CONSTRUCTION AND OPERATIONAL PERFORMANCE OF A HORIZONTALLY ADJUSTABLE BEAM PROFILE MONITOR AT NSLS-II*

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Abstract

The NSLS-II Synchrotron Light Source is a 3 GeV electron storage ring currently in the early stages of commissioning at Brookhaven National Laboratory. In order to observe the electron beam cross section in the injection region of the storage ring, a specially designed, horizontally adjustable beam profile monitor was installed at the downstream end of the injection septum. It allows the profile of the injected, bumped or single turn beam to be viewed and measured. In this presentation, we discuss the final design, construction challenges, and operational performance of this novel device.

DESIGN REQUIREMENTS

The primary design requirements for the NSLS-II beam profile monitor [1] or "flag" are as follows. Insert a scintillator screen into the beam path at three different horizontal positions within the vacuum chamber, allowing the beam cross section and rough position to be captured. The chamber length and internal aperture are defined by the space between the upstream septum chamber and downstream kicker chamber. In this case the overall chamber length is 357mm with 150mm CF (Conflat) flanges. The upstream and downstream internal apertures are different and require a tapered transition over the chamber length.

In order to capture the beam at three different locations, the horizontal screen position needs to be precisely controlled to a resolution of 250µm. It is also desirable to have the screen position infinitely adjustable as opposed to just three discreet positions. A position read back device is also required to verify horizontal position.

Due to space constraints in the injection region, the choice was made to incorporate two sets of RF BPM (radio frequency beam position monitor) button assemblies into the flag chamber. One set of BPMs located 24.25mm from chamber center is intended to measure position of the injected beam while the other set located 15mm from chamber center is intended to measure bumped beam position.

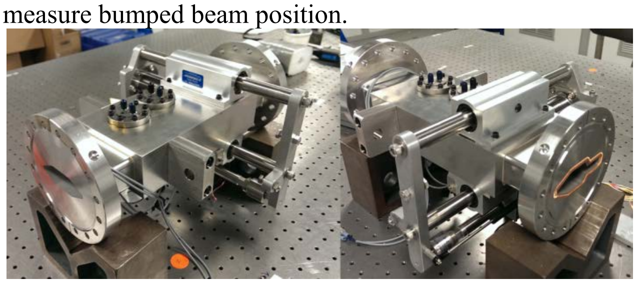

Figure 1: NSLS-II SR Flag in final assembly configuration.

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CHAMBER CONSTRUCTION

The construction of the flag chamber was by far the most challenging aspect of this design. The final design consists of a three piece stainless steel assembly with two brazed joints. The body of the chamber is a rectangular stainless steel "slab" 57mm x 120mm in cross section. The internal aperture is rectangular and is 25mm x 80mm on the upstream side and tapers to 25mm x 76mm over the 230mm length. The internal aperture was precisely cut via a wire EDM (electro discharge machining) process. Ports were machined into the top, bottom and side of the slab to accept the BPMs and bellows assembly. These ports are designed to be used with HelicoFlex® Delta-type UHV (ultra high vacuum) seals and require a specially prepared surface to mate with. The surface finish requirement for these seals is 16 micro inch with a circular lay. Delta-type seals are used extensively in the NSLS-II storage ring with great success.

To simplify the chamber assembly, both the upstream and downstream flanges are a one piece fabrication, each is machined from a slug of 304 stainless steel. This eliminated the need for welding Conflat flanges after the brazing was complete. The upstream aperture has a complex internal geometry, tapering from an asymmetric shape corresponding that of the downstream aperture of the septum chamber to a rectangular aperture that matches the central chamber. Machined into the face of the upstream flange is a dovetailed groove designed to accept a slant coil RF spring, the purpose of which is to shorten any cavities where high order modes can exist. The downstream flange tapers from a rectangular shape to the standard NSLS-II 25mm x 76mm hexagonal aperture. The apertures of both flanges were also cut using EDM. Fiducial targets were machined into the circumference of both flanges for in-situ survey and alignment after installation in the storage ring.

Figure 2: Successfully brazed flag chamber.

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The chamber assembly and brazing (Fig 2) were performed in-house and took place in two stages, a high temperature braze for the upstream flange using an 82%Au-18%Ag braze alloy (Premabraze 131) followed by a low temperature braze for the downstream flange using a 56%Ag-42%Cu-2%Ni (Braze 559). Both braze joints were successful after the first attempt as the subsequent leak check revealed.

SCREEN CARRIER ASSEMBLY

The primary component of the flag is a Cerium doped YAG (Yttrium-Aluminum-Garnet) scintillator screen with a 20mm calibration pattern and is produced by Crytur [2]. The elliptically shaped, 200µm thick screen is mounted into a custom machined aluminium screen carrier such that the angle of the screen with respect to the incident electron beam is 45°. The screen carrier assembly consists of the screen carrier optical tube, the YAG screen and the screen retainer. An aperture is cut into the screen carrier tube to allow the injected beam to pass through when viewing the bumped or single turn beams (Fig 3).

Figure 3: Screen carrier assembly and a beam's eye view of the YAG screen in the first turn position.

The screen carrier assembly is installed in a custom bellows which is mated to the side of the flag chamber via a custom flange and HelicoFlex seal. The free end of the bellows is capped with a fused silica viewport to allow the beam image to be observed by the optical system.

A special provision was designed into the screen retainer. A rim which when the flag is in the parked or home position bears up against a slant coil spring installed in the chamber (Fig 4). This feature serves to shield the cavity inside the bellows and suppress high order modes.

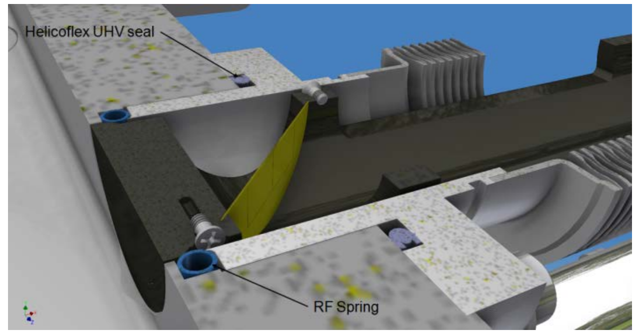

Figure 4: Screen in the parked position showing the RF spring. The HelicoFlex seal is also shown.

MOTION CONTROL

A set of linear bearings secured to the top and bottom of the flag chamber constrain the bellows and screen carrier to purely horizontal motion. These bearings were assembled with a special radiation resistant grease to avoid the problems commonly experienced with organic grease in high radiation environments.

In order to accurately position the screen, a radiation hardened, stepper driven linear actuator with a 100mm stroke was chosen. This type of actuator was employed in other NSLS-II systems and provides resolution of 10µm or better and high repeatability. Precision limit switches are installed at the travel limits, one of which is used for homing. These switches have a repeatability of 2 µm. Finally, a position read back device was installed to report the horizontal screen position. A linear potentiometer was chosen for this purpose since it is resistant to radiation damage and influence from stray magnetic fields and has adequate resolution and repeatability.

FINAL ASSEMBLY OF THE FLAG

Final assembly of the flag took place inside a portable clean hood following standard UHV vacuum practices (Fig 5). A critical aspect of the final assembly was to insure the screen carrier was centered within the bellows and side port of the chamber and that it could traverse the entire 75mm horizontal aperture of the chamber without impediment.

Figure 5: Final assembly of the NSLS-II SR Flag inside a portable clean hood.

OPTICAL TRANSPORT ASSEMBLY

The optical transport for the flag is constructed primarily of commercial off-the-shelf components and has an optical path length of 900mm (Fig 6). It consists of an LED illuminator coupled directly to a kinematic right angle mirror. A remotely controlled filter wheel is mounted to an extruded aluminium rail along with a CCD and lens mounted atop a 100mm focusing stage. The focusing stage is a critical element in the optical assembly due to the fact that the YAG screen is dynamic and can be positioned anywhere within the 75mm range of the chamber aperture. The control system is programmed so the focusing stage follows the linear actuator that controls the screen position. The entire optical transport was pre-assembled remotely and then installed, aligned and tested in-situ.

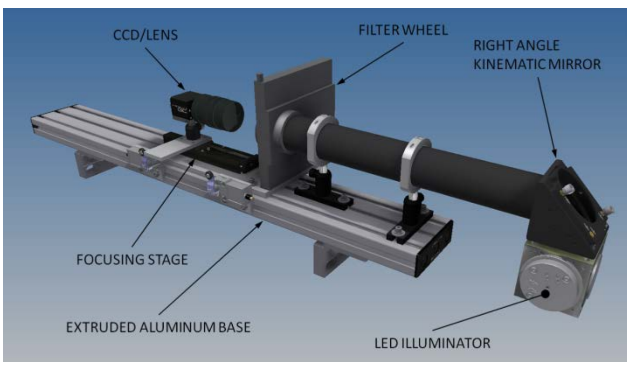

Figure 6: Details of the NSLS-II SR Flag optical transport.

INSTALLATION

Installation within the injection straight took place in stages. The flag itself was installed and vacuum connections made between the upstream septum chamber and the downstream bellows (Fig 7). The system was then leak checked and a bake-out was performed to insure the vacuum satisfied NSLS-II specifications. The optical transport was then installed, aligned and tested followed by the installation of semi-rigid SiO_2 coaxial BPM cables (Fig.8).

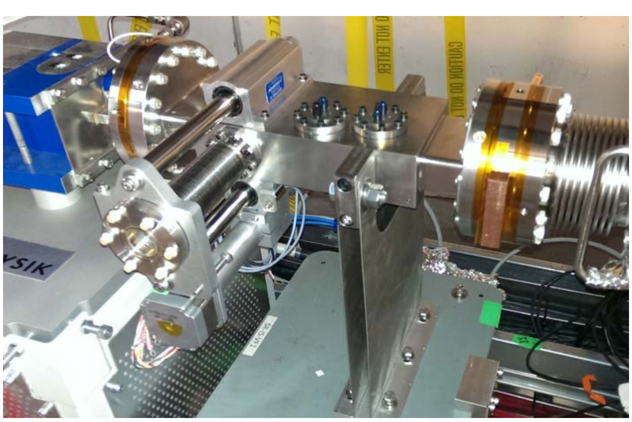

Figure 7: Installation of NSLS-II flag in the injection straight.

Figure 8: Final configuration of NSLS-II SR flag.

COMMISSIONING

The horizontally adjustable flag proved very useful during the commissioning phase of injection. The position and beam cross section were easily obtained using this device. Fig. 9 shows the CSS (Control Systems Studio) screen used to interface with the flag. The Flag Controls toolbar allow the user to move the screen to one of three pre-programmed positions corresponding to the injected, bumped or single turn beam or an arbitrary position can be entered within the physical limits of the chamber. The Camera toolbar shows the image capture with X and Y calibration in terms of µm per pixel as well as filter wheel information.

The pulsed septum injection channel is 1.3 m long and has 20 mm x 10 mm horizontal x vertical inner transverse size. The nominal horizontal size of the beam at the exit of the septum is about 6 mm (6σ) and the design trajectory of the beam is such that at septum exit the beam almost touches the septum wall.

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From the above, it is easy to see that even small errors can cause partial loss of the beam. Indeed, on many occasions we observed a clipped beam image on the flag, and in a few extreme cases, the complete loss of the beam. By monitoring the beam image on the flag and tuning the two injection septa and the beam correctors we were able to correct the trajectory of injected beam and to improve the injection rate.

The injection straight flag was also used together with flags in the Booster to Storage Ring transfer line for proper matching of the injected beam envelope.

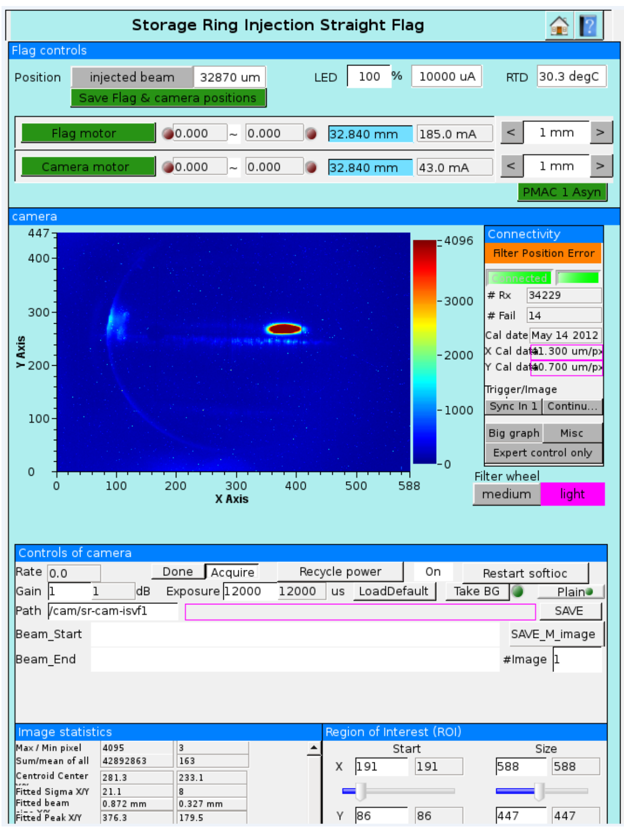

Figure 9: The interface control screen for the NSLS-II SR flag showing an image of the injected beam.

CONCLUSIONS

The overall design of the NSLS-II storage ring flag was adequate to satisfy the performance requirements specified by accelerator physicists. The fabrication and assembly took place with few if any problems. The brazed stainless chamber proved to be a solid design given the complexity of the internal and external features and should be considered for similar applications in the future. The novel aspect of the NSLS-II storage ring flag, the ability to position the screen anywhere within the chamber aperture is shown to be both feasible and useful during commissioning and will be potentially useful during beam studies.

REFERENCES

[1] B. Kosciuk, “Development of a Horizontally Adjustable Beam Profile Monitor for the NSLS-II Storage Ring”, MEDSI-2012, Shanghai, May 2010

[2] Crytur, www.crytur.cz