocurrent connector	subD9F to 4xBNC

3.2.2 Piezo crawler stages

As stated above, the actuation of the blades is carried out by piezo crawler stages providing some main features being advantageous:

- They allow for a very compact design due to the miniaturized design of the crawler without any bulky mechanics sticking out of the vacuum vessel.
- Due to the smaller driving forces the crawlers are not sensitive to “crashes”, i.e. when driving into each other the stages are not damaged.
- They provide extremely high resolution in the sub-µ regime, exceeding the given specifications by at least one order of magnitude.
- As no gears are involved in the actuator a backlash free movement can be achieved.



All positioners from SmarAct are available with a patented Stick-Slip drive, enabling macroscopic travel at high velocities. With this technique the positioners can move with sub-nanometer resolution. The basic principle is explained on the right hand side.

To control each piezo crawler the scope of supply includes the according driver units and cables. For easy integration into the overall beamline motion controls we have selected the MCS driver modules from

[3] For details please refer to http://www.caenels.com/products/tetramm/

SmarAct which allow an ASCII based communication via Ethernet. These MCS drivers are already in use at NSLS2 beamlines and have been integrated into EPICS. The MCS controllers are the MCS-6CC-ETHA-TAB table-top models.

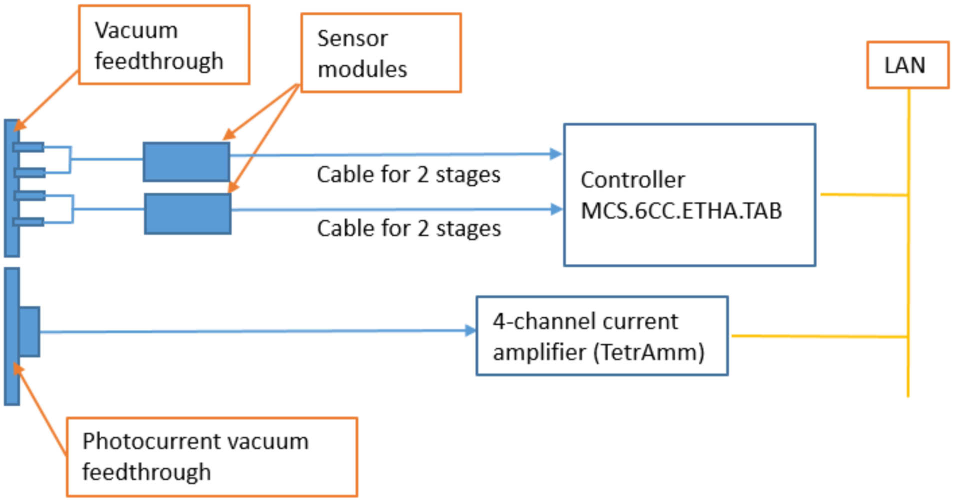


Figure 3.4 – Schematic view of the slit control system for piezo stages and photocurrent readout

The BDM slit controllers will be placed in the A-hutch control rack on the roof of the A-hutch. The cables will be ~ 17 m long to reach from the BDM to the hutch roof (through the labyrinth).

3.3 Visualization Screen

In addition to the slit system, the beam diagnostic module also contains a motorized retractable visualization screen in a second CF100 cross piece (see Figure 3.5). A motorized linear actuator on the top flange is used to insert an assembly into the beam that carries the visualization screen and the glassy carbon foil. The visualization screen will be placed at 45 deg to the beam so that it's 1:1 image is imaged by a camera placed at 90 deg to the beam.

The UHV compatible linear actuator is stepper motor driven with a reproducibility better than 10 µm. Precision limit switches allow referencing of the position with the required 50 µm accuracy. The stroke of 100 mm allows to fully retract the screen/scatterer assembly from the beam.

The beam visualization screen consists of an 1 mm thick plate coated with Y2O3:Eu for luminescence. The imaging screen is placed at 45 deg to the beam and is sensitive at the energy range of 30 to 120 keV. The screen is structured with a centered cross and scale to be used as a reference for the beam position and size.

A ~ 0.2 mm glassy carbon foil placed in the upper holder slot at 45 deg can be used as a uniform amorphous scatterer for later use.

The holder provides an addition mounting frame for additional foils/scatterers/scintillators for future upgrades.

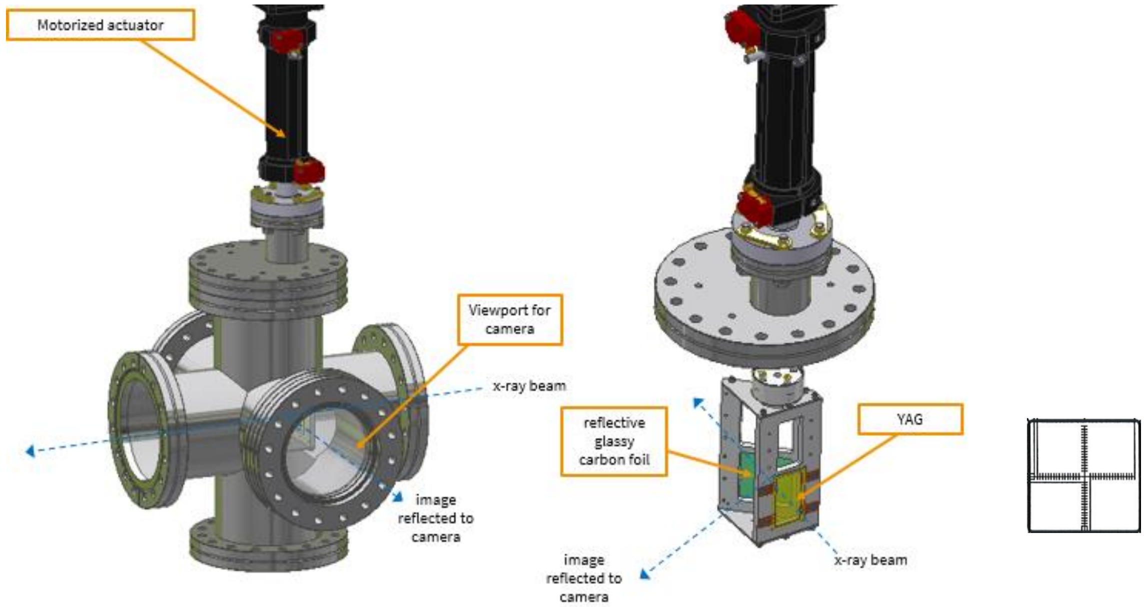


Figure 3.5 – Schematic of the visualization screen. Left: mounted in the cross. Right: detail of the holder geometry *(this figure is to be updated to include the FDR changes)*

table 3.3 – visualization screen parameters

	Parameter
scintillator	Y2O3:Eu coated 1 mm Al plate
scatterer	0.2 mm glassy carbon foil
scintillator/foil actuator	stepper-driven

3.4 BDM FDR Modifications

1) Visualization screen (Y2O3:Eu on 1 mm Al plate) to be placed at 45 deg to beam. Scale division √2 to obtain 1:1 image at camera placed at 90 deg. ☒
2) Glassy carbon foil to be moved to upper holder position for use as intensity monitor scatterer. . ☒

4 Optics Conditioning Module (OCM)

The components of the OCM are mounted and rigidly fixed to a standard bread board. This allows high flexibility for possible re-arrangement or upgrades with additional systems on the OCM. The bread board is being supported by a massive granite support structure and two heavy duty jacks allowing adjustments in height and pitch of the entire OCM. The OCM is built up from the main sub-assembly groups being described in detail in the following paragraphs:

- granite support structure incl. heavy duty jacks and bread board as support for the OCM components
- in-vacuum fast shutter
- in-vacuum attenuator
- in-vacuum slit system
- MON/LSR
- ECS
- retractable flight tube

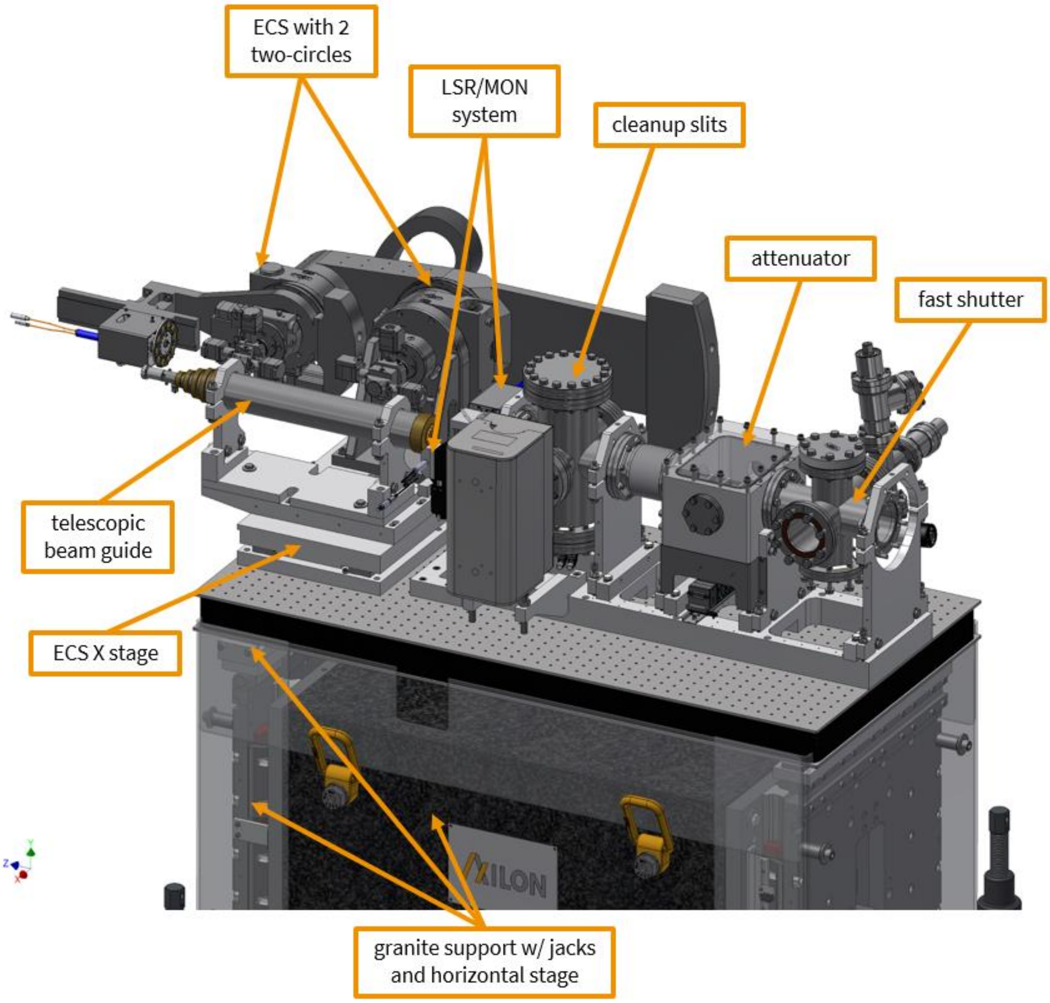


Figure 4.1 – Schematic view of OCM unit with ECS

The motion parameters of OCM components are summarized in the following tables.

table 4.1 – Summary of all adjustment units of the OCS (manual and motorized):

axis	type	stroke	mech. resolution[4]	Uni-dir mech. repeatability	encoded
adjustments of support (for accurate pre-alignment positioning of mechanics)					
horizontal **x, z**	manual	± 10 mm	0.05 mm	n/a	no
vertical **y**	manual	± 10 mm[5]	0.05 mm	n/a	no
tilt (**roll, pitch, yaw**)	manual	± 1°	0.01°	n/a	no
bread board carrying all OCM components					
roll	manual	± 1°	0.01°	n/a	no
upstream jack	stepper	-25 to 85 mm	< 1 µm	< 2 µm	yes / 0.05 µm
downstream jack	stepper	-25 to 85 mm	< 1 µm	< 2 µm	yes / 0.05 µm
pitch (using the 2 jacks)	pseudo	-2 to 6 mrad	< 1 µrad	< 2 µrad	yes / 0.05 µrad
horizontal	stepper	± 30 mm	< 1 µm	< 2 µm	no
slit system					
inboard blade	piezo	± 11 mm	n/a	< 0.5 µm	yes / 1 nm
outboard blade	piezo	± 11 mm	n/a	< 0.5 µm	yes / 1 nm
top blade	piezo	± 11 mm	n/a	< 0.5 µm	yes / 1 nm
bottom blade	piezo	± 11 mm	n/a	< 0.5 µm	yes / 1 nm
res. slit opening (h x v)		-0.5 x -0.5 to 21 x 21 mm²			
mon/lsr					
foil holder, horizontal	stepper	± 10 mm	< 2 µm	< 5 µm	no
laser holder, vertical	stepper	± 10 mm	< 2 µm	< 5 µm	no

[4] typically assuming full step resolution
[5] Should be precisely set via the grouted base plate

axis	type	stroke	mech. resolution[6]	Uni-dir mech. repeatability	encoded
ECS & telescopic beam guide					
common horizontal	stepper	± 50 mm	< 2 µm	< 5 µm	no
ECS1 **θ**	stepper	±180°	< 20"[7]	< 20"	yes / 0.2"
ECS1 2**θ**	stepper	-5 to 150°	< 2"	< 5"	yes / 0.05"
ECS2 **θ**	stepper	±180°	< 20"	< 20"	yes / 0.2"
ECS2 2**θ**	stepper	-25 to +25°	< 2"	< 5"	yes / 0.07"
goniometer head, y	stepper	± 11 mm	< 2 µm	< 5 µm	no
goniometer head, z	stepper	± 11 mm	< 2 µm	< 5 µm	no
goniometer head, Ry	stepper	± 21°	< 2"	< 5"	no
goniometer head, Rz	stepper	± 21°	< 2"	< 5"	no
telescopic beam guide	manual	500 to 2000 mm	< 1 mm	< n/a	no

4.1 Support Table

4.1.1 Granite support

The entire OCM is supported by a massive natural granite. It carries all components including the jack adjustment and horizontal translation units for the table on which the OCM components are mounted to. The use of a granite results in a large and heavy support structure and brings the ground as close as possible to the mechanical system of the components, adds significant weight to the entire support structure and therefore reduces transfer of possible excitations from the ground.

The outer overall dimensions of the granite support is 1156 x 956 x 1374 mm^3 (l x w x h) resulting in a total mass of approx. 1320 kg. The granite support can be moved into the hutch and to its final location in the beamline by means of heavy duty rollers and without the need of a crane.

A base plate acts as an accurate and flat reference surface for the granite. The base plate is aligned with reference to the nominal beam height (fiducial points, Ø6^{H7} holes, are integrated to the base plate for precise alignment with a laser tracker) and then grouted to the floor compensating height deviations of up to ±12.5 mm over 1 m. Pushers attached on all sides allow accurate adjustment of the entire granite support in x, z, and yaw direction. After alignment the granite itself is rigidly fixed to the base plate.

[6] typically assuming full step resolution
[7] The ECS theta stages are not equipped with a gear. However, finer resolution of < 2" can be achieved in µ-stepping.

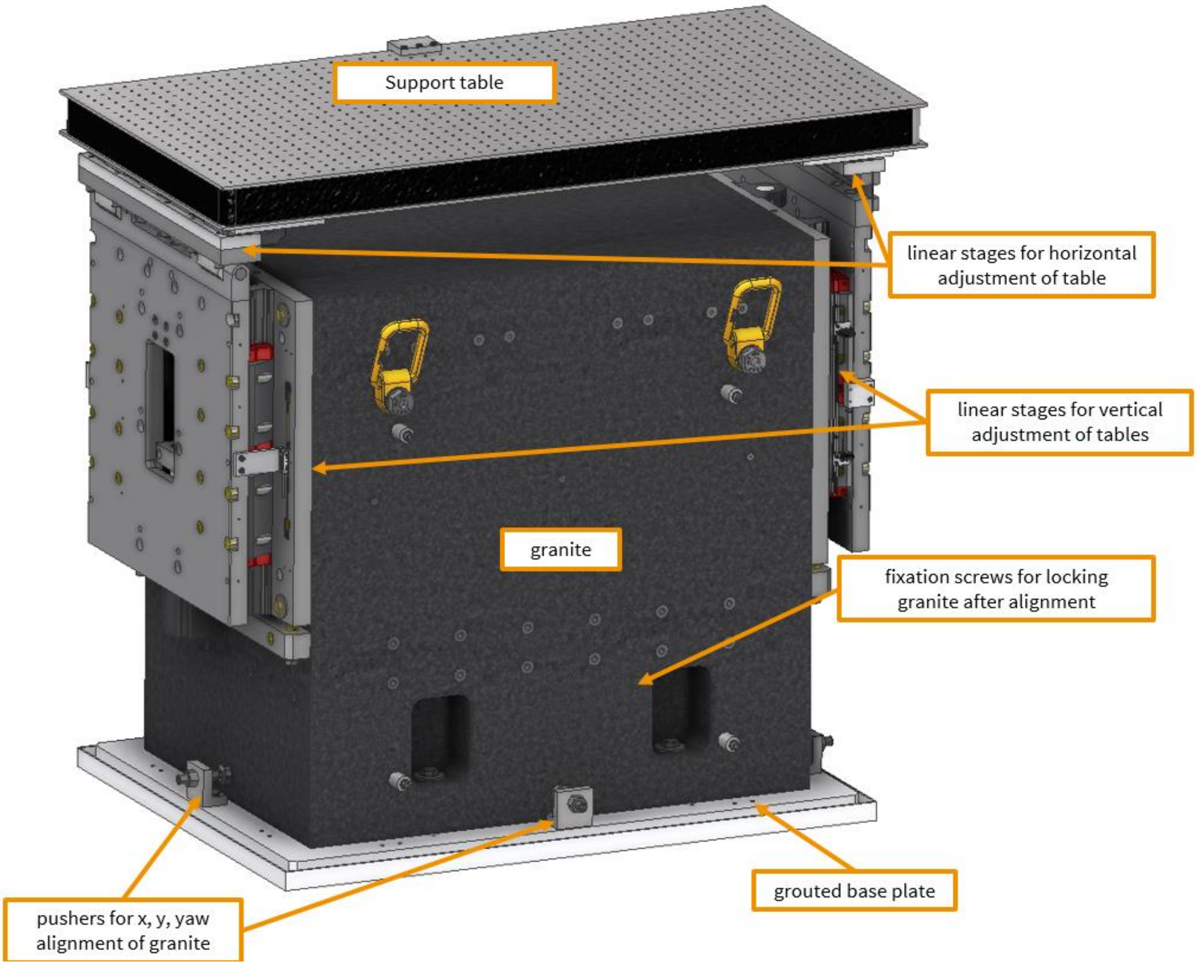


figure 4.2 – 3D view of support structure including the in air adjustment stages for the OCM.

4.1.2 Jack mount for vertical and pitch adjustment of the OCM table

For varying the height and the pitch angle of the OCM table we propose a very rigid and stiff design approach based on two heavy duty jacks mounted to the upstream and downstream of the granite support. These jacks are as wide as the granite upstream and downstream side and therefore provide a very stiff link to the upper mechanics of the OCM. The compensation of linear movement whilst pitching is realized by means of an accordingly designed and sized spring steel metal sheet rather than using a 3-point kinematic mount. That proves to be extremely rigid and has been successfully implemented on similar device being installed at NSLS-II (ISS Harmonic Rejection Mirror at the ISS beamline). Test results demonstrate an angular resolution of < 1 µrad as well as negligible parasitic movements in pitch and roll when moving the two jacks up and down for height adjustment.

Two motorized linear stages allow to adjust the table carrying the OCM in vertical (y) and in pitch direction (around x) in order to manage different operation modes (upstream mirror either in or out) that result in varying incoming beam heights and angles. The translation stages for the vertical jacks are based on precision ball screw driven linear stages equipped with stepper motors and planetary gear boxes (see figure 4.3). Precision preloaded linear slides from Bosch-Rexroth are mounted to the up- and downstream side of the granite. The holding torque and gear ratio are selected to self-lock the stage when no drive or holding current is applied and the system is under full vacuum load taking also vacuum forces from the upstream bellows into account.

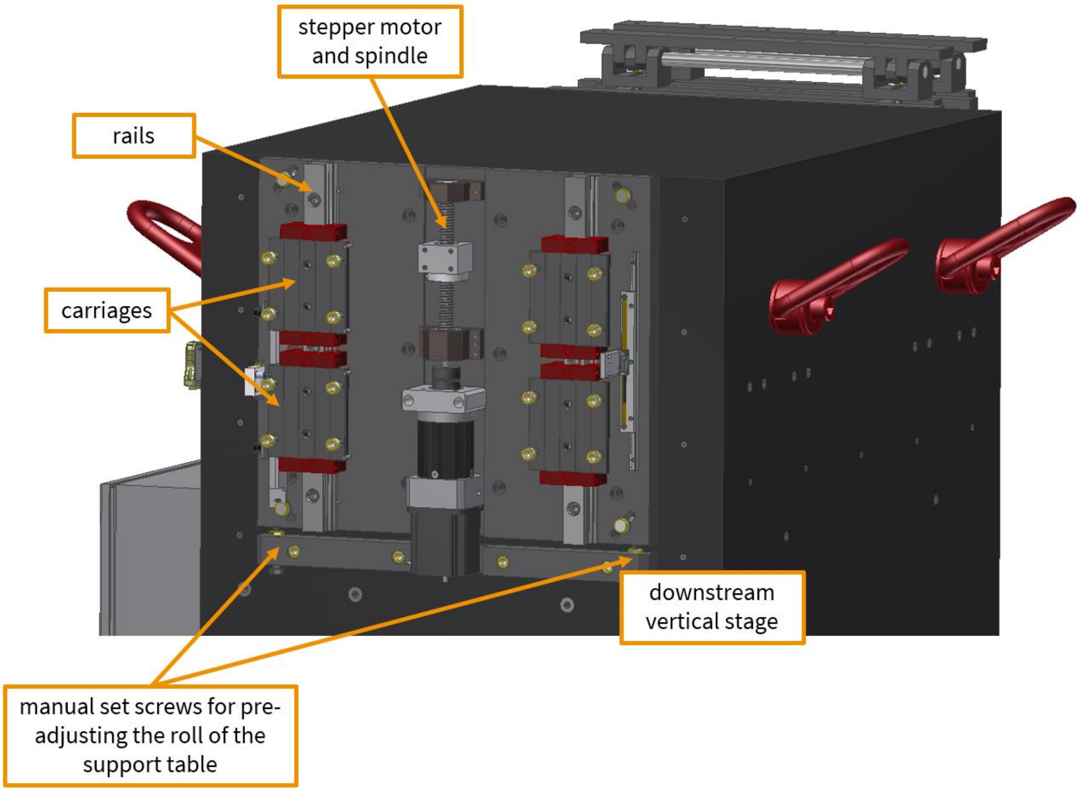


figure 4.3 – Vertical translation stages and manual roll for the OCM.

By moving both jacks simultaneously in the same direction the height of the OCM is varied. The angle can be changed by moving only one of the jacks or both in opposite direction. For that pitch adjustment the moveable plate of the downstream jack is equipped with a precision shaft along the entire width of the jack. Precise bushings linked to the top horizontal translation are fitted to this rigid shaft that allows only for rotation of the table around the x-axis. At the upstream side a metal sheet made from spring steel is mounted to the table allowing for the necessary longitudinal displacement along the beam axis while blocking any movements in the direction perpendicular to the beam.

To limit the pitch angle to that within the mechanical limits, a tilt switch will be mounted which will output a signal to be routed to the EPS and which should trigger a response to cut the motor phase currents (or disable the amplifiers) in case the mechanical limit of pitch angle is reached. The protective response of the control system is to be implemented by BSA. Such a switch was provided with the HRM for the ISS beamline and has been implemented into the controls at this beamline.

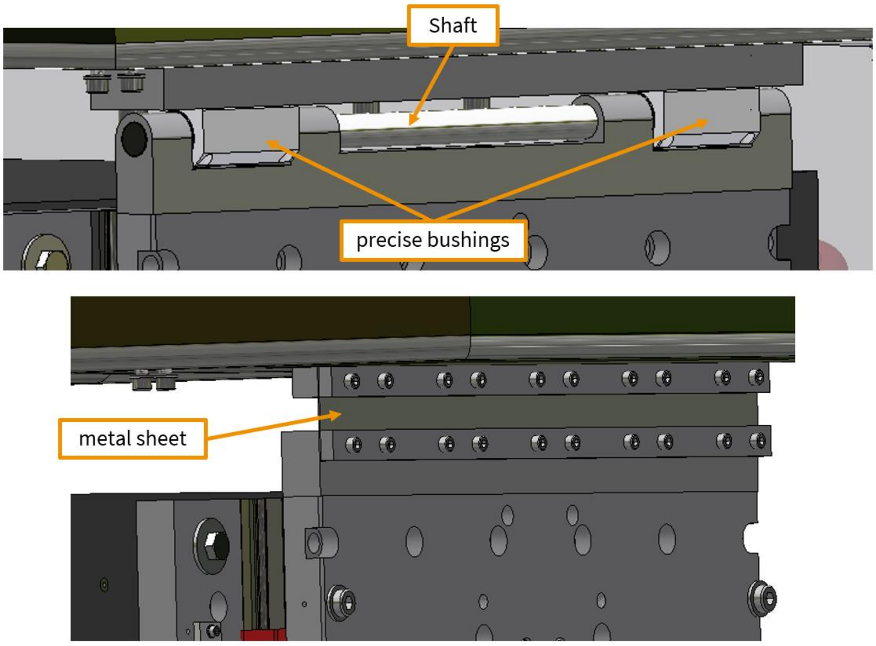


figure 4.4 – Pitch mechanism of vertical jacks.

In order to pre-align the optics table in roll direction each vertical stage can be manually adjusted around the z axis by means of set screws pushing against the outboard/inboard side of the translation stage (see figure 4.3). With that an alignment of ± 5 mrad with a resolution of 0.1 mrad is achieved. This manual adjustment is locked after final alignment.

4.1.3 Horizontal translation of the OCM table

The OCM is equipped with a horizontal translation stage allowing adjustment of the OCM table perpendicular to the beam in x-direction. This horizontal stages is based on two separate adjustment units being directly mounted to the two heavy duty jack mounts up- and downstream of the granite table. These units are built up from Schneeberger minirails with a wide but very low profile. With this design approach the horizontal stage can be made extremely compact in height. The carries of the stages are actuated by means of a preloaded precision ball screw. On the upstream end this ball screw is linked to a standard stepper motor with gear to achieve sufficient resolution and to provide self-locking when no holding current is applied. The actuation of the downstream spindle unit is realized by means of a belt being tensioned between the two spindles with toothed wheels mounted to the ends. This allows for a synchronous movement of both horizontal stages with one motor only. The timing belt is preloaded by means of an according mechanism allowing to apply tension to the belt.

The advantages of this design approach are in particular high compactness and less material usage as one does not need an additional big base plate for the two stages.

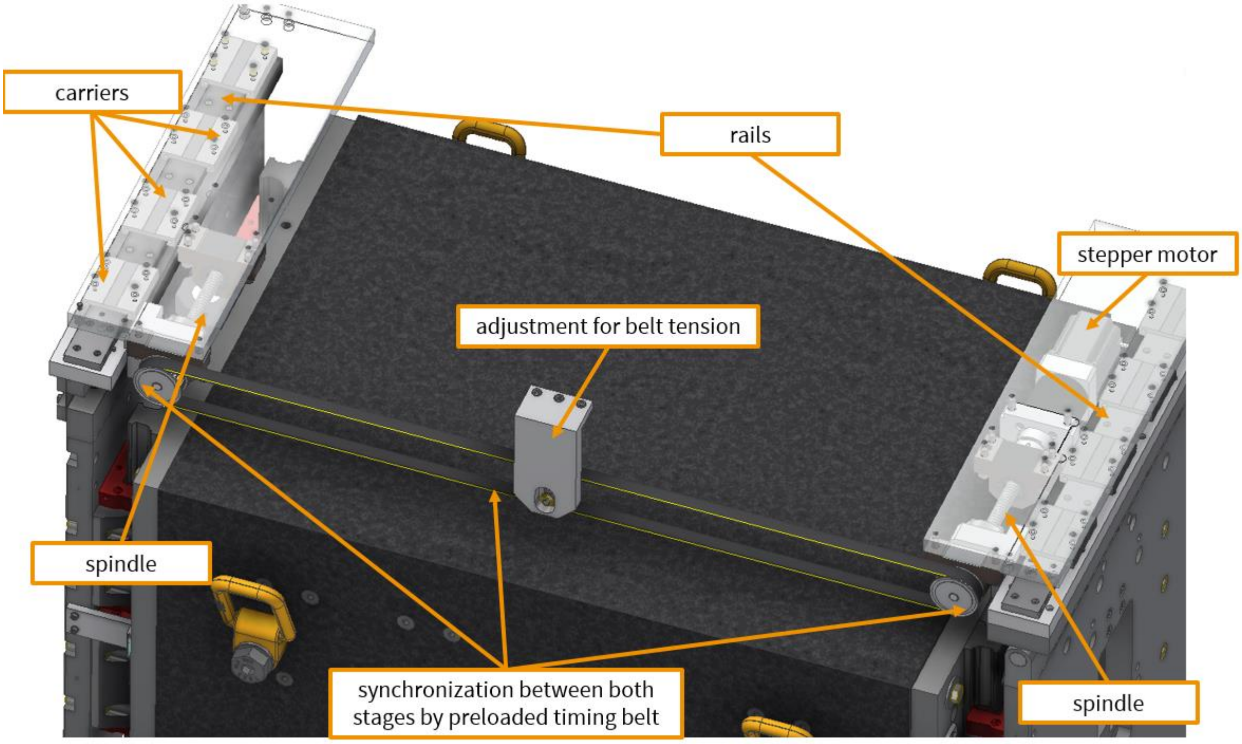


Figure 4.5 – Schematic view of the horizontal translation of the OCM table

4.2 Fast Shutter

The UHV fast x-ray shutter is based on an ESRF development which is in operation at the ESRF beamlines ID14 and ID29 and is characterized by a fast transition time, high reliability and large aperture. The shutter head is mounted to a stepper motor. To open and close the shutter, a 90° rotation is executed. An inductive sensor is provided to home the motor when powered on. The shutter is compatible to < 5x10-7 mbar and is mounted in a standard 6-way CF63 cross with a subD electrical feedthrough. The shutter window will be a 10 x 10 mm aperture. To optimize the opening time (≤ 30 ms) and yet provide enough stopping power for 74 keV x-rays, the thickness of the W blades will be a total of 2.2 mm. This yields a stopping power of ~1e13 at 80 keV.

The shutter will be delivered together with a controller rack which allows 5 functional modes.

1) open and close the shutter triggered by the 5V TTL signal
2) set opening and closing delays individually
3) set an "exposure time"
4) define a duty cycle: set delays to open and close the shutter, set times at which the shutter is open and closed and set the number of cycles to be repeated
5) define a fixed duty cycle frequency of the shutter < 50 Hz.

The modes 2-5 above are set via an Ethernet connection to the driver. The trigger is a 5V TTL signal.
The default position of the shutter (NO or NC) can be set on the driver

The controller is a rack-mountable 2U unit which will be provided with a 10 m cable to connect to the shutter. A communication interface will be provided to integrate the shutter controller into the beamline control system.

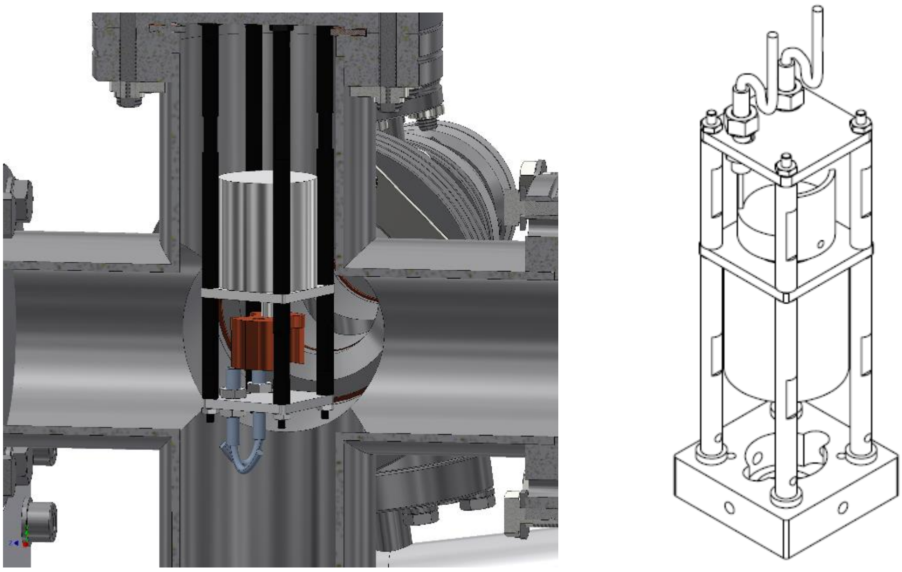


Figure 4.6 – The fast shutter in a standard CF63 cross

4.3 Attenuator

The OCM is equipped with an attenuator unit for reduction of the flux of the monochromatic beam down to the sample. We offer a customized in-vacuum design to meet the base pressure requirements of 1e-7 mbar.

The attenuator is based on selectable foils, housed inside a vacuum chamber allowing to change the foil configuration without breaking the vacuum. There is a total of 4 actuators moving the foils in and out of the beam. Each foil holder can be equipped with foils / plates up to a thickness of 6 mm.

The system is designed to avoid any vacuum feedthroughs for motions, signals or medium. Furthermore no in-vacuum electronics like motors, switches or sensors are required.

Hence, the foils are moved in and out of the beam by magnetically coupled, pneumatically driven stages. We have chosen pneumatically driven actuators instead of stepper driven stages for simplicity and to avoid the need for additional stepper drivers. This furthermore facilitates miniaturization and compactness of the system. The four foil actuators are divided into 2 groups – two inboard and two outboard actuators staggered. The pneumatic actuators are driven by 24 V digital outputs generated by the EPS PLC.

The full system is housed inside a vacuum chamber with a minimized flange-to-flange dimension. The lid of the chamber is sealed with a VITON™ O-ring.

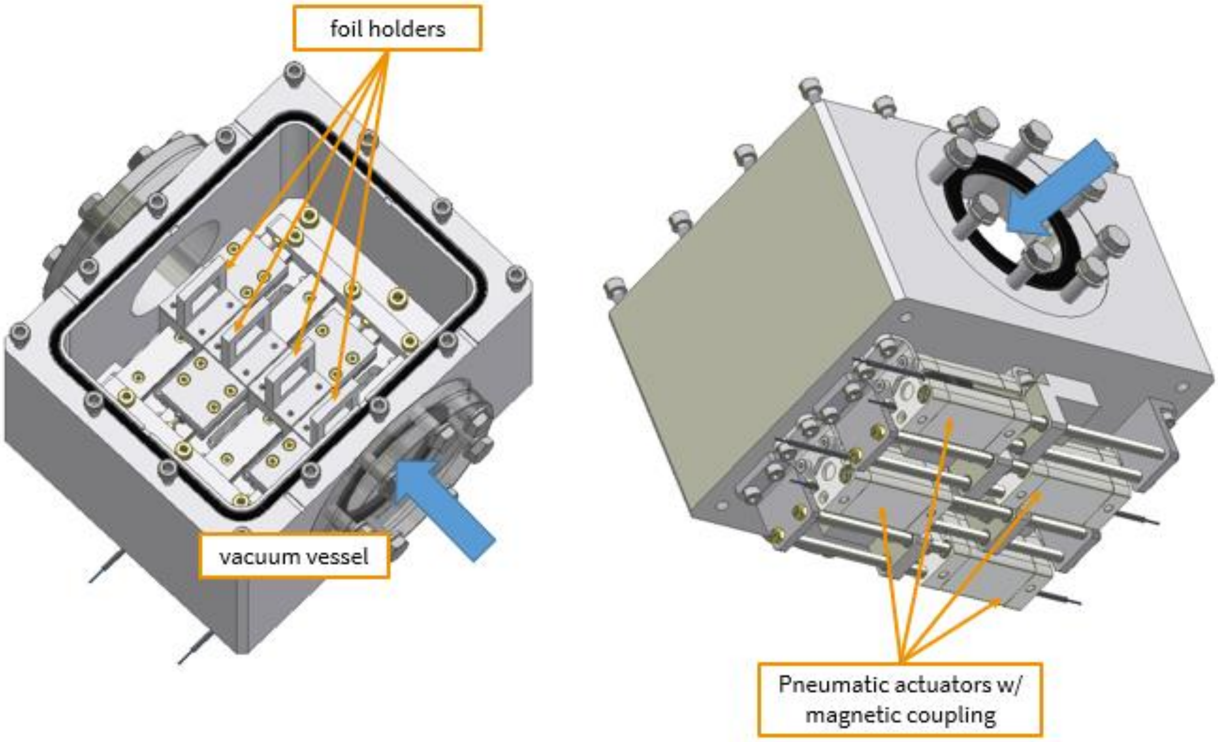


figure 4.7 pneumatically driven 4-foil attenuator unit

Beneath the chamber bottom all 4 pneumatic actuators are mounted staggered in inboard and outboard direction. The pneumatic cylinders push on a guided magnetic coupler comprising three super magnets (NeFeB, 20x10x5mm^3, appr. 1.3T each) and two pole pieces. This magnetic coupler is guided smoothly at a minimum gap to the locally thinned vacuum chamber and interacts with the in-vacuum counter coupler, comprising the similar setup. The magnets are Ni coated and compatible for vacuum purposes. The magnetic coupling is strong enough to pull safely the in-vacuum foil carriage to each limit position.

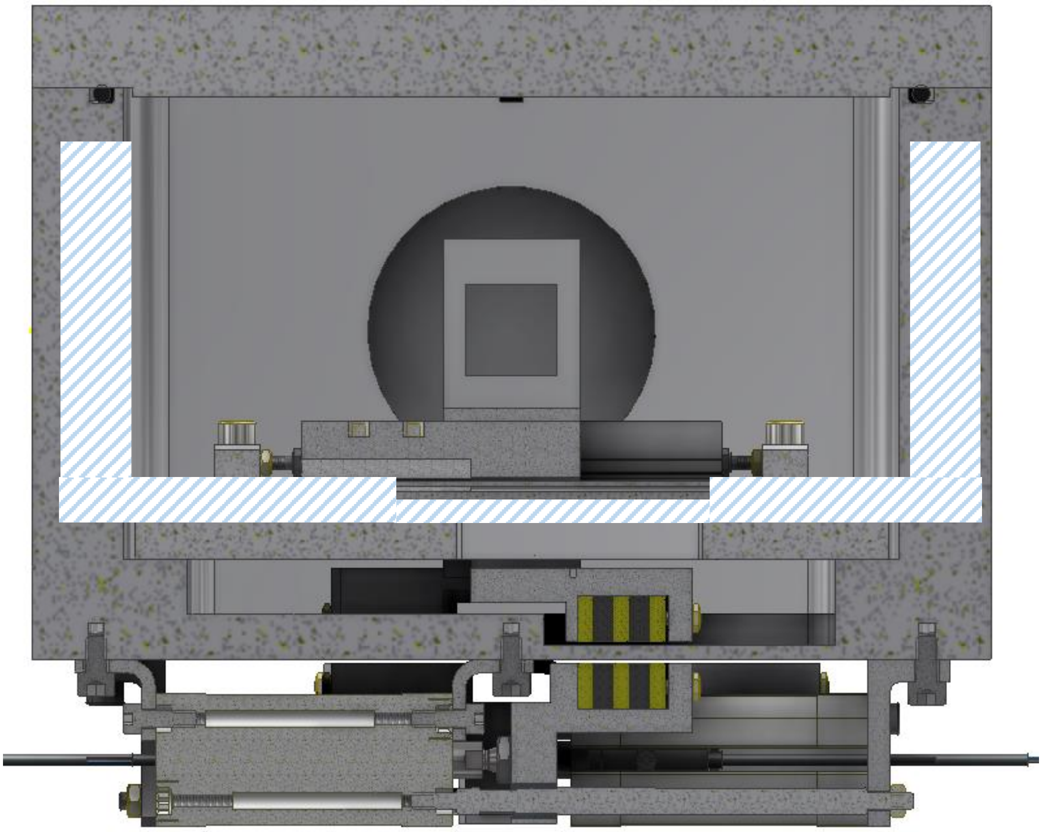


figure 4.8 – Illustration of actuator principle and in-vacuum setup. One foil actuator is shown in it's out of beam position. The stroke of the pneumatic cylinder is 25mm to move to the in-beam position (here: to the right). The magnetic coupling and locally thinned chamber bottom (hatch) can be seen. The guided in air magnetic coupler is shown partially.

The in-vacuum base plate comprises 4 openings for the magnetic coupler assembly to interconnect mechanically to each of the foil carriage assemblies on top of the plate. The foil carriage is based on a milled aluminum part mounted to a Schneeberger high precision linear rail (MiniRail) with two slides. The rail and slides ensure the precise motion from the out- to the in-beam position. The in-beam position is precisely set by an accurate adjusted hard stop and verified during assembly and testing. On top of the foil carriage the holder is mounted comprising a rectangular aperture of 25 x 25 mm². The frame is equipped with 4 threads as mounting interfaces for the BSA foil holders, a final interface drawing will be provided after the FDR.

The in/out positions of the individual foil actuators are indicated and read via reed contacts at the pneumatic cylinders. In the unlikely case of a decoupled magnetic actuator possible malfunctions may be easily observable through the full field transparent chamber lid. A reactivation of the actuator catches then a decoupled carriage and the system is back to work without the need for disassembling or braking vacuum.

The pneumatic valves needed to control the four actuators are compactly located as a valve battery mounted under the attenuator chamber which has one power supply connection. This also means that only one compressed air line needs to be run from the house air supply. Similarly all the reed contact status signals are collected at two subD15 pin connectors are routed to the PLC at the interface box.

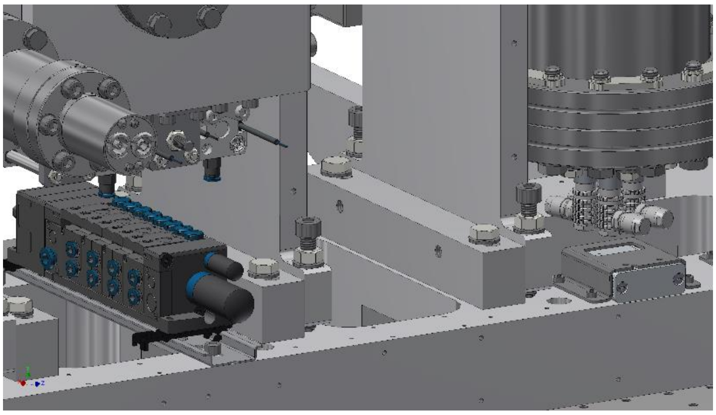


figure 4.9 valve battery showing four 2-way valves placed under the attenuator chamber

4.4 Cleanup Slits

The cleanup slits of the OCM are identical to the slit system of the BDM (besides a restricted motion range), i.e. it is based on piezo crawlers and being integrated into the according vacuum cross of the OCM. As the vacuum requirements regarding the base pressure are less for this OCM section we have selected the HV version of the SmarAct piezo crawlers rather than the UHV version as being provided for the BDM slits. The HV version is still compatible with pressures in the E-07 mbar range.

The OCM slit controllers will be mounted to the upstream side of the interface box. The cables will be short (~ 3 m) to reach from the slit assembly to the controllers. The Caenels TetraAmm will also be mounted to the same panel. Power supplies for both controllers will be provided.

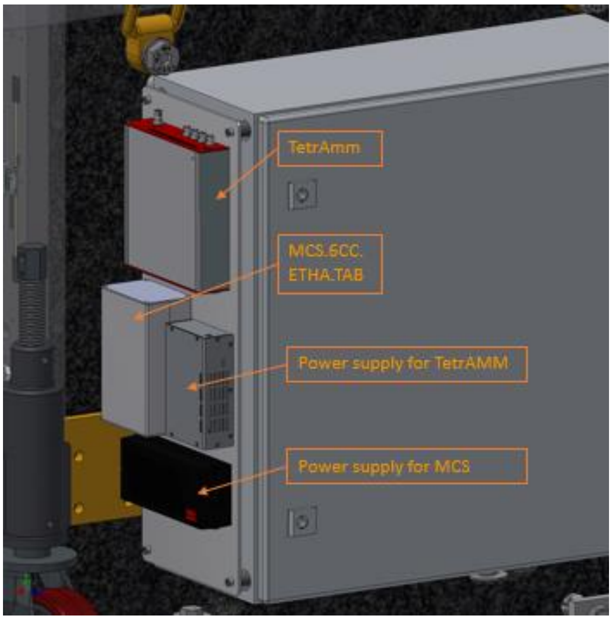


figure 4.10 – Mounting of the electronics for the OCM slit system

4.5 Beam Monitor & LASER Alignment System (MON/LSR)

The MON/LSR unit will serve the function of monitoring the intensity of the incoming x-ray beam and simultaneously reflecting an alignment laser towards a sample. A conceptual layout is shown in the figure below. From right to left, the following components are positioned:

- an alignment green laser of type 3R with power supply mounted to a motorized vertical stage to allow alignment of the laser beam to the sample in the vertical direction. The laser will be mounted a kinematic mount to allow the adjustment of the angle between the laser and the foil.
- a transmitting reflecting foil mounted to a horizontal stage at 45 deg to allow positioning of the laser beam to the sample in the horizontal direction. The transmitting/reflecting foil which allows reflection of the beam as well as transmitting of more than 98% of the x-ray beam above 30 keV.
- a stepper-motor-driven filter wheel with 12 positions for 12 x 12 mm^2 (clear aperture) foils (foils are to be provided by BSA).
- scintillation detector: C13NA50B + CP10-A pre-amplifier + 30 cm cable

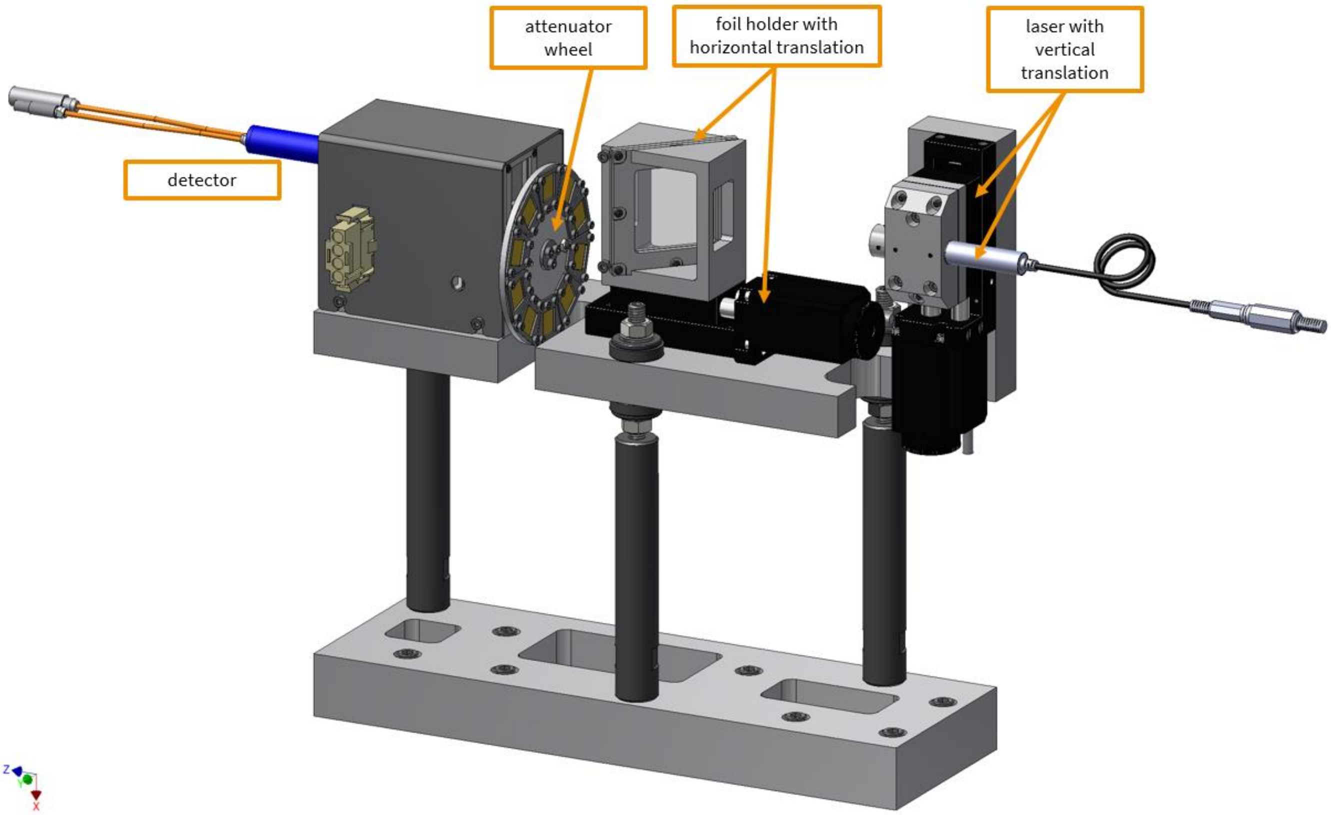


Figure 4.11 - Layout of the MON/LSR system

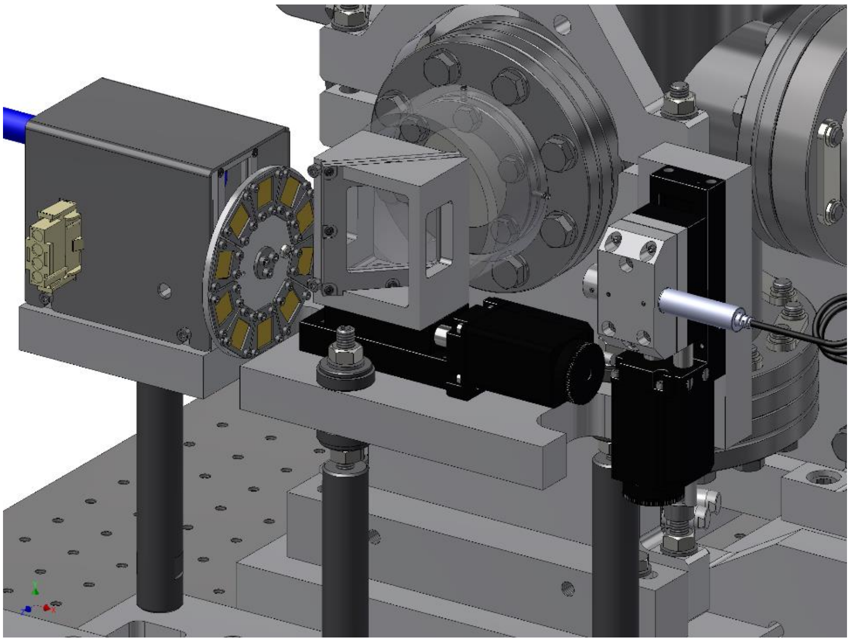


Figure 4.12 – Positioning of the MON/LSR system downstream of the Be window on the OCM

We have included in our scope a reflective coated glassy carbon foil of 25 x 25 x 0.5 mm^3 to reflect, transmit and scatter the x-rays. Glassy carbon is a suitable choice in terms of its amorphous character, x-ray transparence for the energy range considered, and the possibility to have a reflective coating deposited on it. The 530 nm green laser beam has a collimated beam size of 3 mm diameter. An aperture will be mounted in front to reduce the beam size to 1 mm diameter.

The laser and the foil holder are both mounted onto stepper-driven translation stages which allows the beam to be aligned in the vertical Y direction (by moving the laser) and in the horizontal X direction by moving the reflective foil. Both stages are equipped with limit switches.

The foil can be easily inserted and removed in the foil holder by sliding it into the 45 deg slit in the holder.

The glassy carbon foil also partly scatters the incident beam which can then be measured by the scintillator detector placed on the inboard side. The incident flux on the detector can be restricted using the absorption foils in the filter wheel. The absorption foils are not included in the scope of supply.

The identical filter wheel + scintillator detector assembly is also mounted to the ECS. The filter wheel has a capacity of 12 foils and two limits switches which can be used for referencing the foil position.

4.6 Energy Calibration System (ECS)

The energy calibration system (ECS) will be installed at the downstream most position on the OCM table. It is mounted onto the same horizontal X translation stage as the telescopic flight tube so that either one or the other can be aligned in the beam. The ECS is intended to be used either as an energy calibration system with a Si crystal mounted on the first theta and an analyzer crystal on the second theta or with a sample on the first theta and an analyzer on the second theta. The Si crystals and the analyzer crystals are not in the scope of supply.

As agreed upon during the PDR, the ECS comprises two Huber 2-circle rotation stages (circle 1: 411+408, circle2: Huber 410+408) and one Huber motorized 4-axis goniometer head 1006-MS mounted to the theta stage. The 2nd goniometer head (1003-MS) is provided by BSA. A filter wheel and scintillator detector (identical to that described in section 4.5) is mounted to the 2nd two-theta arm.

Based on discussions with BSA, the final design of the ECS has to accommodate only the load of the goniometer heads on the theta circles and the weight of a small crystal or capillary sample.

The Huber circles have been selected based on their performances and load capacities. For minimizing the momentum on the stages both two-theta stages are equipped with accordingly sized counter weights.

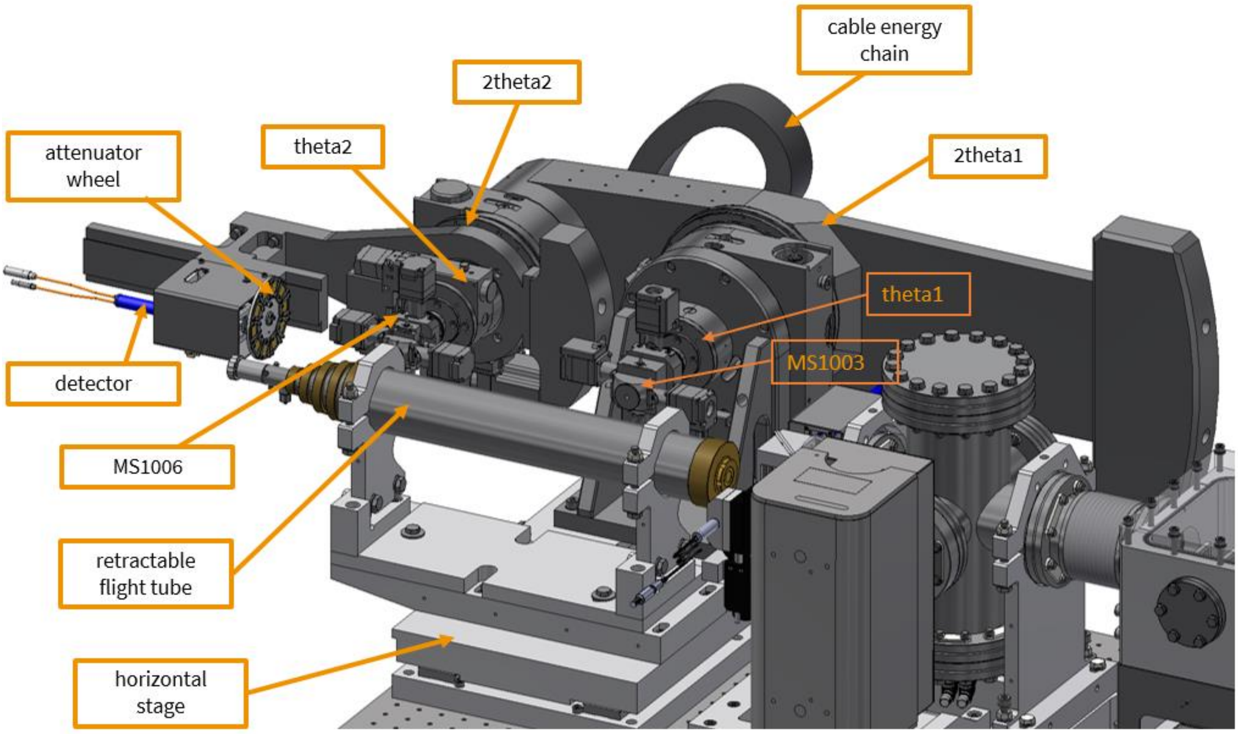


Figure 4.13 – The components of the ECS and retractable flight tube

Due to the large number of cables arising from the components mounted to the 2theta 1 arm, which have to be routed to the OCM interface box, and the large angular range of the 2theta1 arm, an energy chain is mounted to the inboard side of the 2theta1 arm. This allows the cables to move over the large angular range without getting caught in the moving parts.

As required, the ECS also comprises of the filter wheel + scintillator detector unit (C13NA50B + CP10-A preamplifier + 30 cm cable) which will be mounted to the 2theta2 arm along a dovetail carriage. This allows the complete unit to be positioned at varying distances from the theta2 center. The scintillator detector is equipped with a holder for a slit to be positioned in front of the detector which can be used to define the beam in 2theta. The slit is not included in the scope of supply.

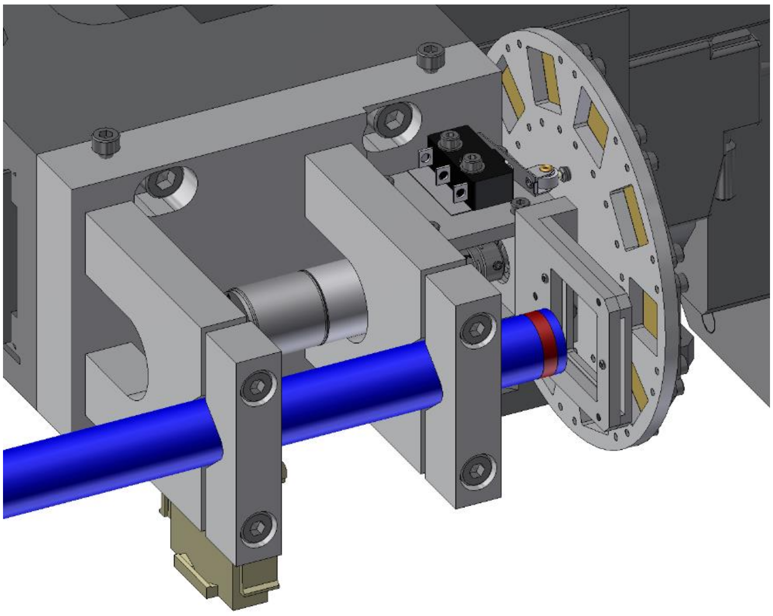


Figure 4.14 – The filter wheel and scintillation detector mounted on the 2theta2 arm of the ECS. The holder for a slit to be placed in front of the detector is also visible.

4.7 Retractable flight tube (RFT)

The retractable flight tube is used for passage of the x-ray beam from the clean-up slits to the sample position. As the sample position is variable in beam direction the length of the RFT is manually adjustable from 500 to 2000 mm. For that six precisely machined tubes, of wall thickness 3 mm, with subsequently smaller diameter made from steel are used which fit into each other. The guidance of the tubes is realized by means of the two PEEK bushings for each segment as shown below. The tolerances of the guiding rings and the tubes is selected to provide precise and therefore negligible sag (< 1 mm) at the end of the tube when being fully extracted. For leak tightness a Viton O-ring is compressed between PEEK bushing and pipe. A “v” groove in the end piece will allow better compression into the o-ring. Note, the leak-tightness is not meant as UHV leak-tightness.

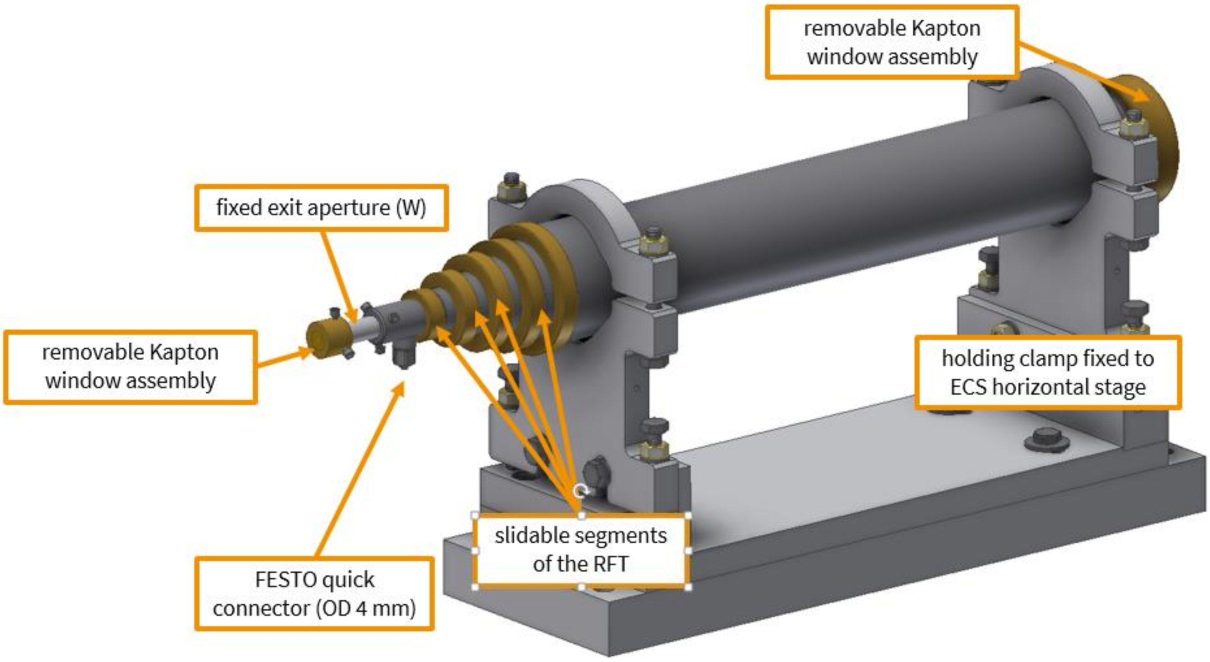


Figure 4.15 – Design of the RFT

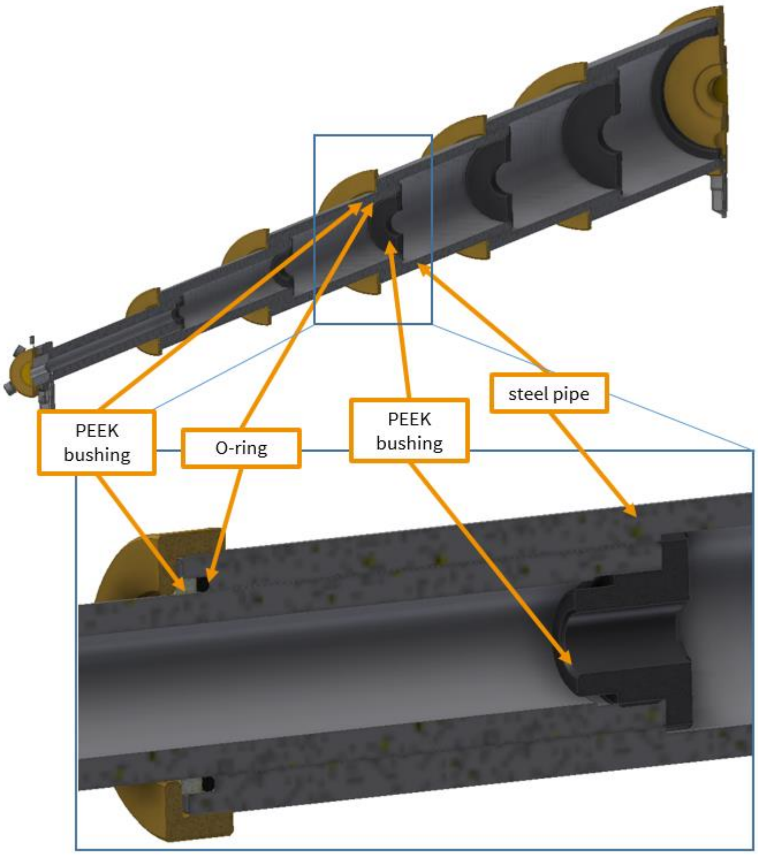


Figure 4.16 – Close up of intersection of two tubes of the RFT

The downstream tube is equipped with a fixed aperture mask with 4 mm ID and 50 mm length made from Tungsten. For leak tightness of the entire tube Kapton windows are attached to the ends and fixed with o-ring sealed clamping rings allowing for quick exchange.

The base of the flight tube will allow for a yaw adjustment of the pipe using two pusher screws about a pivot point.

4.8 OCM FDR modifications

1) Fast shutter blade thickness to be increased to 2.2 mm. Increase in opening time is acceptable. ☒
2) SW communication interface for the shutter to be provided. ☒
3) LSR/MON: add an optical 3-prong adjustment to align the laser in angle to the foil. ☒
4) Filter wheels to have limits (+180/-180 deg) rather than home switch. ☒
5) Telescopic pipe – wall thickness to be reevaluted. 4 mm thickness is not possible. ☐
6) Telescopic beam pipe to have threaded sealed caption window on upstream end. ☒
7) Telescopic beam pipe: put v groove in tungsten piece end so that it can more easily compress into the o-ring. ☒
8) Telescopic beam pipe: implement a yaw adjustment for the pipe using two pusher screws about a pivot point. ☒
9) ECS: the angular adjustment range for the 2^{nd} 2theta should be 0 to -20 deg. ☒

5 End-Station Bridge (ESB)

The details and design given below reflect the close-to-final design of the end-station bridge.

This most downstream component of the BTS is equipped with two detectors (not part of the scope) and a holding plate for different sample environments. All these three units are required to move along the bridge in beam direction as well as perpendicular to the beam and vertically up and down. The end-station bridge is built up from the main sub-assembly groups being described in detail in the following paragraphs:

- Heavy duty support frame
- Longitudinal z-translation for both detectors and the large M6 grid 1
- Detector mounts with x and y translation
- M6 grid 1 with x and y translation
- M6 grid 2 & 3 with x and y translation

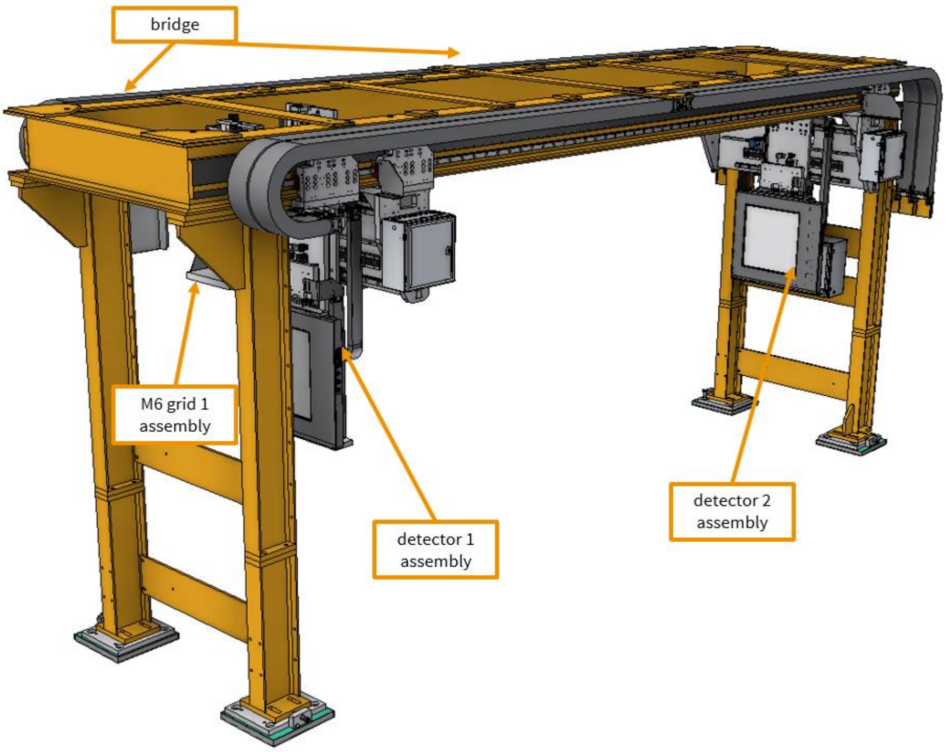


Figure 5.1 – Layout of the end-station bridge.

The main challenging requirements for the end-station bridge mainly apply for sag of the entire bridge as well as for the longitudinal translations of the detector 1 and 2 assemblies as well as the M6 grid 1. Summarized, those challenges for the design are:

- Negligible sag of the end-station bridge assuming worst-case conditions
- Large translation ranges of up to 4 m
- Overlapping ranges for all three units and resulting collision preventive measures
- Capability of moving the assemblies close together to exceed the given motion requirements
- Relatively fast movements of particular stages with speeds of > 0.1 m/s up to 0.3 m/s (best effort).

Within our scope and the herein proposed design all these points are covered with a suitable concept which is described in the following sections. In particular choosing linear motors as actuators for the z-translation offers tremendous advantages compared to a spindle driven solution. This approach for itself allows for high speeds and requires less space and therefore allows for enlarged translation and overlapping ranges. This concept is commonly used in industry and has proven highly reliable.

The motion parameters of end station bridge components are summarized in the following tables.

table 5.1 – Summary of all adjustment units of the bridge (manual and motorized):

axis	type	stroke	mech. resolution[8]	mech. repeatability (uni-dir.)	encoded
adjustments of support *(for accurate pre-alignment positioning of mechanics)*					
horizontal **x, z**	manual	± 15 mm[9]	0.05 mm	n/a	no
vertical **y**	manual	± 15 mm[9]	0.05 mm	n/a	no
tilt (**pitch, yaw**)	manual	± 0.3°	0.01°	n/a	no
tilt (**roll**)	manual	± 1°	0.01°	n/a	no
detector mount 1					
z	lin. mot.	-150 to 3550 mm	< 1µm	< 2 µm	yes / 50 nm
x	lin. mot.	± 240 mm	< 1µm	< 2 µm	yes / 50 nm
y_pneum	pneum.	240 to 620 mm	n.a.	< 5 µm	no
y_mtr (mounted to yb_pneum)	BLDC	± 240 mm	< 1µm	< 2 µm	yes / 50 nm
detector mount 2					
z	lin. mot.	300 to 4050 mm	< 1µm	< 2 µm	yes / 50 nm
x	lin. mot.	± 240 mm	< 1µm	< 2 µm	yes / 50 nm
y	BLDC	± 240 mm	< 1µm	< 2 µm	yes / 50 nm
M6 grid 1					
z	lin. mot.	-400 to 3000 mm[10]	< 1µm	< 2 µm	yes / 50 nm
x	BLDC	± 100 mm	< 1µm	< 2 µm	yes / 50 nm
y	BLDC	± 100 mm*	< 1µm	< 2 µm	yes / 50 nm
M6 grid 2 & 3					
x	stepper	± 50 mm	< 0.3µm	< 0.5 µm	no
y	stepper	± 50 mm**	< 0.3µm	< 0.5 µm	no

*) M6 grid 1 at 0 means that the mounting surface is at 1,900 mm.

**) M6 grids 2/3 at 0 means that their mounting surfaces is at 2,180 mm.

[8] typically assuming full step resolution
[9] Should be precisely set during initial alignment
[10] Refers to the center of the M6 grid

Due to the speed requirements in particular for the long z translation the motors and moving elements are designed accordingly to cope with those requirements and even exceed them significantly. The maximum achievable speed for each axis is listed below:

table 5.2 – Maximum speed of the axes of the bridge:

axis	RFP spec [mm / s]	speed* [mm / s]	acceleration time [s]
z of detector 1 and 2	≥ 100	200 (300)	< 1
x of detector 1 and 2	≥ 50	200	< 1
y of detector 1 and 2	≥ 50	50	< 2
z of M6 grid 1	≥ 100	150 (200)	< 1
x and y of M6 grid 1	≥ 10	15 (20)	< 2
x and y of M6 grid 2 & 3	≥ 1	2	< 1

*) Values in bracket are best effort numbers. Note, the simulations of the linear motors indicate that with the standard Delta Tau Geobrick (LV) used at NSLS-II, with 48 V supply, the best effort values can be achieved with the estimated loads (see table 5.3), however the contingency is almost zero . Therefore also the guaranteed values (no brackets) are stated.

The following table states the maximum allow weights for the detector stages and the grids.

table 5.3 – Maximum allowable weights

axis	max. weight	comment
D1 z stage	200 kg	total weight including all components
D2 z stage	180 kg	total weight including all components
M6 grid 1 z stage	200 kg	total weight including all components
Detector 1 mount	40 kg	including cover
Detector 2 mount	40 kg	including cover
M6 grid 1	100 kg	
M6 grid 2/3	2 kg	

5.1 Support Frame

The purpose of the support frame of the end-station bridge is to provide a stable and stiff support for the 13 adjustment units of this device with the main requirements of providing sufficient clearance for the sample environment and minimum deflection under worst case conditions, i.e. all stages positioned close to the middle with full load.

To fulfil this we propose a simple yet very stable support frame built up from heavy duty I-beams made out of steel (see Figure 5.1 for the shape of the frame). The standardized size of these beams is selected to cope with the requirement of minimal deflection (< 0.5 mm under full load), an according FEA is carried out in Rp-2184-1020-0 (FEA on bridge support). The frame is supported by 4 legs, also made from I-beams, providing a solid base for the frame carrying the motion mechanics. To avoid any twist of the frame during installation at NSLS-II due to height deviations in the floor it is foreseen to have an adjustment unit (three set screws / leveling elements) on each leg. Once aligned it is foreseen to grout the support legs to the floor to provide a stiff connection to the ground. The support legs will provide 30 mm period M6 holes for the mounting of uni-struts for later use. However, BSA should ensure that added equipment will not interfere with the travel of the detectors.

Extensive mounting and testing effort will be required for the bridge components which is complicated by the full height of the bridge. Therefore each leg is designed to consist of two parts which will be bolted together to deliver the final required height. This will allow the bridge to be assembled and tested at the factory at a maximum height of 1.8 m, avoiding the need and associated risks of using an elevated stage during the assembly and testing. The chosen assembly and testing height of 1.8 m allows the interface box to be finally cabled and mounted to the downstream end at the factory. The two sections of the legs will be bolted together and delivered as single units so that for the purpose of the installation at the beamline, each leg will be a single unit. The joint will also serve as a stiffening element along the length of the leg.

For further stiffening of the entire support the two support feet at the downstream end are reinforced with cross beams. We also include additional enforcing stiffening / gusset plates between the support legs and the upper bridge frame for further stiffening.

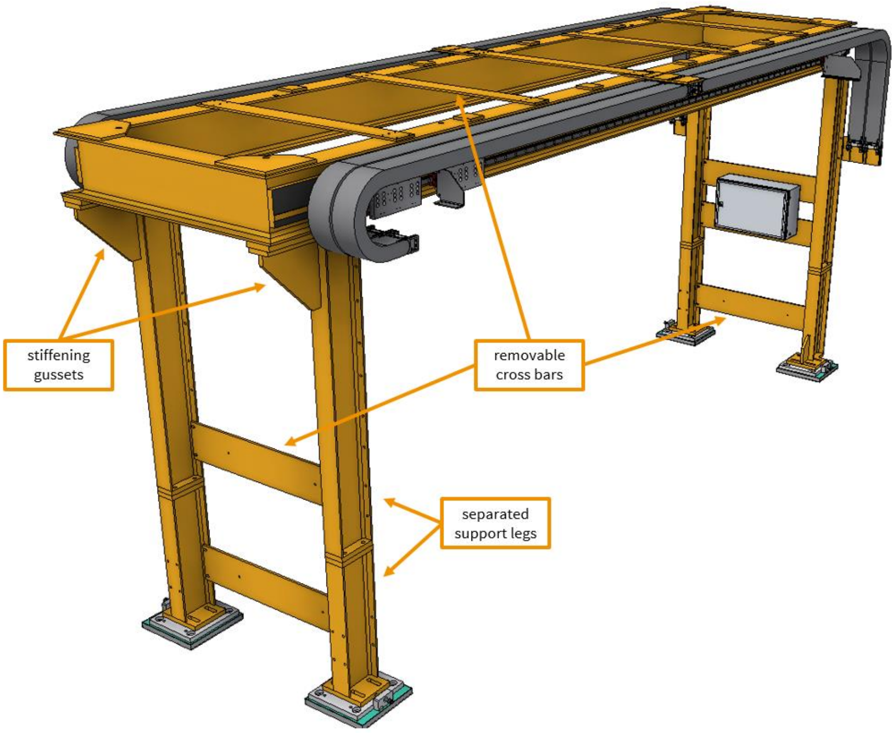


Figure 5.2 – Layout of the end-station bridge.

Intrinsically the welded upper frame of I-beams does not provide a very accurate mounting surface for the precision rails being used for the z-translation. Therefore additional plates are welded to the both sides of the frame. After welding the frame these plates are machined on the surface to provide an accurate and even mounting surface for the rails with sufficiently high flatness and parallelism to each other. Note, the machining process for those reference surfaces is carried out with the bridge frame being mounted on its four support points. Thus, the gravitational sag caused by the tare weight of the frame is already compensated partly (also refer to Rp-2184-1020-0 for details on the FEA evaluation for the bridge).

The entire bridge is disassembled into the four support feet and the upper frame which allows easy mounting during assembly in the factory, packaging and installation on-site in the beamline.

To ensure no large deflection of the bridge under worst case conditions an FEA evaluation was carried out. Please refer to Rp-2184-1020-0 (FEA evaluation of the bridge support) for details of the analysis.

5.2 Longitudinal Translation (z) for Detector 1 & 2 and the M6 grid 1

As stated above, the longitudinal translation of the detector 1 and 2 as well the M& grid 1 in beam direction are actuated by means of linear motors that has its stator and rotor "unrolled" so that instead of producing a torque (rotation) it produces a linear force along its length. Therefore it can be controlled in the same way as a DC servo motor and no additional controls is needed.

The z-translation for the three assemblies is built up mechanically as follows:

- Linear guides:
  For guiding the assemblies along the beam high precision rails are mounted to the sides of the support frame. In order not to affect the straightness of the rails the mounting surfaces on the support frame are precisely machined after welding the frame. That guarantees straight movement with negligible parasitic movements when moving along the z-translation. Mounted to the rails are three sets of carrier assemblies, one for each detector assembly and one for the M6 grid 1. Also here stiffness is the driving factor in the design and each carrier assembly is equipped with 6 pre-loaded carriers. That reduces possible parasitic movements when changing the load on these stages by moving the detectors or the grid in x and y directions.

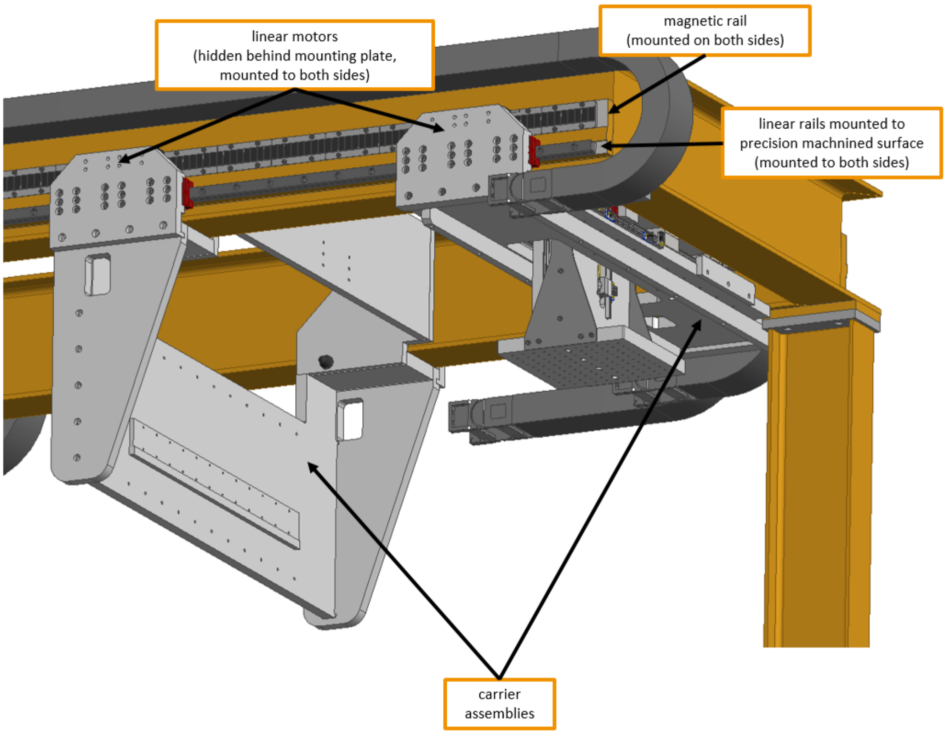


Figure 5.3 – Layout of the z-translation with linear motors. Picture shows carrier assemblies for D1 and grid 1.

- Magnet assembly:
  For actuation the linear motors require a magnet assembly. The main advantage of the chosen actuator concept is that all three carrier assembly can use the same magnetic assembly. For applying an evenly distributed driving force while moving, two magnetic rails are mounted to the bridge frame on either side close to the precision rails.
- Linear motor:
  For actuation of each carrier assembly two linear motors are used, one on each side. The motors are attached to the carrier assembly on the outer sides of the frame fitting to the magnetic rail. All linear motors are identical and designed for the biggest load of the M6 grid 1.

For safety reasons each carrier assembly is equipped with an additional brake. This brake is mounted in series to the six carriers and shall be actuated in case no power is applied to the linear motor as those provide almost no holding force when unpowered. It means in case of movement and a sudden power failure the stage continues to move if not hold by a brake and is decelerated slowly by the pre-load of the carrier assembly. Even though this does not cause an imminent risk of breaking components (please refer to section 5.7 for collision protection) the brakes are an integral part of this translation.

5.3 M6 grid 1 assembly

The bridge carries an M6 grid as mounting surface for different sample environments. It comprises a 300 x 300 mm² grid with M6 threads in a 25 x 25 mm² hole pattern. This bread board is mounted upside down to an x-y-translation stage as close as possible to the z-translation to leave sufficient space to accommodate a sample environment down to the sample position. The x-y-translation is mounted to one of the z-translation carriers to allow adjustment in beam direction.

The x-y-translation stage for the M6 grid 1 is based on standard linear drives built up from pre-loaded carries mounted to high precision linear rails. The actuation is realized by brushless DC motor driven precision ball screw assemblies. That concept has been selected for the M6 grid 1 due to the higher load and the stage will be self-locking when not in motion or unpowered through use of brakes mounted to the motor shafts. These brakes will be engaged whenever the axis is not moving and will need to be disengaged to move the axis. Motor size and gear are dimensioned accordingly.

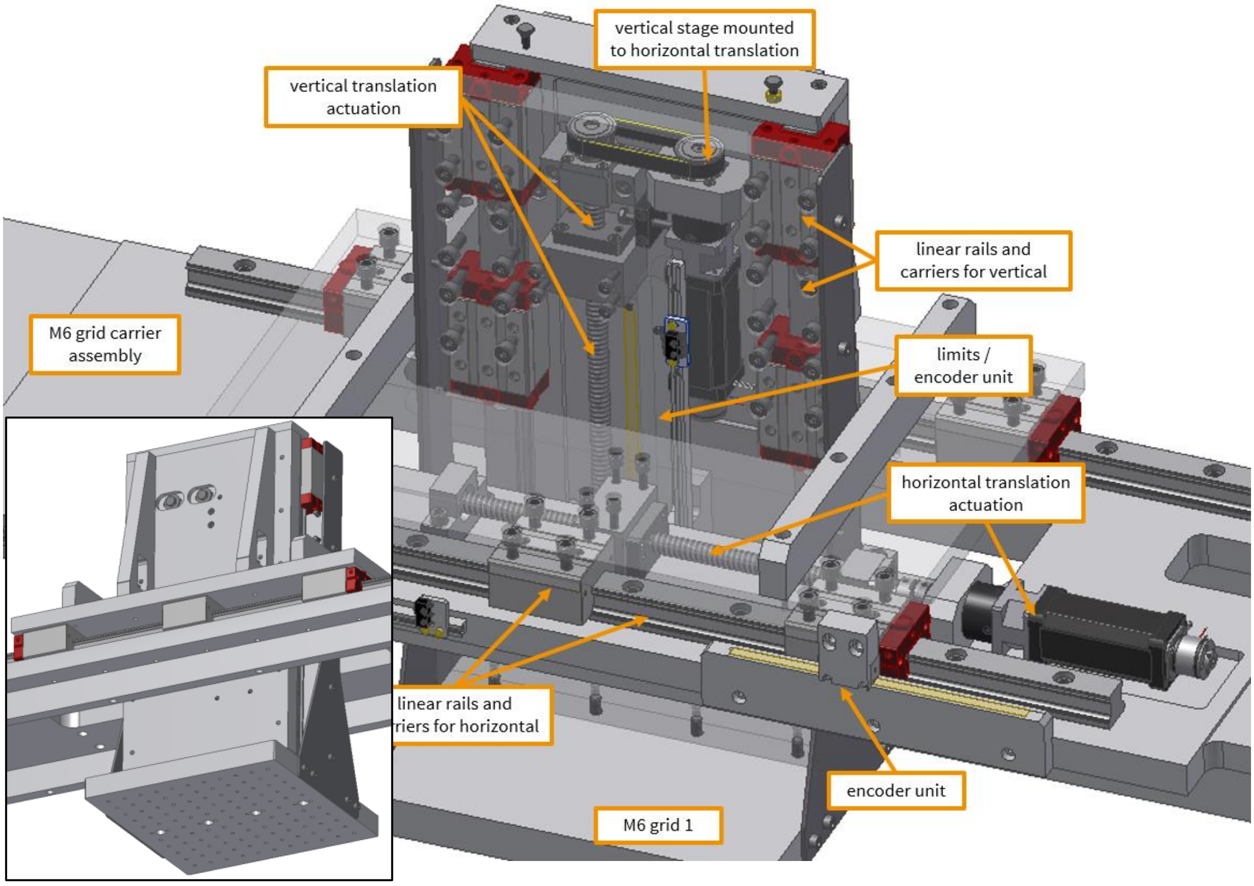


Figure 5.4 – Layout of the M6 grid assembly with its x-y-translation table (lower left: view from bottom on grid)

5.4 Detector 1 & 2 assemblies

The end-station bridge carries two almost identical detector assemblies for the foreseen detectors of the PDF end station. Both detectors (by BSA) have identical dimensions and the required motion ranges are almost identical, therefore for both mounts the same design approach applies.

Both, x- and y-translation are based on pre-loaded carriers mounted to linear high precision rails as being realized for the other stages. Due to simplicity and compactness the x-translation is similarly actuated as the z-stages described further above, i.e. a linear motor is used. That provides the advantage of making the stage as compact as possible and results in high speeds being possible with the stage.

For the y-translation the design of the D1 and D2 assembly differ from each other. That is due to the fact, that D1 must also be able to move out of the beam path in upwards direction. Based on the foreseen duty cycle for this beam in/out movement (~possibly up to 1,000x per day) the vertical stage for D1 is split into two stages, one based on a DC motor driven precision ball screw driven stage for the operational movement of +/- 240 mm (the same is being implemented for D2) and the other based on pneumatically actuated stages for moving D1 in and out of the beam. Guidance for both stages is realized by means of precision rails and carriers.

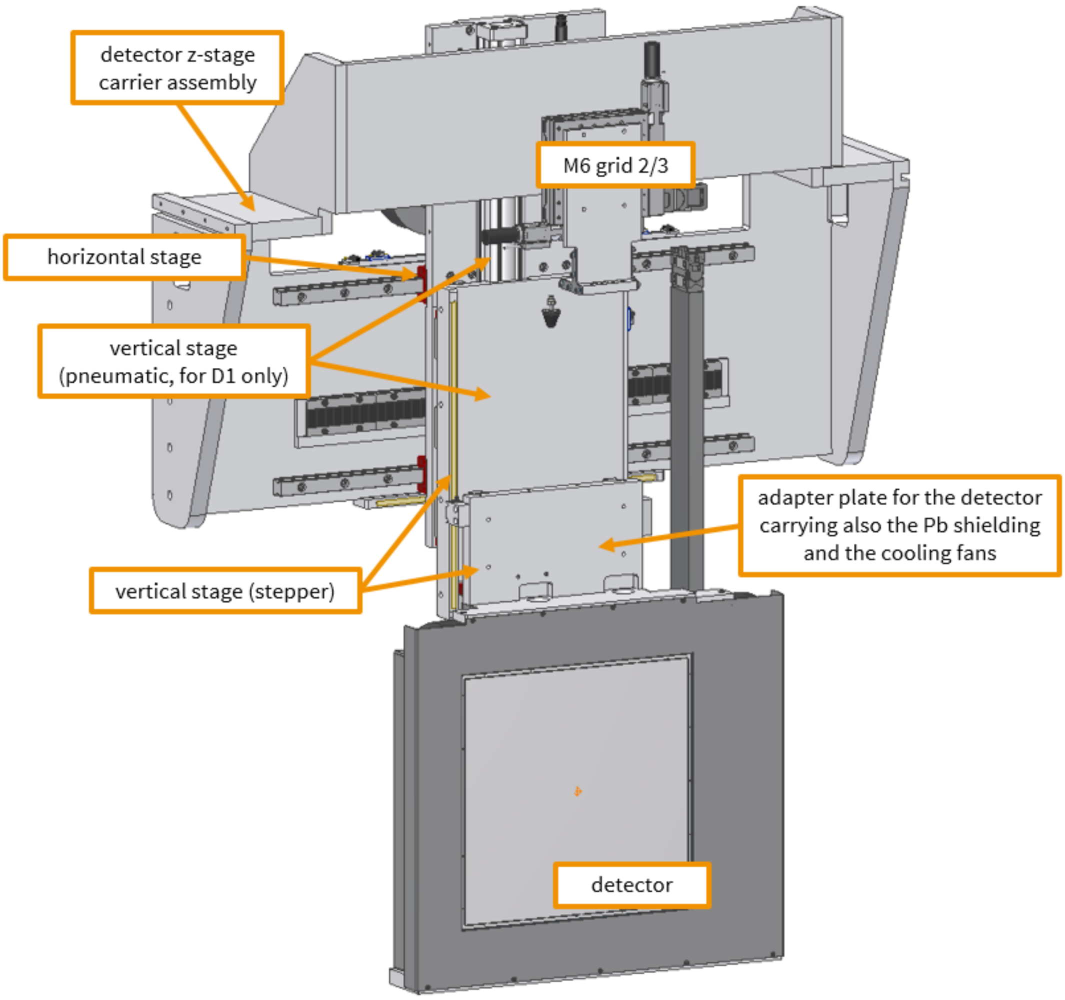


Figure 5.5 – Detector assembly from upstream side, shown at nominal 0 position, i.e. detector center at 1,400 mm beam height.

The stage with the DC motor is equipped with a motor brake to ensure self-locking when no motor current is applied and / or the power is lost. Note, the motion controls shall ensure activation of the brake when no motor current is applied.

For the pneumatic driven stage (D1 only) a standard cylinder by FESTO for industrial applications is used providing a life time of > 2,000 km whereas we assume approx. 250 km travel per year for this stage (1000x up/down cycle per day on 300 days / year). The pneumatic stage is equipped with hardened hard stops at the end of travel for precise and repeatable (< 5 µm) re-positioning, in particular for the in-beam position. Furthermore, shock absorbers are mounted to reduce the speed when running into the hard stop.

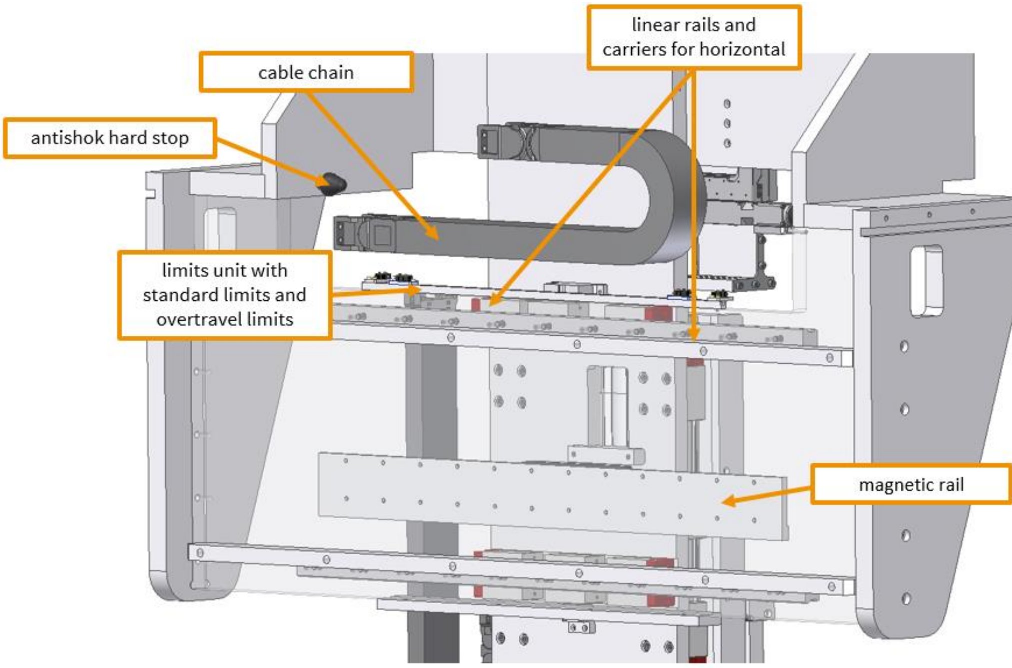


Figure 5.6 – Detector assembly horizontal stage from downstream side.

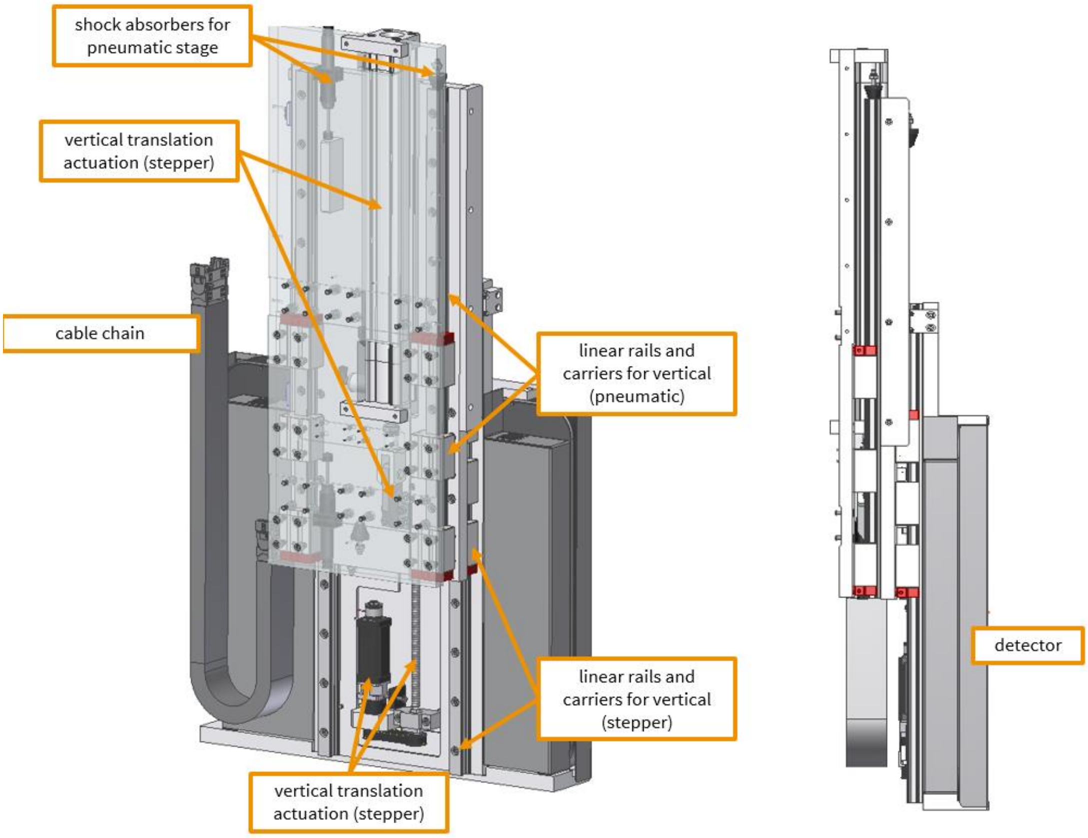


Figure 5.7 – Detector assembly vertical stages from (left) downstream side and (right) outboard side.

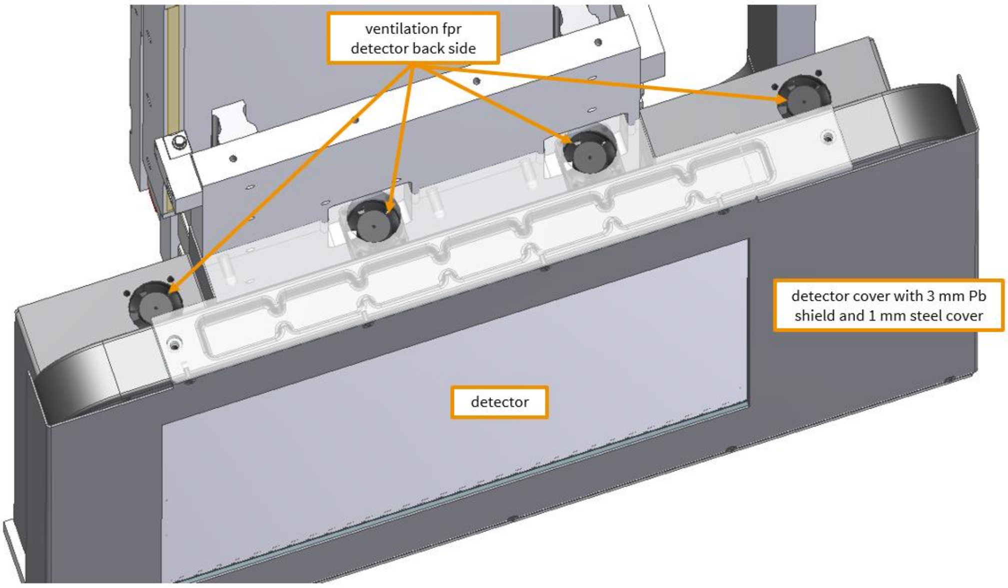


Figure 5.8 – Detector assembly ventilation system.

The moveable plate of the vertical translation acts as interface plate for the detector holder and allows for easy integration of the detector during installation. It carries also the 3 mm thick lead cover placed on the upstream side of the detector with an aperture for the effective detector area. The lead cover is protected against direct exposure with a steel plate (1 mm thickness). Cooling of the detector is provided by leaving approx. 20 mm free space between the detector back side and the mounting plate for the vertical stage. That free space is segmented into four vertical channels being equipped with small cooling fans at the top sucking the air from the bottom through the channels and blowing the warm air out towards the top.

5.5 M6 grid 2 & 3 assemblies

For positioning a beam stop (beam stop not part of the scope) upstream of the detector high precision translation stages are mounted to the common z-translation of each detector, i.e. those beam stop translation stages follow the according detector when being moved in beam direction.

Each grid assembly (2 & 3) comprise a standardized x-y-translation unit allowing for adjustment in x- and y-direction around the nominal beam path. We assume the weight to be carried by the grids 2 & 3 to be limited to 2 kg.

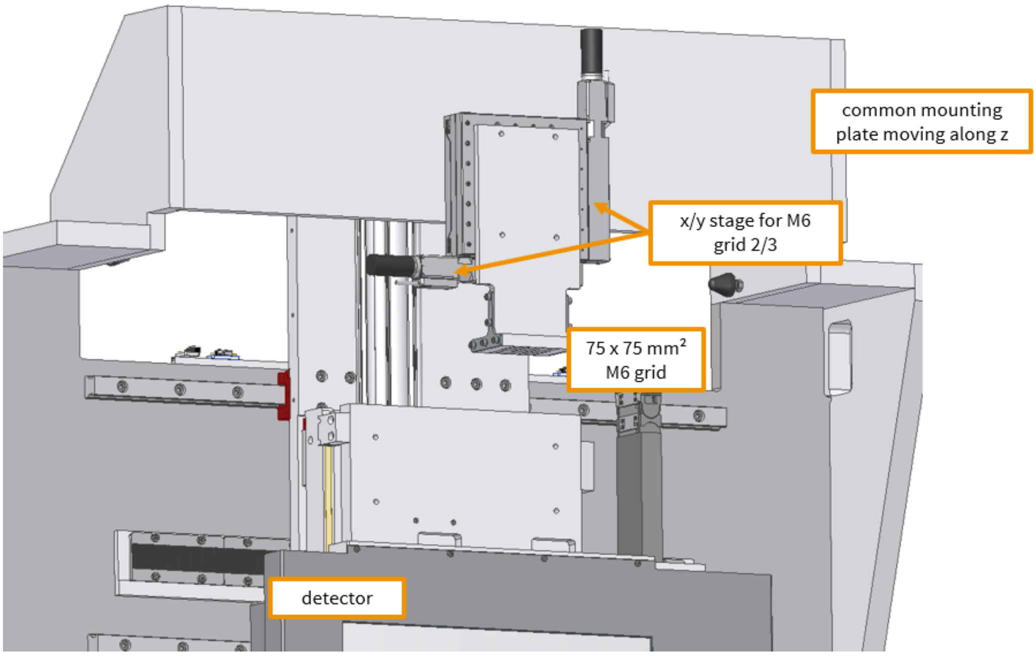


Figure 5.9 – View of the M6 grid 2/3 with x and y translation.

5.6 Cable management of the end-station bridge

Due to the number of motorized axes of the end-station bridge (in total 13) and the large distances all the axes have to over-come, cable management is essential and to be considered in the design. All large translation stages, i.e. all three z-translations and the x- and y-translations of the detector 1 and 2 are equipped with accordingly sized drag chains to accommodate the required number of cables. In addition to all the motor, encoder and switch cables we also reserve space for up to 3 standard sized cables per detector. The radius of the drag chains is selected to be larger than the specified bending radii of the used cable (LSZH) for dynamic applications.

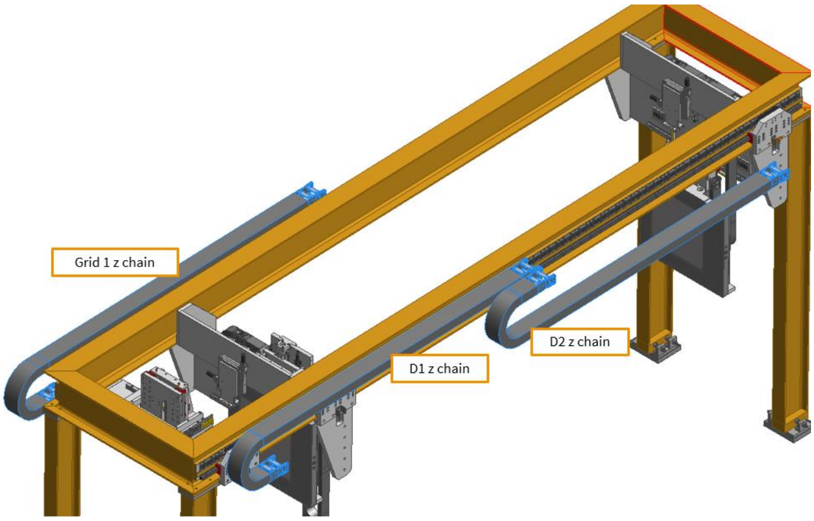


Figure 5.10 – View of the cable drag chains along the Z axis. Three chains are foreseen to manage the cables from theD1, d2 and G2 assemblies

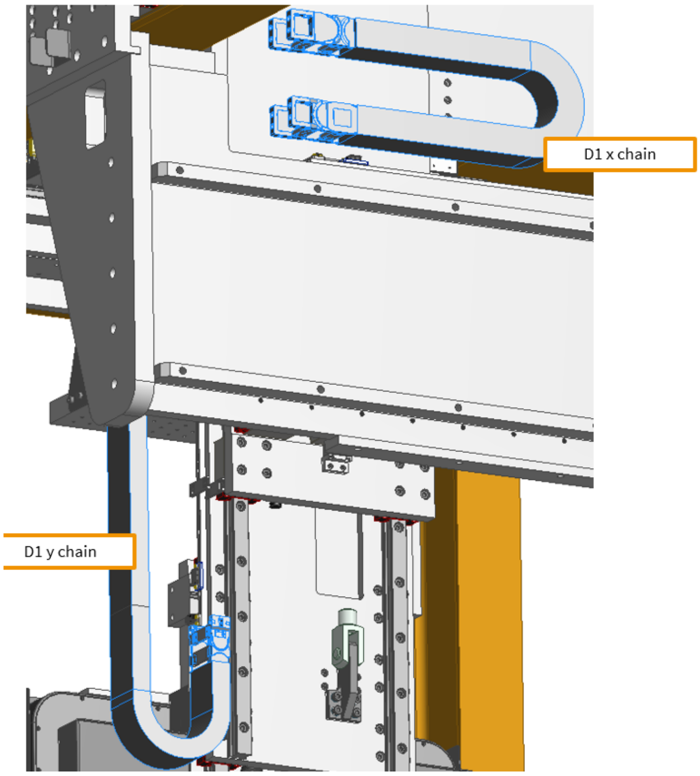


Figure 5.11 – View of the cable drag chains along the Y and X axes for D1 and D2 assemblies

All motor/limit/encoder and motor brake cables are routed to an interface box mounted to the downstream legs of the bridge where they can be interfaced to NSLS-II controls. For the EPS signals, three sets of BSA free-issued PLC modules will be mounted inside smaller interface boxes mounted to the three z-stage assemblies (G1/D1/D2) to ease cable management. These boxes then only need to be supplied with 24 V power and an Ethernet cable.

5.7 Encoding, limits and collision protection.

All axes of the end-station bridge are encoded except those of the M2 and M3 X/Y grids. We foresee the usage of absolute encoders for position monitoring (RENISHAW, RESOLUTE), in particular for the long translation, in order to allow for constant absolute position monitoring at all times, even after a power loss (avoiding the need for complex homing procedures over long travel ranges). Furthermore the use of absolute encoders allow constant determination of where the three carrier assemblies are positioned which can be integrated to the motion software setting software limits for collision protections.

All motorized axes of the bridge are equipped with adjustable limit switches (normally closed). All stages besides the small grids have additional over travel switches to detect when the stage runs beyond its limit; these over travel limits need to be interfaced to the EPS. Furthermore the large stages are equipped with rubber stoppers. Running into these dampened hard stops will result in stalling of the motor not damaging the actuation unit. For the z-translation stage with its three carrier assemblies damping elements are provided on the stage. This prevents the stages from running into each other directly.

Please note, that the design is carried out in a way that a collision of the detectors with the mechanics is avoided by making the z-translation carriers slightly longer than the entire length of each detector assembly in z-direction, i.e. prior to a collision of the detectors with the mechanics the z-translation carriers run into each other being stopped by the dampeners.

The limits described above are for limiting the motion ranges only, not for collision protection specifically in the case of unpowered runaways. Protection is realized by (1) the dampeners for the z-translation as already mentioned above and acting in a similar way as a hard stop and (2) by implementing proximity switches. The only possible collision on the end-station bridge which may occur is along the z-translation assuming the sample environment does not extend the dimensions of the M6 grid 1 in z-direction. As described above, all z-translation carriers are slightly longer than the mounts underneath them and therefore only collision of these carrier assemblies is to be prevented. Here the stated proximity and over travel switches are integrated:

- Proximity switches:
  Each carrier assembly is equipped with optical proximity switches on both ends. Those switches start to be activated and remain activated when the stages get close (< 100 mm) to their end of travel or close to another stage, respectively. It is recommended to program the motions controls in such a way that it limits the speed once a proximity switch is activated. The active range for those proximity switches can be defined and adjusted to be between 50 and 300 mm. Note, these switches are contactless.
- Over travel switches:
  Each carrier assembly is additionally equipped with over travel switches on both ends. Those switches are activated a few mm prior to the hard stop (dampeners) and have an actuation stroke of > 5 mm prior to hitting the hard stop. These limits shall be integrated to the motion controls logic in such a way that it cuts the motor current and additionally activate the brakes of the corresponding axes, thus preventing the stage from running into each other.

Below we summarize the provided features for safety measures on the bridge and propose an according action to be carried out (integration of this logic to the controls and EPS is responsibility of BSA).

Table 5.4 – Protection levels for powered case

level of protection	safety device	reaction
level 0a:	software protection by monitoring the absolute encoder values	stop motion through controls if thresholds are reached
level 0b:	proximity switches detecting that stages are getting close to limits / each other	Stop motion and reduce speed in critical area
level 0c:	limit switches	stop motion through controls
level 1: (motion controls fails)	over travel switches	activate brakes on carriages through EPS or disable amplifiers
level 2: (level 1 fails)	damping elements	decelerating the stages due to increasing damping force until complete stop prior to reaching the hard stop (the damping force is sufficiently large to work against a powered motor and resulting in stalling of the motor)
level 3: (level 1,2 fail)	hard stops	motor stalls, due to dampeners only slow movement into hard stop

Table 5.5 – Protection levels for unpowered case (assuming power and therefore control loss during movement):

level of protection	safety device	reaction
level 0:	friction of z and x stages	z and x stage will slow down due to friction
level 1:	EPS (by BSA)	activate brakes through eps, brakes are wired that they activate in case of power loss
level 2: (level 1 fails)	damping elements	decelerating the stages due to increasing damping force until complete stop prior to reaching the hard stop (the damping force is sufficiently large to work against a powered motor and resulting in stalling of the motor)
level 3: (level 1,2 fail)	hard stops	due to dampeners only slow movement into hard stop

Table 5.6 – Protection levels for pneumatically driven D1y stage:

error	safety device	reaction
power loss	integrated brake of FESTO cylinder	stops movement, keeps cylinder in position
loss of pneumatic pressure	integrated brake of FESTO cylinder (required compressed air to deactivate)	brake activates if compressed air is lost
brake fails	damping elements	decelerating the stages due to increasing damping force until complete stop prior to reaching the hard stop

As a final safety measure emergency stops are placed on the bridge support to allow immediate stopping of all axes.

To summarize, there are two kinds of brakes which can be engaged/disengaged in the system. The activation/deactivation of these brakes can be triggered either by the motion control system or by the EPS.

We suggest the following separation:

a) brakes mounted to the motor shafts which need to be disengaged each time the axis is to be moved (by applying 24 V) and will be engaged when the axis is not in motion (either powered or unpowered) should be activated by the motion control system. These are the brakes on the G1X, G1Y, D1Y and D1X motors.
b) brakes which need to be engaged either when there is a loss of power or a loss of pneumatic air pressure should be activated by the EPS system. These brakes are all pneumatic so that when there is no air pressure the brake is engaged and motion is prevented or stopped.

In addition the emergency switches are to be wired so that when these are activated, all power to the stages is lost, the brakes are activated and all motion is stopped.

5.8 Bridge FDR Modifications

1) Implement M6 holes, multiple of 50 mm period along the legs for mounting of unistruts. ☒
2) Implement a mm scale along the Z rail, visible from the outboard side. ☒
3) Implement the distributed PLC scheme on G1/D1/D2 assemblies. ☒
4) Color of bridge (AXILON RAL 1037 sunyellow) to be approved. ☐
5) Changes in the Z travel range of the D1 and G1 stages to be approved. ☒

6 Ancillary

6.1 Support stands

The support structures for the BDM, the OCM and the end-station bridge are already described further above in detail.

For the remaining components such as the pumping crosses, the flight tubes inside the hutches and the shielded flight tube standardized steel frames are provided. These welded stands are rigidly anchored to the floor and provide manual adjustment capabilities in x- and y-direction to support the components on top without applying any strain. After manual alignment the support stands can be locked in place with according fixation screws.

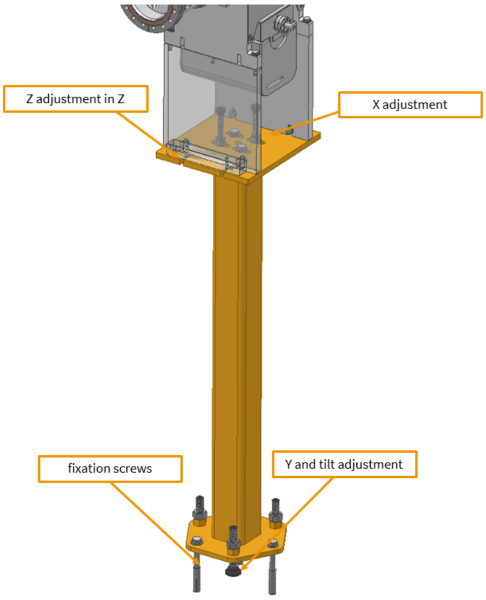


Figure 6.1 – Design of the support stands including adjustment mechanisms

6.2 Shielded beam transport

For the beam transport from the FOE to the experimental hutch a lead shielded flight tube is part of the scope. Its design follows the standard radiation safety guidelines for synchrotron facilities and is in accordance with the specifications laid out by BSA.

Due to the rather short length from the FOE to the experimental hutch the shielded beam transport comes as one single pipe reaching from the photon shutter down to the pumping cross just upstream of the OCM.

This single segment comprises a CF100 / 6" vacuum tube and is wrapped with 12 + 1 mm lead for radiation shielding. The lead is covered with a thin layer of stainless steel to allow no direct access to the lead. This cover is spot welded, during welding it will be ensured that no damage is done to the lead. In order to ensure sufficient lead thickness at all points. Axilon specifies 13 mm lead thickness to the manufacturer.

Customized lead collars are used to connect the lead shielding of the transport pipe to the hutch walls. These collars are made from two halves with a special geometry so that both halves intertwine to each other when mounted around the pipe and compressed to the hutch walls. This avoids any direct line of sight and therefore avoids radiation leakage.

The shielded pipe is supported at both ends with a welded stand in order to put no load on the hutch guillotines and the hutch walls nor on directly on the up-/downstream components. The stands allow manual adjustment in x any direction.

As the supplier for the shielded pipe we foresee Innospec who builds all kinds of radiation shielding equipment for synchrotron facilities worldwide and has proven its reliability in a long track record, amongst that record also NSLS-II can be found.

Note, between lead collar and lead of the pipe there will be a gap of 1 mm caused by the steel cover. The steel cover reaches under the collar to account for position and manufacturing tolerances and to ensure that no lead is exposed after final mounting. The overlap of collar and beam pipe shielding is 55 mm, i.e. the ratio of overlap and gap is 55:1 and should be therefore sufficient.

The shielded pipe will be delivered with the lead already wrapped and covered / protected with a 1 mm steel sheet, i.e. during handling of the pipe no direct access to the lead is possible. The 13 mm (12 mm is required) is wrapped around the pipe and welded at the abutting face in such a way that the thickness of the lead remains > 12 mm. The steel cover is spot welded.

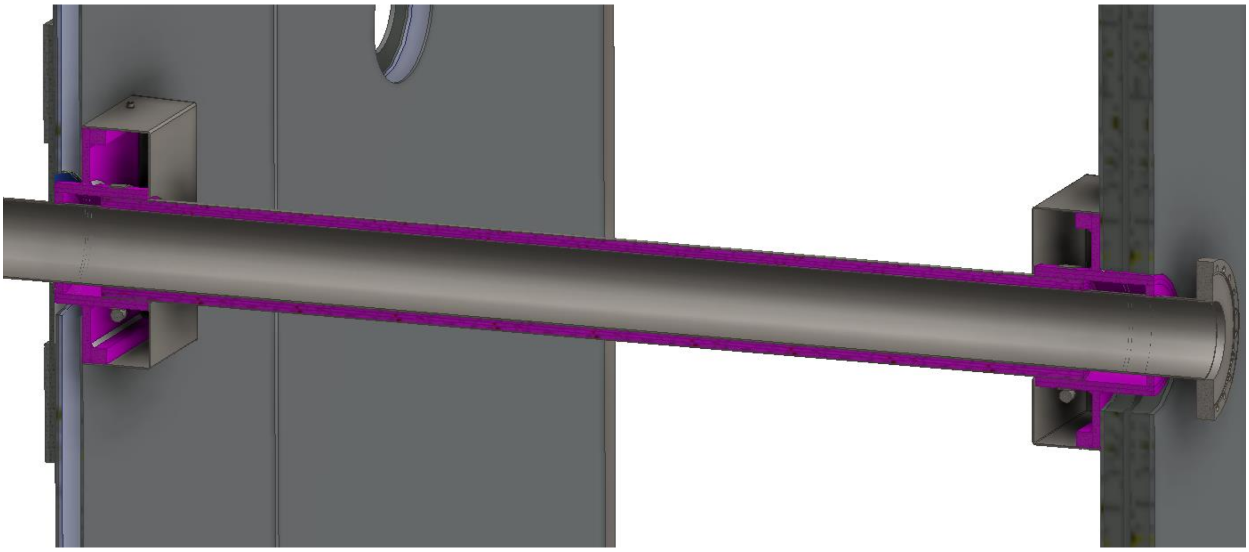


Figure 6.2 – schematic of lead shielded pipe.

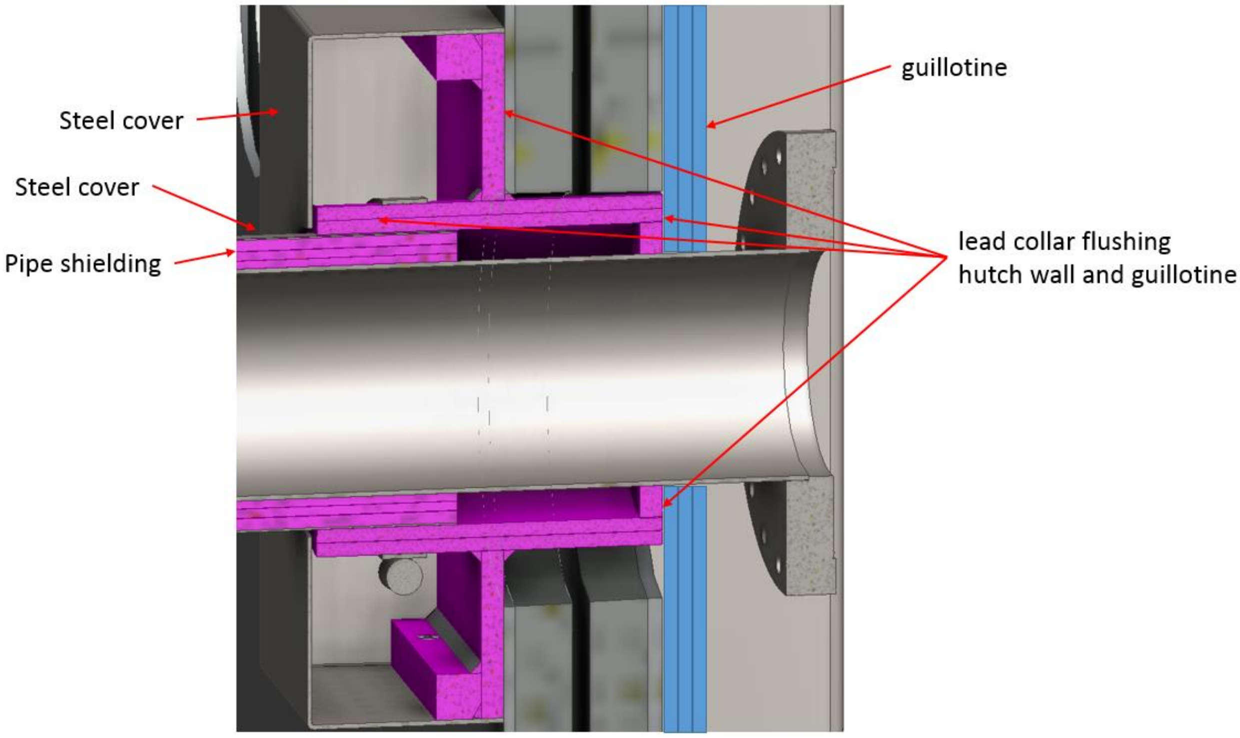


Figure 6.3 – schematic of lead shielded pipe, detailed view at upstream hutch wall.

Once the shielded pipe is installed the lead collars are slid over the pipe into the opening of the walls until they flush with the hutch walls / guillotines. During handling of the painted collars gloves shall be worn (even though the lead is protected by paint). Clamping of the collar halves is carried out by means of accordingly sized pipe clamps. Once installed the collar is protected with a steel cover (also 1 mm thickness).

Note, dismounting and mounting of the hutch wall guillotines does not fall in the scope of work of Axilon and shall be carried out by BSA.

Refer to document Rp-2144-1020-1 and updated information provided which describes all the interfaces between the provided scope and the PDF beamline.

6.3 Beamline vacuum layout and equipment

Refer to document Rp-2146-1020-1 for the vacuum layout of the PDF BTS.

6.4 Be window

The scope of supply includes two Beryllium windows at different locations of the BTS. We foresee the use of Be windows being diffusion bonded to the according flange as it is provided e.g. by MATERION.

The following table summarizes the specifications of the different Be windows.

table 6.1 – specifications of Be window

parameter	value
general	
material	Be, IF-1® grade or similar (as provided by MATERION or similar)
Be window #1, upstream of OCM, for separation to the upstream part of the BTS	
free aperture	D38 mm round aperture Note, it is foreseen to mount the Be window on the upstream end of the OCM, i.e. the windows moves up and down with the OCM following the deflected beam of the upstream mirror. This reduces the required aperture height and allows therefore for thinner a thinner foil.
Thickness	130 µm
mounted to	bonded to standard CF40 flange
Be window #2, downstream of the OCM clean-up slits	
free aperture	D39 mm, round aperture sufficient for the max aperture of 20 x 20 mm² of the slits
thickness	130 µm
mounted to	bonded to standard CF40 flange

6.5 Control system

We have not included a customized control system into our scope of supply. All motors, besides for the slit system, used throughout the beamline (ex-vacuum and in-vacuum) are standard bi-polar stepper motors, DC servo motors or linear motors requiring no special drivers or motion control. The standard NSLS-II motion controls based on the customized NSLS-II DELTA TAU controllers is fully suitable and compatible with the used motors. Required combined motions are typically supported in the standard available EPICS packages (e.g. pitch and height of the OCM). All other movements are single axis movements requiring no customized control.

In order to read the absolute encoders of the bridge axes, the free-issued Geobrick will need to be configured to read absolute encoders. We suggest that the 8-axis Geobrick be configured to have 6 axes with absolute encoder inputs and 2 axes with incremental encoder inputs.

For the slit motions using piezo actuation according drivers are included in the scope (see section 3.2).

The interfaces to the motors, limits and encoders will be as defined by the NSLS2 requirements. Please refer to the initial example wiring schematics provided (document number 17-05-038418-00) for the pinning of the motors, limits and encoders. A complete set of as-built schematics will be included in the end-user documentation.

The complete axis parameters for all axes can be found in the document Rp-2185-1020-0. This includes the motor model and parameters, gear model and parameters and encoder model and parameters.

The complete list of EPS signals can be found in the document Rp-2186-1020-4.

6.6 Interfaces

Refer to document Rp-2144-1020-1 which describes all the interfaces between the provided scope and the PDF beamline.

6.7 Equipment protection

The equipment protection system (EPS) is not part of the scope. We assume to integrate according PLC modules (to be provided by BSA) into the component's interface boxes. All signals relevant for equipment protection can be interfaced to those PLC modules. Foreseen signals used for equipment protection are:

- actuation and position indication switches for gate valves
- over travel switches for specific axes
- position switches for specific axes
- collision and proximity switches for the end-station bridge
- emergency stop
- solenoids for the attenuators and filters

These signals are to be processed in the EPS from BSA. AXILON provides a list of potential hazards, thresholds values and necessary actions during the design phase. The logic and software is not part of the scope of supply but will be programmed by BSA. Similarly Personal Protection is not part of the scope of supply.

Refer to Rp-2186-1020-4 (eps signal list) which describes the EPS signals to be routed to the PDF beamline EPS.

Axilon will wire all signals directly to the EPS modules (to be provided by BSA) unless otherwise agreed (e.g. motor brakes).

6.8 Ancillary components FDR Modifications

6.8.1 Beam transport sections

1) Be window design parameters needs to be reviewed based on discussion between Axilon and Materion. ☐
2) Color of support stands (AXILON RAL 1037 sunyellow) to be approved. (ACTION) ☐