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Installation, alignment and access strategy

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Contents

1 Scope

In this document a method for aligning the target optical systems, described in [1], is outlined. The strategy for installation and alignment is described, along with the parts of the optical system that needs to be accessible for the various installation steps. A description of the successful alignment of the target wheel prototype is included.

2 Introduction

The main goal of alignment is to come as close as possible to recreating an optical axis going from the center of the object, i.e. the target wheel beam entrance window and proton beam window, to the center of the camera lens aperture through the center of all the apertures and mirrors along the path.

The mirrors in the PBIP will be inaccessible after the PBIP is installed in the target monolith. These mirrors will be installed into the PBIP and aligned in the mock up. The remaining mirrors will be installed and aligned after the PBIP has been installed in the monolith.

M2-M7 will be mounted on adjustable mounts, described in [2], M1 will be mounted on a mount that is not adjustable, described in [3]. To minimize errors, the interface surface for M1 will be surveyed, and a custom mount will be made.

Initial mirror positions will be surveyed and adjusted to the nominal positions. A camera or alignment telescope will be used to ensure that the mirrors are well centered on the apertures in the PBIP, the vacuum window, and the shield wall.

For alignment adjustments a camera with a telephoto lens, or an alignment telescope will be used. It would be an advantage if the optical axis of the alignment equipment is surveyable, so that the it can be determined directly with the laser tracker. The equipment needed will be tested and specified well in advance of the installation.

Alignment adjustment can be done either from the camera to the object, or from the object to the camera. Alignment equipment will be positioned on the nominal optical axis. The telescope will be adjusted so that it is parallel to the optical axis by aiming it at an alignment target placed in front of the closest mirror. The closest mirror will then be adjusted so the telescope can be focused on an alignment target on the optical axis between the closest mirror and the next. This process continues all the way through the optical system. As the mirror surfaces will move when they are adjusted, some iteration will be needed between re-centering the mirrors on the optical axis, and adjusting the angles.

In the final installation, M1 will be mounted on a non-adjustable mount. Even with a custom made mount from survey, there will be a small non-adjustable error on the installation. The ray of light going from the center of the object to the center of M1, will not perfectly hit the center of the remaining mirrors. It may therefore be easier to align from the surveyed position of M5 towards the object. A camera on the optical axis placed at the nominal position of M5 would then not see the image of the object perfectly centered, but the image of M1 should be. In this case, the optical axis on top of the PBIP can be found by placing the camera so that both M4 and M1 are centered on the image.

The errors from the alignment of the mirrors should be small compared to the errors from thermal deformations and installation listed in [3].

3 Installation, alignment and access strategy

The full optical path will not be accessible at any time during installation and alignment, so the alignment process will consist of several steps:

- Installation and initial alignment of mirrors in the PBIP.
- Final alignment of PBIP mirrors in the mock-up.
- Verification of alignment after the installation of the PBIP in the target monolith.
- Installation of M5-M7, final alignment of full path.

In addition to this, it would be very beneficial to have access to the mirror interfaces in the PBIP, before it is transported to Lund, as soon as possible to make sure the mirror components are compatible with the PBIP, and that it is possible to center the mirrors on the apertures. This is not a formal part of the PBIP acceptance tests. Oslo will supply all equipment and manpower for the tests.

3.1 Installation and initial alignment

The final installation of M2-M4 mirror mounts will be done at ESS with the PBIP placed horizontally. Installation will be easiest with full access to the mirrors and the optical path of the PBIP on a horizontal bench.

This will be the first time we will have the chance to do a complete alignment of the mirrors in the PBIP, so going through the complete alignment procedure would be beneficial.

Camera, mirrors and object will be placed at the nominal positions and be centered on the apertures. M1 will be mounted on a temporary mount with some adjustment possibilities, so that it too can be aligned.

Final alignment is achieved when:

- The optical axis is within 250µm of the center of the mirrors.
- The optical axis should be within 250µm of the center of the clear aperture between M3 and M4.
- M2 should be within 250µm of the center of the aperture between M1 and M2.
- M1 will be places close to the back of the aperture between M1 and M2, but the full mirror should be visible when seen through the optical system from the top of the PBIP.

We should be able to place alignment targets or alignment equipment near the nominal position of the objects. A 2m clearance above M1 would be sufficient. We should have the ability to place alignment equipment at the nominal position of M5. That means 1350mm along the optical axis leaving M4 for the target wheel system, and 1433mm for the proton beam window system. The direction of the optical axes leaving M4 are shown in Figure 1.

We should be able to move around the plug slices to access all mirrors.

Two weeks should be sufficient for aligning both slices. For the final alignment we would need an 8 hour shift without disturbance in the area, to avoid any vibrations or external light sources.

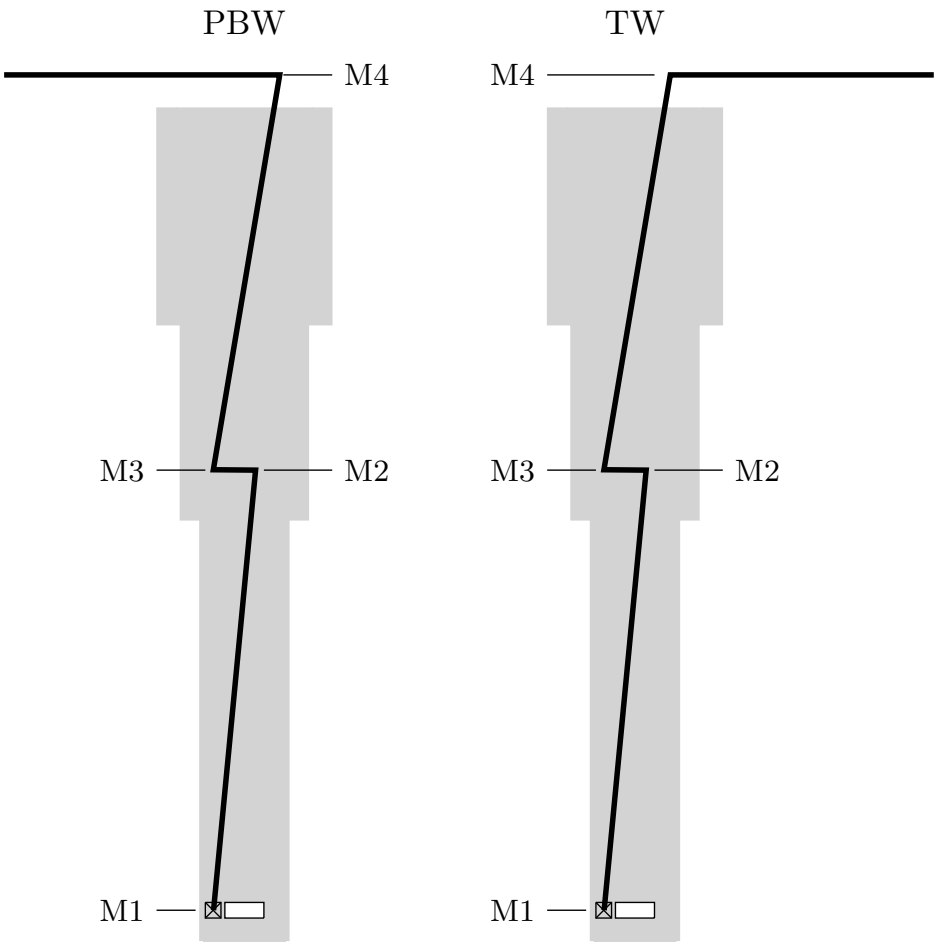

Figure 1: The optical path through the PBIP for the target wheel and the proton beam window systems as seen from the object.

3.2 Final alignment of the PBIP mirrors in the mock-up

Due to the flexibility of the PBIP, the alignment of the mirrors are expected to change when the plug is installed in the vertical position. Final adjustments to the alignment of the PBIP mirrors will be done with the plug installed in the vertical position in the ESS mock-up.

The alignment goals would be the same as in the previous step.

The aligned position of M1, as well as the surface M1 is attached to will be surveyed, and a custom mount will be made.

For the alignment, we will need full access to M1, M2, M3 and M4. We will need access to the optical path around the mirrors in order to place alignment targets and use survey equipment. We would need access to the optical path outside M4, at the nominal position of M5, for placing alignment equipment.

The error in the custom mounts for M1 should be quantified. The shift of the image of the object as seen from M5 should be quantified. The illumination system for the next step should be tested and validated.

Two weeks should be sufficient to align mirrors and manufacture a custom mount, but this needs to be confirmed.

For the final alignment we would need an 8 hour shift without disturbance in the area, to avoid any vibrations or external light sources.

3.3 Verification of the installation of the PBIP in the target monolith

None of the mirrors should move with respect to the PBIP when the PBIP is moved from the mock-up to the target monolith. The tilt of the PBIP with respect to the TCS should be less than 0.3°.

As soon as possible after the installation of the PBIP, these assumptions should be verified.

With a camera and an illumination system placed at the nominal position of M5, the optical axis should be re-centered on the camera by adjusting M4 so that both M4 and M1 are centered on the camera.

Tolerances can be verified by seeing all fiducials around the objects. We can make sure tolerances are met by measuring the distance from the fiducials to the edge of M1.

It should be possible to perform this task within a day.

3.4 Installation of M5-M7, final alignment of full path

Some time after the PBIP has been installed, the rest of the system should be installed and aligned. This includes

The shield wall will separate M6, M7 and the camera from M5 and M4, making it impossible for a laser tracker to create a nominal optical axis for the full part of the system.

The best option may be to align it in two steps. First alignment equipment can be placed in the connection cell, and align it to the center of the vacuum window, then to the center of M5 and M4. M4 would then be adjusted to center M1.

Alignment could then proceed from the camera to the shield wall aperture, validating that the remaining apertures are also well centered.

The optical axis should be centered within 1 mm on the shield wall aperture, the vacuum window, M5, M4 and M1.

During installation we will need access to M4, M5, M6, M7 and the camera position. We should be able to place alignment equipment in the connection cell, and have full access to the nominal camera position in the A2T access ares. We must to the vacuum window and the shield wall aperture to center alignment targets on them.

For the final alignment we would need an 8 hour shift without disturbance in the area, to avoid any vibrations or external light sources.

4 Alignment of prototype

The prototype, described in [1], has been aligned from the camera to the object with the help of a camera with a telephoto lens and a light source.

For initial alignment, a light source has been placed in the image plane of the lens, where the camera sensor would normally be. The light coming out of the lens has then been centered on the mirrors all the way to the object.

The mirrors are not rotated about the center of the mirror face, so they will move when they are adjusted. The mirrors in the prototype can only be adjusted for tilts, not translations. Achieving alignment of the full system can be done by iterating the procedure until the movement due to alignment adjustments are small.

Instead of surveyed alignment targets along an optical path, the path has been aligned by aiming at targets placed on or directly in front of the mirror centers.

An image of a part of the aligned system is shown in Figure 2.

The prototype has also been used to make sure we can find the optical axis on top of the PBIP part of the system, as shown in Figure 3. If the camera is not placed on the optical axis, we are also able to recenter it by moving M4, as shown in Figure 4.

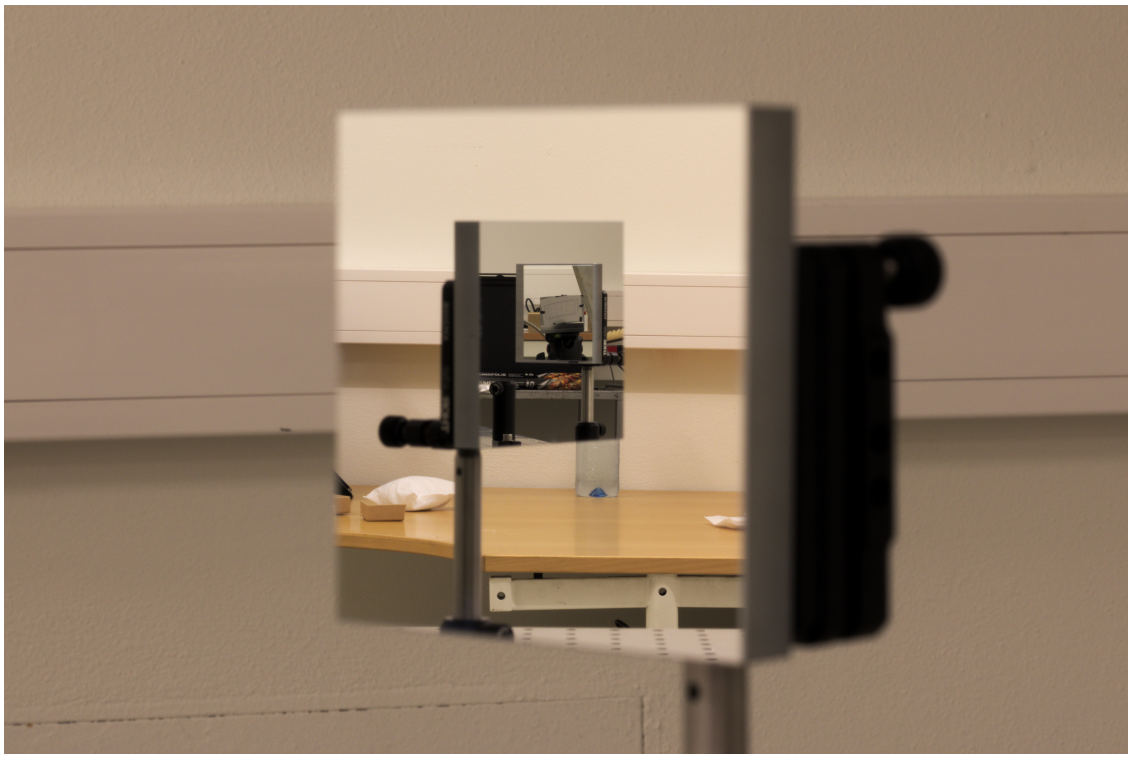

Figure 2: Aligned mirrors in the target wheel prototype. The image shows M5, M4, M3, M2, M1 and the test pattern placed in the object plane. M3 and M2 are very close to each other, and nearly overlap in the image.

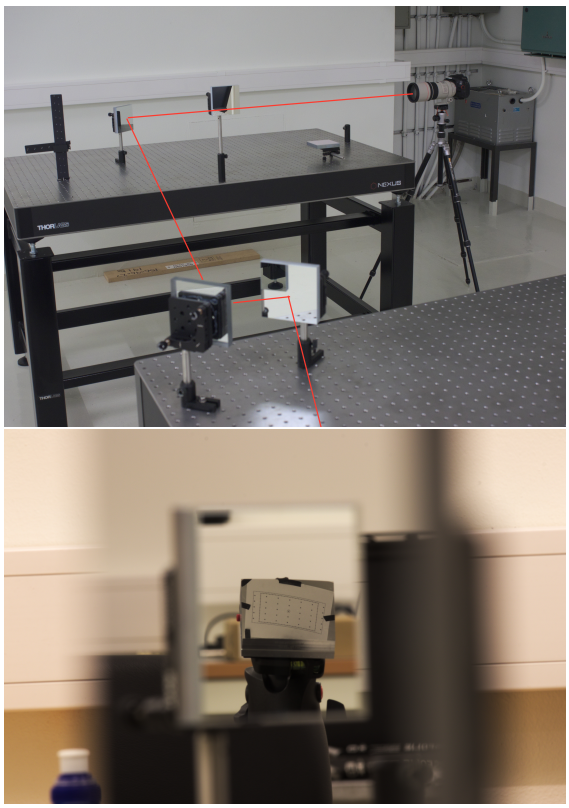

Figure 3: It is possible to find the optical axis on top of the PBIP by using a camera. The camera is not perfectly centered on the optical axis, as the camera is simply placed by hand on a tripod. The optical axis is where both M1 and M4 are centered on the image.

Figure 4: The top image is taken with the camera placed a few cm off the optical axis outside M4 by. The bottom image is taken after adjusting M4 to center the optical axis on the camera.

5 Summary

The installation and alignment strategy is summarized in the table below. The estimated time is agreed as a result of discussion with ESS Target and the in-king partner for the PBIP.

Action	location	Time	Duration
Final installation and initial alignment of PBIP mirrors	ESS Hall	Mid 2019	Two weeks
Final alignment of PBIP mirrors	ESS mock-up	Mid 2019/ End 2019	Two weeks
Verification of alignment in target	ESS	After PBIP installation	One day
Installation and alignment of M5, M6 and M7	ESS	After PBIP installation	One week

During the various steps, we will need access to the following parts of the optical path:

- During installation in the horizontal position, will need access to M1, M2, M3 and M4, and the full optical path between them. Should be able to place alignment equipment along the optical axis leaving M4.)
- During installation in the horizontal position, will need access to M1, M2, M3 and M4, and parts of the optical path between them. Need to be able to place alignment targets between mirrors. Should be able to place alignment equipment along the optical axis leaving M4 towards M5 (not installed).)
- To verify alignment after installation in target monolith, we need full access to M4, and to place alignment equipment(camera + illumination system) along the optical axis leaving M4.
- Installation and alignment of M5, M6, M7, camera: We need access to M4, M5, M6, M7, and camera position.

Alignment from camera to object using the camera and a light source has been tested with the prototype, and has yielded good results.

6 References

[1] Target optical systems, ESS-0149764
[2] Bendamount, ESS-XXXX
[3] Thermal simulations, ESS-0149765