ALIGNMENT MONITOR SYSTEM FOR THE PIP-II CRYOMODULES*

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Abstract

For the first prototype PIP-II SSR1 cryomodule, an alignment monitor system based on HBCAM will be used. The main focus will be changes in alignment due to shipping and handling or during cool down and operation process. The SSR1 cryomodule contains eight 325 MHz superconducting single spoke cavities and four solenoid-based focusing lenses, and an alignment error better than 0.5 mm RMS for the transverse solenoid, based on function requirement specification. The alignment monitor system has been configured to the objectives of SSR1 cryomodule: low space for integration; presence of magnetic fields; exposure to non-standard environmental conditions such as high vacuum and cryogenic temperatures. The mechanical design and first results of system performance will be presented.

INTRODUCTION

The alignment of the SSR1 cryomodule components was studied as the acceptable beam deflection, offset and defocusing, which may otherwise cause beam loss. Simulations and measurements established that the maximum deviations of the vacuum chamber from the reference orbit should not exceed 5% of the beam aperture. The requirements for cavities and focusing elements (solenoids) are summarized in Table 1 [1].

Table 1: Alignment Requirements

	SSR1	Solenoid
Angular error RMS, [mrad]	< 10	< 1
Transverse error RMS, [mm]	< 1	< 0.5

ALIGNMENT MONITORING STRATEGY

For this prototype cryomodule the alignment monitoring will be accomplished using optical targets installed on the internal assembly. The aim is to monitor relative translations and rotations of the components due to environmental conditions and cooldown operations. The targets positions are observed by monitoring cameras (HBCAM) installed on the metrology tables at the two outside ends of the cryomodule [2].

This alignment concept was inspired by the system used for the alignment setup of the HIE ISOLDE experiment at CERN [3]. The design of this cryomodule was initially not oriented to the alignment and the available space was limited. We therefore chose to monitor only relative movements of the cryomodule components, and have as calibrated distance the difference between two glass balls mounted in the same target, at a distance of 12 mm +0.003 mm-0.009 mm. The glass balls are chosen to have a high reflective index (about 2) to act as a retro-reflector for the HBCAM device.

MECHANICAL DESIGN

The SSR1 cryomodules contain eight cavities and four focusing lenses, with a total twelve elements need to be monitored.

The inner network of four target frames per element creates two internal view zones located from both sides of two-phase pipe (Fig. 1).

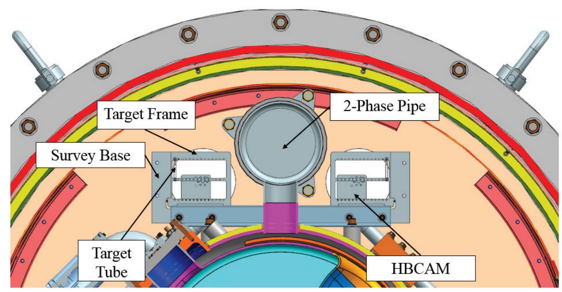

Figure 1: Cryomodule view.

Each target frame includes one target tube, in which two glass balls are spaced inside along with ceramic balls and spring. The target tube is machined with rectangular slot and allow glass balls being seen from both sides. It is mounted on target frame within a v-groove, in order to allow initial position of all targets without over shadowing the frame mount on survey base. The target frame can be adjusted with the respect to survey base vertically as well as horizontally. Once the position of the target frames is established are locked inside the survey base (Fig. 2).

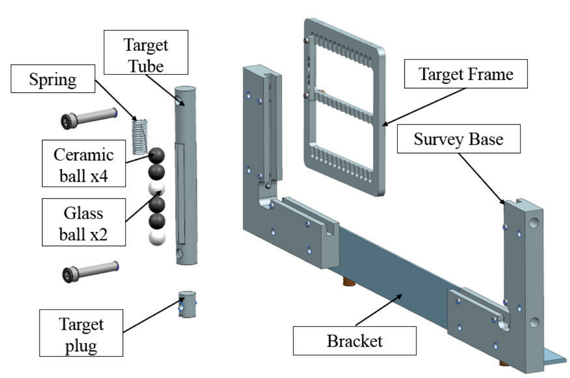

Figure 2: Frame and target assembly.

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Metrology tables are attached to the cryomodule side flanges from both sides of vacuum vessel. This allows each camera to be individually positioned (Fig. 3). The cameras position can be measured by laser tracker for calibration purposes.

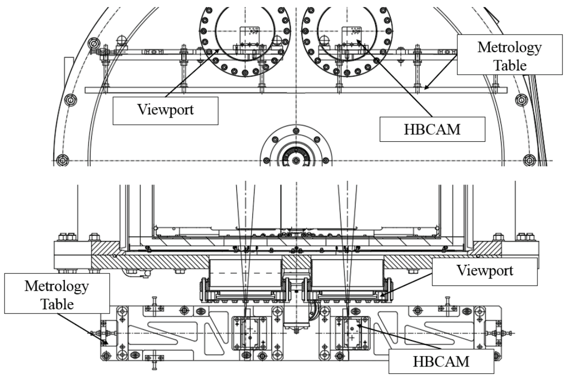

Figure 3: Top: Cryomodule end side view. Bottom: Cryomodule top cross section.

Each view zone contains 48 glass balls located in spatial distribution in order to not over shadow each over and allow the camera a full view of the target pattern (Fig. 4).

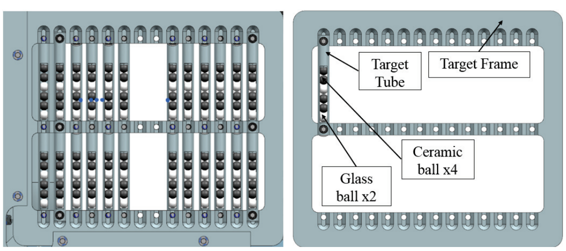

Figure 4: Left: Full target frame as seen from the camera. Right: individual target frame mounted on each component.

DATA ACQUISITION

The cameras from both sides of the vacuum vessel can view all glass balls, although 0.8 m minimum focal length do not allow to monitor closest cavity and solenoid to each camera therefore they will be monitored from opposite side.

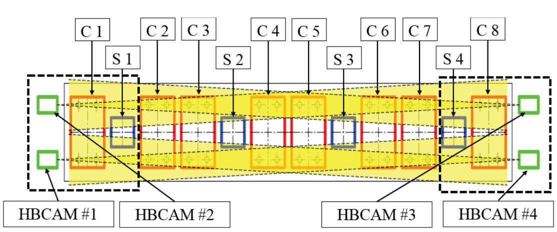

Figure 5: Cryomodule alignment monitoring scheme.

The first upstream and downstream cavities and solenoid will be monitored by one camera the rest six cavities and two solenoids will be monitored by two cameras and will have redundancy in measurements (Fig. 5, Fig. 6).

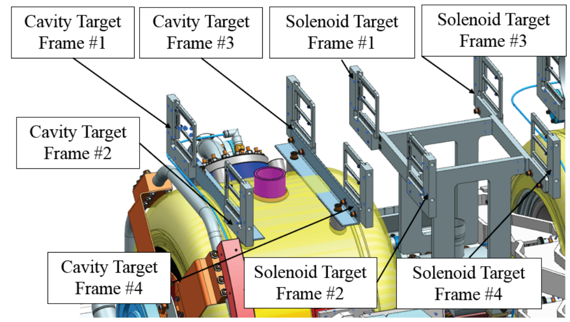

Figure 6: Cryomodule coldmass view.

A laser source from the camera is flashed on the targets, the images are acquired on CCD sensors and the position in pixel points is found by scanning the luminosity peaks in the picture. A proper calibration is needed to translate pixels to real measurements in the reference frame (Fig. 7). [4]

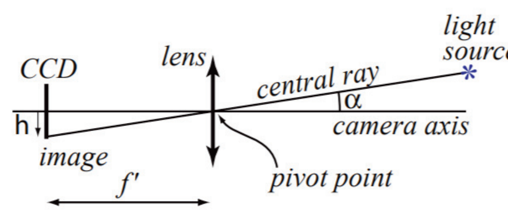

Figure 7: BCAM measuring principle.

The targets are scanned one after the other, by selecting restricted areas of the image to improve the observation reliability. Figure 8 shows a view of the targets as seen from the HBCAM. Repeated measurements are taken and averaged for a better accuracy.

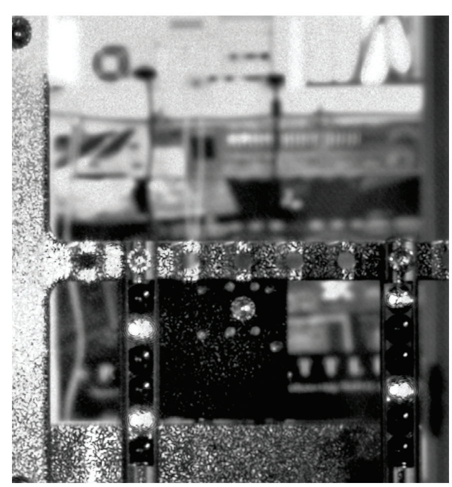

Figure 8: Picture of a portion of the frame, including the retro-reflective targets, and the facing camera as observed by the HBCAM.

BCAM VALIDATION

First measurements have been performed on a test bench to evaluate the performances of the setup. On the bench two cameras are facing each other, the targets are mounted on translation stages moving in the beam direction (*z-axis*) and the transverse horizontal direction (*x-axis*). A Coordinate Measuring Machine (CMM) initially acquires the position of the two cameras and the targets. The survey of the targets is repeated at each step of the translation stages from both the CMM and the cameras. Tables 2 and 3 show the geometry parameters of the bench as measured from CMM, and the nominal step sizes of the translation stages, respectively.

Table 2: Test Bench Geometry, from CMM Survey

	x	y	z
BCAM 1, [mm]	0	0	0
BCAM 2, [mm]	2.507	-22.130	2141.723
Target frame, [mm]	64.795	83.974	914.428

Table 3: Nominal Step Sizes

Axis	Step
x-axis, [µm]	200
z-axis, [µm]	500

The raw data from the cameras have been analyzed and cross-checked with the CMM acquisition. The results are summarized in Table 4. We observe a good agreement between the independent measurements of the BCAM and the CMM, with an sub-micrometric error on the *x-axis* and a larger spread on the beam direction.

Table 4: Results Summary

	x-axis		*z-axis*	
	mean	var	mean	var
Step size, [µm]	198.1	0.4	505.6	42.1
Relative error, [%]	1.25	0.84	1.44	16.96
HBCAM 1-2 distance, [mm]			2125.5	0.3091

Figures 9 and 10 show the distributions of the step sizes on the two axes in absolute and relative values. Fig. 11 depicts the data distribution of the distance between the two cameras. The absolute error could be resolved through calibration, while the variance of the data is aligned to the sensitivity measurement, that depends from the target separation and distance (d and r, respectively):

$$\sigma(r) = \sqrt{2}\sigma(\alpha) - \frac{r^2}{d}, \quad (1)$$

where $\sigma(\alpha)$ is the uncertainty on the measurement of the angle between the target and the camera axis [Fig. 7].

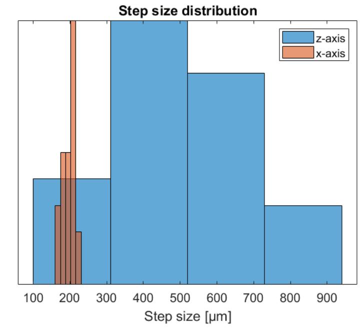

Figure 9: Step size distribution.

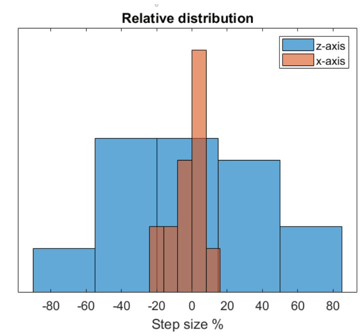

Figure 10: Relative error.

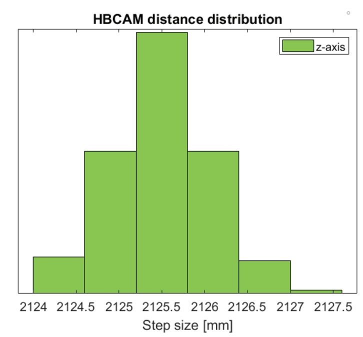

Figure 11: HBCAM 2 to HBCAM 1 distance.

CONCLUSION

The SSR1 prototype alignment monitor system was designed and validated on a test mock up. The plan is to prepare complete system and integrate it into the cold mass assembly by end of CY 2019.

REFERENCES

[1] *PIP-II Conceptual Design Report* https://pxie.fnal.gov/PIP-II_CDR/default.htm

[2] *OSI* http://www.opensourceinstruments.com/HBCAM/

[3] Gayde, J. C., *et al.*, "HIE ISOLDE Alignment and monitoring system technical design and project status", eConf 1209102.CERN-ATS-2012-269 (2012): 25.

[4] *HBCAM Prospectus* http://alignment.hep.brandeis.edu/Devices/BCAM/Prospectus.pdf