DESIGN AND FABRICATION OF NSLS-II STORAGE RING VACUUM CHAMBERS AND COMPONENTS*

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Abstract

The National Synchrotron Light Source II (NSLS-II) is a 3-GeV synchrotron radiation facility currently under construction at Brookhaven National Laboratory [1]. This 792-meter circumference facility will provide ultra-high flux and brightness with a nominal circulating current of 500 mA and sub nm-rad horizontal emittance. The majority of the storage ring vacuum chambers are made of extruded aluminium with the remainder composed of Inconel and stainless steel. Chambers sections are interconnected using low impedance RF shielded bellows. Synchrotron radiation from the bending magnets is intercepted by photon absorbers made of GlidCop [2] which are water cooled to dissipate heat. This paper describes the design and fabrication of vacuum chambers, the RF shielded bellows and the photon absorbers. The fabrication of the chambers and components are almost completed. The vacuum system is now moving into the conditioning, installation and testing phase of the project.

INTRODUCTION

The NSLS-II storage ring consists of 30 double-bend-achromatic cells which are further divided into five magnet/chamber girders (Figure 1). Between each cell are straight sections with alternating lengths of 6.6 m and 9.3 m which provide space for a variety of insertion devices (IDs) in addition to RF cavities and injection from the booster ring. In total, over 300 aluminium chambers and 90 short Inconel are required to complete the storage ring.

Figure 1: Completed NSLS-II DBA cell

VACUUM CHAMBERS

Most storage ring chambers are comprised of extruded aluminium sections welded to explosion bonded aluminium-to-stainless CF flanges. Aluminium was chosen as chamber material for its good mechanical and thermal properties, low magnetic permeability, ease of fabrication, and low impedance to the beam [3].

The chamber extrusion cross sections were primarily driven by the magnet geometry but also needed to meet the photon fan extraction requirements and minimum safe wall thickness while maximize pumping conductance. In the end, two different but similar profiles were designed (Figure 2). Both extruded profiles have an elliptical or hexagonal shape beam channel of 76 mm (H) x 25 mm (V) connected to an ante-chamber via a narrow extraction slot (Figure 2). The multipole profile has a flat surface in the center of the beam channel which simplifies the beam position monitor (BPM) mounting and allows closer spacing of the pickup buttons. In addition, three round holes were extruded into the profiles. Two of these channels are used for cooling water to help maintain a stable chamber temperature. A cal rod heater is inserted into the third channel (at top-right side) to facilitate in-situ bake out.

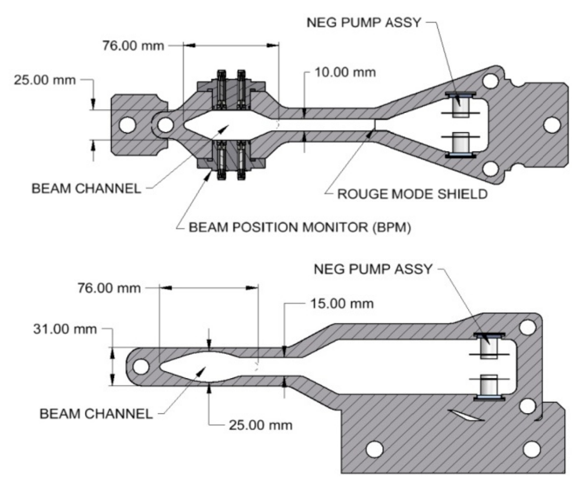

Figure 2: Extruded multipole (top) and dipole chamber cross sections

The development and procurement of the required extrusions took place over a period of ~ 2 years. The dipole extrusions were bent to a 6° curvature using a large hydraulic press at BNL. After bending, the extrusions were thermally cycled twice to 180° C to relieve the stress and assure the stability of the curvature in subsequent operation from machining to in-situ bakes.

After the extrusions were measured and deemed usable, they were machined to accommodate the various magnet pole tips. The nominal design clearance between the

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chambers and the magnet poles was ~ 2 mm. In addition to pole clearance, precision machining with extremely tight tolerances was required at the welding interface for the various pumping and instrumentation ports as well as end transition plates, prior to the welding of the bimetallic CF flanges. Mounting provisions for BPMs were machined directly into the multipole chamber extrusions.

All individual chamber components were shipped to Argonne National Laboratory (ANL) where they were cleaned and inspected. The large cell vacuum chamber welding was accomplished at ANL's automated welding facility (Figure 3). The cleaning and certification of the completed chambers was also provided by ANL. Currently all 150 long cell vacuum chambers have been completed and are ready for integration into magnet/girder assemblies. The welding of day one straight section chambers is scheduled to be completed this July.

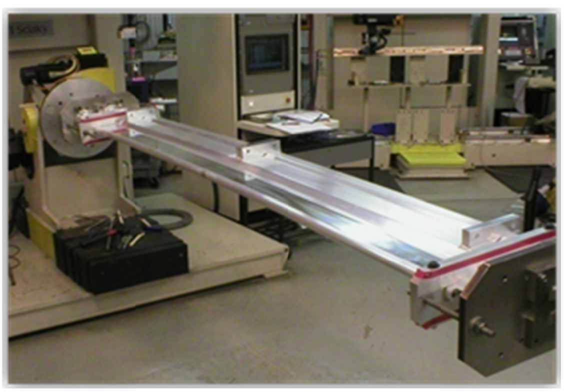

Figure 3: Welding facility at Argonne National Lab

Besides the large cell vacuum chambers, there are 150 smaller vacuum chambers in the storage ring. Sixty of these chambers are fabricated from a narrow aluminum cross section with beam aperture dimensions similar to the multipole cross section. This smaller profile was required to provide clearance for the photon exit pipes and to accommodate the narrow gap three-pole wiggler magnets. Bimetallic CF flanges were also used for the end flanges and pump ports.

The other 90 chambers were fabricated from thin walled Inconel sheet and provide a mounting location for the fast corrector magnets. Inconel was chosen for its low magnetic permeability, high strength and high resistivity, thus minimize eddy current and its effect from the fast correct magnets (up to 1 kHz). The two halves were seam welded to form a tube with the same cross section as the multipole extrusion. This tube was then brazed to stainless steel CF flanges in a vacuum furnace at BNL. Two braze alloys with different liquidus temperatures were used to allow the flanges to be brazed one at a time so the tube could remain vertical thus ensuring good braze flow. This technique, while more time consuming, produced more consistent results with dimensionally superior assemblies.

PHOTON ABSORBERS (ABS)

The unused bending magnet radiation and that from mis-steered beam must be intercepted to shadow and protect downstream flanges, bellows and other components in order to prevent damage and vacuum leaks. There are three types of ABS used in the storage ring stick, crotch and flange (Figure 4).

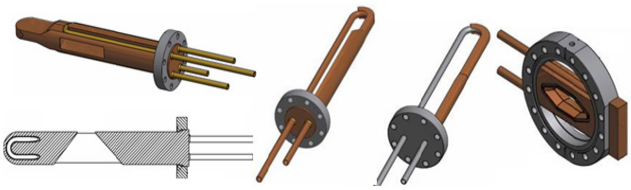

Figure 4: From left to right: Crotch ABS with opening, crotch ABS without opening, stick ABS and flange ABS.

Stick absorbers, located at the downstream end of multipole chambers, are used to trim the radiation fan from upstream bending magnets. Crotch absorbers are located at the downstream end of dipole chambers and are used to trim the majority of the bending magnet fan. In straight sections where IDs are installed, an opening is provided in the crotch absorber to extract the resulting photon fans. Blank crotch absorbers without an opening will be used downstream of straight sections not populated with ID. This eliminates the need to install photon exit pipes and other required components until an ID is ready. The third type of absorber is built into a CF flange and ensures critical components are protected from large beam offsets during beam studies.

The relatively weak bending field of the NSLS-II storage ring (0.4 Tesla) results in a synchrotron radiation fan with low power density compared to other light sources. This fact allowed for a compact and simplified stick absorber design that is inserted through a 3.38" CF flange port on the outer wall of the ante-chamber. The design consists of an 8mm OD stainless steel tube bent into a 'U' shape which provides structure and a loop to circulate cooling water. A GlidCop shell is then brazed onto the side that faces the beam to intercept the photon fan. The brazed assembly is then welded to a stainless steel CF flange. This design allows the tip to flange dimension to be adjusted for variations in the extruded chamber cross section and accommodate the different apertures required using the same brazed sub assembly.

A similar design was chosen for the zero opening crotch ABS. However the stainless steel tubing was replaced with copper tubing to increase the heat transfer to the cooling water. Without the support of the stainless steel tubing, additional features needed to be machined into the GlidCop shell to ensure the rigidity of the assembly after brazing. Proper forming of the tubing was critical to ensure uniform clearance between the parts for the braze alloy to flow properly. Contact between the cooling tube and the GlidCop shell of 75% or better is required to ensure adequate heat transfer to the cooling water. X-ray imaging of the assemblies before brazing was used to ensure a conformal fit between the pieces.

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Additional x-rays taken after brazing were used to confirm the braze alloy flowed as expected (Figure 5).

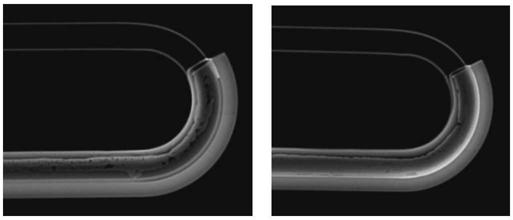

Figure 5: X-ray imaging showing incomplete braze flow (left) and complete braze flow (right)

For crotch ABS with opening, since most of the high power fans from IDs will be intercepted at the front end masks, a similar GlidCop brazed to copper cooling tube approach was chosen. Given that the cooling tubes cannot be placed on the mid-plane due to the aperture, a second tubing loop was added to ensure adequate cooling. One standard size opening (75mm H x 18mm V) was chosen for all apertured crotch ABS to eliminate the chance of installing an ABS with the wrong opening at a given location. This is also a major safety requirement for top-off injection.

The last type of absorber used in the storage ring is the flange ABS. The insert of the flange ABS is made of GlidCop which has a tapered aperture of 64mm H x 21mm V. Flange ABS are located downstream of the dipole chambers, and upstream of some critical components such as kicker chambers. Due to the low power expected at these locations, braze flow is not as big of a concern as with the other ABS.

RF SHIELDED BELLOWS

An RF shielded bellows joins chambers between adjacent girder assemblies, which compensates for chamber to chamber misalignment. BPMs mounted to the multipole chambers are positioned relative to the magnetic center of the girder assembly, which prevents the end flanges from ending up in the ideal position and can result in alignment errors of a few mm between chambers. The RF bellows were designed to accommodate a lateral offset of ±2 mm as well an angularity of ± 15 mrad. In addition the bellows must accommodate the compression due to the in-situ bake out.

The internal structure of the bellows was optimized to have low impedance and minimal losses in the extreme mounting positions [4]. After several iterations, an outside RF finger [5] design was chosen for its lower impedance with the various offsets required [6]. The outer bellows weldment which includes the convolutions, end flanges and water cooling provisions was purchased as a complete unit from a commercial vendor. The internal components were produced in house at BNL. The mechanical assembly work is performed in a class 1000 clean room to prevent the possibility of contamination.

The internal structure of the NSLS-II RF bellows is shown in Figure 6. Starting from left to right, a stainless steel clamp plate (shown in green) with an RF spring groove is used to secure a pair of GlidCop fingers (brown) to the upstream bellows flange. The RF spring provides electrical contact to the adjacent chamber.

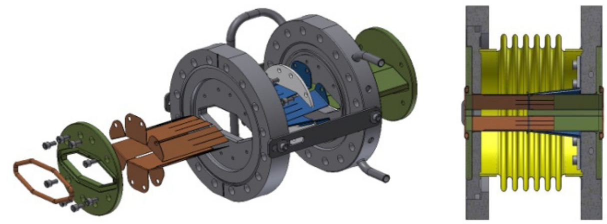

Figure 6: Exploded view of RF bellows (left) with convolutions removed and side view of completed unit

The GlidCop fingers were slotted to improve the flexibility and provide multiple points of contact. A silver plated stainless steel sleeve (shown in green on the right) with RF spring groove is inserted from the downstream flange. The sleeve is silver plated to increase the thermal conduction of heat from the sleeve to the water cooled flange and to decrease the sliding friction between the sleeve and GlidCop fingers. Silver plated Inconel springs (shown in blue) are used to provide contact pressure between the sleeve and the GlidCop fingers. The silver plating reduces the particle generation resulting from sliding interface between the springs and the fingers.

Currently the RF bellows are in full scale production with over 100 units ready for assembly. To date, three storage ring cells have been successfully interconnected with RF shielded bellows.

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