Development of a Horizontally Adjustable Beam Profile Monitor for the NSLS-II Storage Ring

Presenting author: Bernard Kosciuk#
Organisation: Brookhaven National Laboratory, Upton, NY, USA 11973

Co-author: Sergei Seletskiy
Organisation: Brookhaven National Laboratory, Upton, NY, USA 11973

Co-author: Alexei Blednykh
Organisation: Brookhaven National Laboratory, Upton, NY, USA 11973

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Abstract:

The NSLS-II Synchrotron Light Source is a 3GeV electron storage ring currently under construction at Brookhaven National Laboratory. During the commissioning phase, there will be a need to profile the beam shape after injection and it will be desirable to have the ability to measure the profile the injected beam as well as the single turn beam in either the stored or bumped positions. Traditional beam profile monitors are typically installed at discreet locations allowing the beam to be viewed in only one position. To view the beam in the injected, bumped and stored beam positions, three profile monitors would need to be installed at specific locations across the chamber aperture. Here we present a novel design that will have the ability to position the beam imaging screen infinitely between the parked position and the extreme horizontal limit of the chamber allowing the injected, single turn bumped and stored beam profiles to be measured.

1-Motivation for Horizontally Adjustable Profile Monitor

The motivation for this novel design came from the desire during the commissioning phase of the NSLS-II storage ring to have the ability to measure the transverse beam profile of the injected beam as it exits the septum chamber. However, in addition there was also the desire to measure the transverse beam profile and position of the first turn stored and bumped beam at this location. Since space was limited to 356mm, it was difficult to fit three discreet screens in this location. A screen that could me positioned horizontally at the point of

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#bkosciuk@bnl.gov

interest seemed like the ideal solution to this problem however certain design challenges needed to overcome in order to make this concept feasible.

2-Basic Requirements

The performance and mechanical requirements for this beam profile monitor of "flag" (hereafter) are as follows. The fluorescent screen was chosen to be Yttrium-Aluminum-Garnet doped with Cerium (YAG:Ce) as a visible light scintillator. Screens of this type provide good spatial resolution for low charge beams [1]. The screen must also have etched calibration marks since an external virtual target is impractical due to the dynamics of the flag.

The screen must be able to traverse the entire horizontal aperture. At this location, the stroke requirement needed to achieve this is 78mm. Since this flag will be used to establish rough beam position, the positional accuracy of the screen required is ±250µm.

The chamber length is defined by the positions of the adjacent chambers and must be 356mm long with 6" Conflat flanges. The upstream aperture of the flag chambers will match that of the downstream aperture of the adjacent septum chamber. The downstream aperture matches that of the standard NSLS-II 25mm x 76mm vacuum chamber. The chamber must transition smoothly to minimize losses due to longitudinal wakefields.

A secondary requirement unrelated to those of the flag is to have provisions in the chamber for two sets of RF BPM button feed throughs to resolve the positions of the injected and bumped beams.

3-Design Concept

The design that evolved from the above requirements is shown in Figure 1. It consists of a three piece brazed stainless chamber with a penetration on the inboard side to allow the flag screen to protrude.

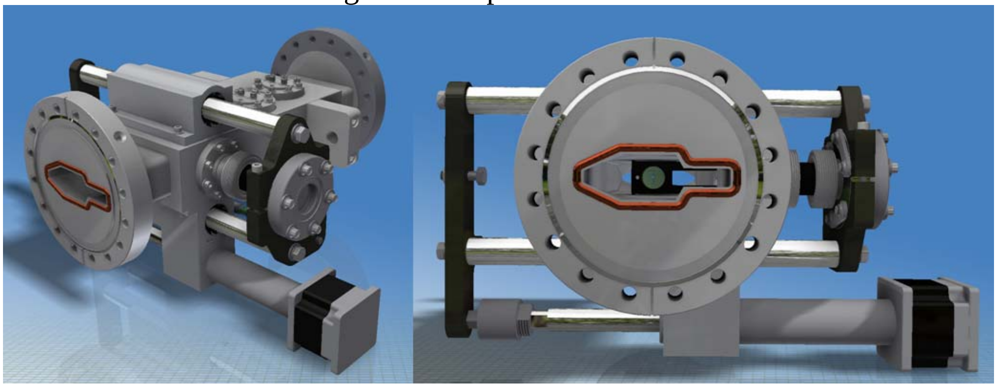

Figure 1: Design concept of horizontally adjustable flag.

The unique design of the YAG screen carrier allows the screen to be supported at 45 degrees to the incident beam while allowing the beam image to be transported to the optical system regardless of horizontal position. A rectangular aperture cut through the screen carrier tube allows the injected beam to pass through unfettered (Fig 2a).

The screen carrier assembly is mounted to an edge welded vacuum bellows with a sapphire viewport from which the beam image is extracted. There is also a provision at the end of the screen carrier that suppresses beam excited high order modes from forming within the bellows cavity. A circular spring seal is installed in the flag penetration such that when the flag is in the parked position, a raised portion of the screen carrier seats against this spring and electrically shorts it to the chamber. This feature acts as a shield and will not allow high frequency energy to penetrate (Fig.2b).

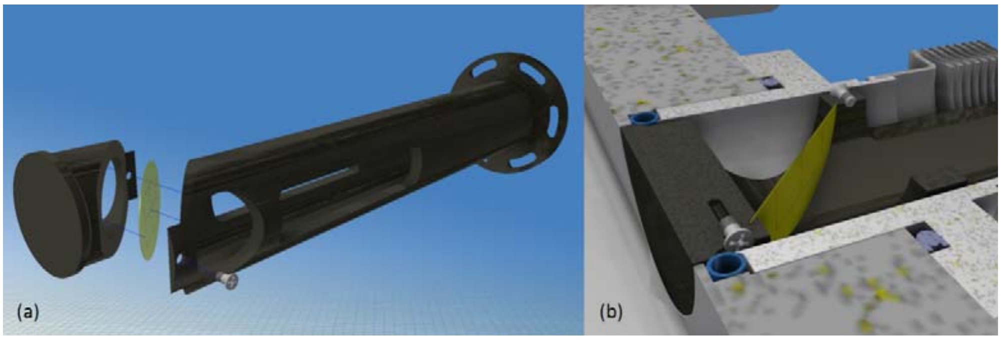

Figure 2 (a) Screen carrier assembly. (b) Carrier in parked position shorted against RF spring seal.

The screen carrier and bellows assembly are mounted to a set of linear slide bearings secured to the top and bottom of the chambers and insure precise horizontal travel of the screen. The position of the entire movable assembly is controlled via a radiation hardened stepper motor linear actuator capable of micron resolution.

4-Vacuum Chamber Design

The most challenging aspect of this design was the tapered vacuum chamber. The unique shape of the septum exit port was such that a one piece flag chamber was impossible. The middle portion of the chamber required a rectangular aperture to allow clearance for the screen to traverse the entire 78mm. Effectively, the internal chamber geometry transitioned from the unique septum aperture to a horizontal shape and then back to the hexagonal shape of the NSLS-II vacuum chamber. We chose a three piece design that would be brazed at the interfaces and could be manufactured with wire EDM machining (Fig3).

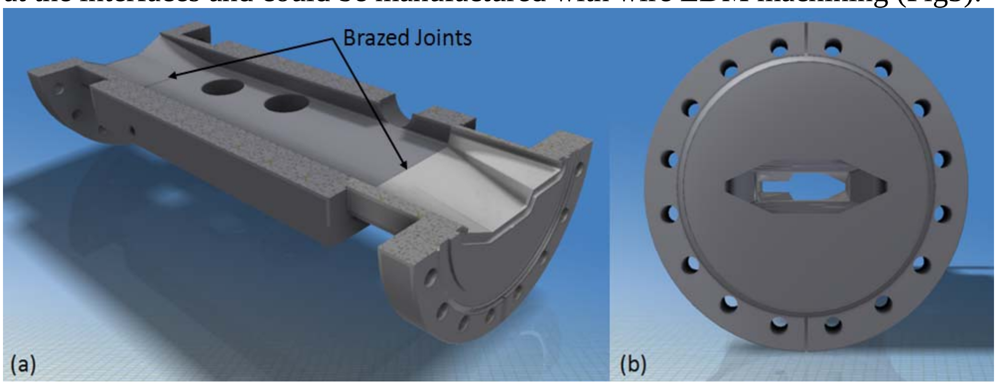

Figure 3 (a) Cross section of a three piece vacuum chamber. (b) View looking upstream towards septum chamber.

An electromagnetic analysis was performed using GdfidL [2] to verify that there were no significant power losses due to the longitudinal wakepotential and no strong resonant modes in the area of the septum knife. The horizontal dipole impedance indicates (Fig. 4) that there are no trapped modes in the transition region and the estimated kick factor for a 3mm bunch length using the simulated horizontal dipole wakepotential (Fig. 5) $\frac{k_x = 4\frac{V}{pC}}{m}$, which is quite small when compared with results for other vacuum elements installed in the NSLS-II storage ring.

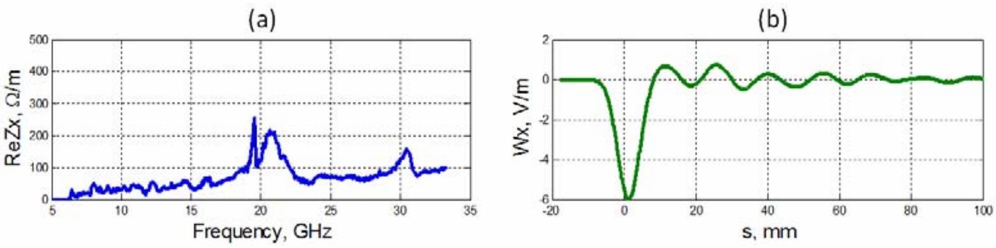

Figure 4 (a) Real part of horizontal dipole impedance. (b) Horizontal dipole wake potential, k_x=4V/pC/m

The primary focus in these analyses was to address issues reported by many facilities in the area of the septum knife. Our design consists of a smooth transition in the area of the septum knife. It allows us to reduce the geometrical loss factor and to eliminate existence of trapped mode which can also contribute to the loss factor due to multi-bunch passing. The estimated loss factor for a 3mm bunch length using the calculated longitudinal wakepotential (Fig. 7) is $k_{loss} = 24\frac{mV}{pC}$. The results of this analysis indicate a loss of 14 W for a 500 mA circulating average current in $M = 1080$ bunches with the revolution period of $T_0 = 2.6\mu s$.

$$P_{loss} = \frac{k_{loss} I^2 T_0}{M}$$

We included provisions in the chamber for the addition of temperature sensors in the area where this power will be deposited.

The real part of the longitudinal impedance is shown in Fig. 6 There are two peaks with low quality factor, which are generated due to 1.5mm height of RF shielding. To eliminate these two peaks we would need to decrease the height of RF shielding. We significantly improved the septum chamber design by introducing the smooth transition, since there are no other resonance modes in the frequency spectrum up to 32GHz.

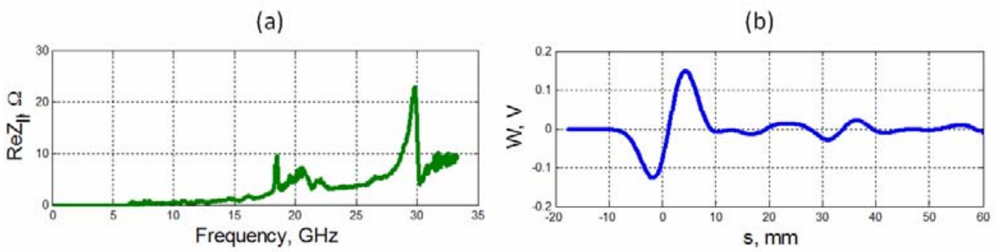

Figure 5 (a) Real part of longitudinal impedance. (b) Longitudinal wake potential.

5-Optical Transport

The requirements for the flag optics are driven by the necessity to resolve the beam image in the full range of flag motion. From the start we abandoned the idea of moving the camera in synchrony with the flag screen, since this option significantly complicates the overall mechanical design of the flag. Therefore we were left with two possibilities. One can either have the fixed optics, which results in the 75 mm depth of field (DOF), or alternatively one can use remotely adjustable lens, which gives 14 mm DOF (determined by the size of the flag screen). To choose between these two options we performed a set of dedicated tests. Our studies show that the fixed optics provides 100 um resolution. On the other hand, the camera with remotely adjustable optics can provide 50 um resolution. To finalize the optical design for either case, we suggest choosing the lens and camera-to-flag distance that provides several (2-3) pixels per image of the object of 50 um size. The circle of confusion for the given DOF shall be as small as possible and the lens aperture shall be open to 20 mm. All these considerations along with the desire for simplicity of the design led to the optical setup that is shown in Figure 5. We will use Proscilica GC1290 camera (pixel size is 3.5 um x 3.5 um) with the motorized Computar H10Z1218 lens. The effective distance from the flag to the lens will be L=1.5m.

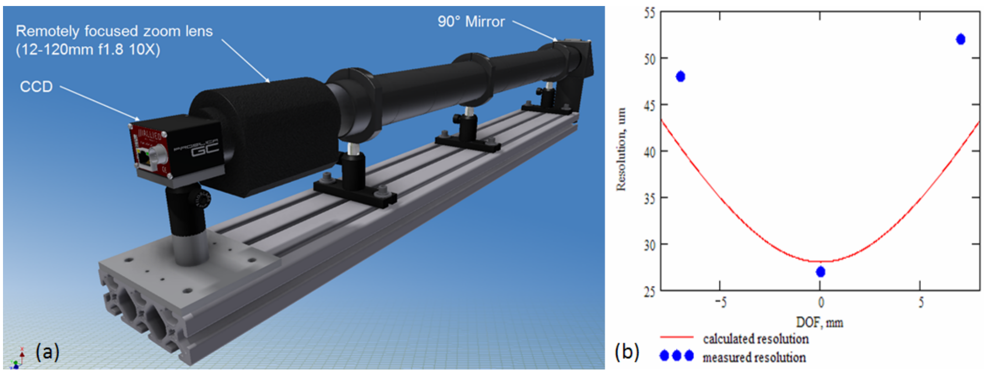

Figure 6 (a) Optical transport design. (b) Test results of optical arrangement showing resolution.

6-Conclusion

At the time of this writing, the final design is complete and we expect to have a prototype ready for testing in 4-6 months. This will include a 10,000 cycle test of the motion system to exercise the vacuum bellows and mechanical actuator. We will also test and measure the performance of the optical system.

References

[1] W.S Graves and E.D Johnson, A High Resolution Electron Beam Profile Monitor, IEEE (1998)

[2] W. Bruns, GdfidL, http://www.gdfidl.de.