STATUS OF NSLS-II STORAGE RING VACUUM SYSTEMS*

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Abstract

National Synchrotron Light Source II (NSLS-II), being constructed at Brookhaven National Laboratory, is a 3-GeV, high-flux and high-brightness synchrotron radiation facility with a nominal current of 500 mA. The storage ring vacuum system has extruded aluminium chambers, with ante-chamber for photon fans and distributed NEG strip pumping. Discrete photon absorbers are used to intercept the un-used bending magnet radiation. In-situ bakeout is implemented to achieve fast conditioning during initial commissioning and after interventions.

INTRODUCTION

NSLS-II storage ring, with a circumference of 792 m, has 30 double-bend-achromatic cells [1]. In each cell, there are five magnet/chamber girders; and one straight section, with alternating length of 9.3 m and 6.6 m, for insertion devices, radio frequency cavities and injection. Due to the low bending field of 0.4 Telsa, the radiation power from each bending magnet is ~ 2.4 kW at 500 mA, with critical energy of 2.39 keV and power density < 88 W/mrad^2. Therefore the unused bending magnet radiation is intercepted by discrete absorbers at normal incidence. The insertion device photon fans, due to their high power density, are mostly trimmed at front ends.

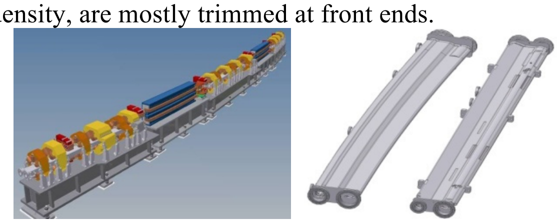

Figure 1: Models of NSLS-II DBA cells (left), dipole chamber (middle) and multipole chamber.

The storage ring vacuum systems are divided into 60 vacuum sectors with RF-shielded gate valves mounted at both ends of each straight section. The designed average pressure with beam is < 1×10^{-9} mbar. The beam lifetime due to beam-gas inelastic scattering is > 30 hr, much longer than the 3-hr Touschek lifetime. However, localized pressure bumps will produce bremsstrahlung radiation toward front ends and beam lines, and have to be suppressed.

VACUUM SYSTEM DESIGN

Aluminium was chosen [2] as NSLS-II cell chamber material for its good mechanical and thermal properties, low magnetic permeability, ease of fabrication, and low impedance to the beam.

Due to the low bending field, the photon fan from the bending magnets has a small dispersion from electron beam, which allows a narrow chamber geometry design. Therefore, the cell chambers were made from extruded aluminum with uniform cross sections. The need to accommodate the exiting photon fans and to provide NEG strip distributed pumping also favors extruded aluminum since an ante-chamber configuration can be incorporated.

Cell Aluminum Chambers

There are five aluminium chambers of 3-4 m in length in each DBA cell with two cross sections as shown in Figure 2. The two curved dipole chambers fit inside the C-type bending magnet gap and the three straight multipole chambers are surrounded by quadrupole, sextupole and corrector magnets. The straight sections, prior to the installation of insertion devices, also have chambers with multipole cross section. In addition, there are two short and narrow aluminium chambers bracket central dispersion section to accommodate exit port/beam pipe for ID fan and for mounting three-pole wigglers upstream of 2nd bending magnet/chamber.

The electron beam channel has an elliptical or hexagonal shape envelop of 76 mm (H) x 25 mm (V). The outer width of the dipole and multipole extrusions are 320 mm and 280 mm, respectively. The inner heights of the photon exit gaps between beam channel and ante-chamber are 15 mm for dipole and 10 mm for multipole. The ante-chamber geometries are a balance among the photon fan requirements, the minimum wall thickness, the pumping conductance, and mostly to minimize magnet radii.

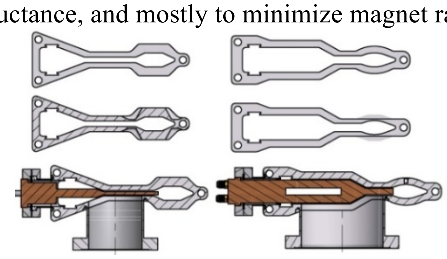

Figure 2: Extruded cross sections for multipole (top left) and dipole (top right) chambers; after machining (middle) at sextupole location and in the dipole gap; and at absorber locations (bottom) with pumping ports.

The dipole extrusions were bent to a 6^o curvature using a large hydraulic press at BNL. The extrusion was standing on ante-chamber side and captured at beam channel. Adjustable shims were used on top and bottom to

*Work performed under the auspices of U.S. Department of Energy, under contract DE-AC02-98CH10886
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provide the limits during bending and to achieve the desired curvature. Spacer blocks were inserted into the photon exit gap to prevent the collapsing of the gap. After bending, the extrusions were thermally cycled twice to 180^o C to relieve the stress and assure the stability of the curvature in subsequent operation from machining to in-situ bakes. The overall success rate of the extrusion bending was greater than 60%.

The extrusion walls are machined to accommodate the magnet poles. The wall thickness of the dipole chamber is 3 mm in the middle of beam channel, and 2.5 mm at the sextupole pole locations in the multipole chamber, thus providing a nominal clearance of ~ 2 mm between the chambers and the magnet poles. The measured maximum deflections are less than 0.3 mm x 2 at the photon exit gap when under vacuum load, consistent with that of finite element analysis. The ends of extrusions are precision machined for welding (Fig. 3) to the adapter plates, then on to the aluminium-to-stainless bi-metal flanges. Ports are added for beam position monitors (BPM), absorbers, ion pumps, vacuum gauges, etc. Cleaning, welding and weld certification are done at the APS vacuum facility by APS staff with robotic welding machines.

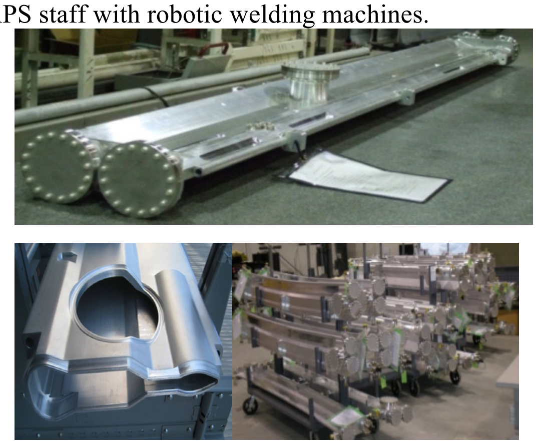

Figure 3: A completed multipole chambers (*top*), machined dipole extrusion end (*left*) and assembled chambers (*right*) ready for girder integration.

Upon arrival from APS, the completed cell chambers are measured for dimensional accuracy, in particular at BPM mounting ports and at the absorber port. They are installed with BPM buttons, RF screen, NEG strip assembly, small ion pumps and vacuum instruments in a class 1000 clean room. The assembled chambers are baked to 130^o C for 8 hrs to ensure vacuum integrity. A few chambers did show significant contamination and were subsequently treated with a flow of 400 ppm ozone in oxygen at ~ 70^o C for 6 hours, which remove and reduce the hydrocarbon levels by a few decades. A comparison of RGA spectra before and after ozone treatment is shown in Figure 4.

After vacuum certification, the chambers are installed into the pre-positioned magnets, as shown in Figure 5. The magnets are subsequently aligned to within ±30 μm using vibration wire technique. The chambers on the girder are then instrumented with ion pump, titanium sublimation pump, absorbers and vacuum gauges, and wired with heaters and temperature sensors for bakeout and final certification prior to installation in the storage ring tunnel. At moment, over 30% of cell chambers are assembled, ready for girder integration and ~40% of chambers are at various stage of fabrication.

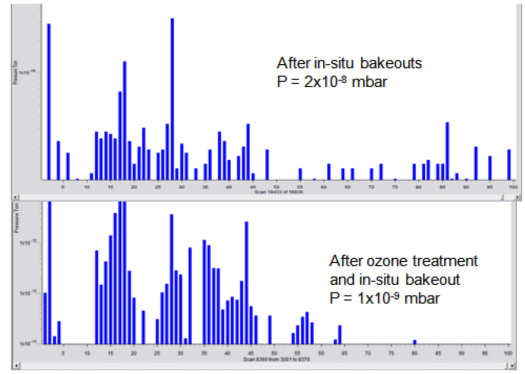

Figure 4: Residual gas spectra of a contaminated cell chamber before and after ozone treatment, showing the effectiveness of ozone in reducing high mass components by a few decades.

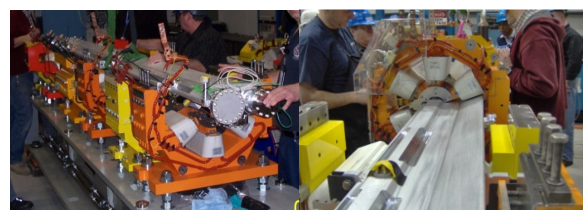

Fig. 5: Assembly of vacuum chamber into split magnets before magnet alignment, bakeout and tunnel installation.

Photon Absorbers (ABS)

Due to the low bending field, both power and power density of the bending magnet radiation are low, relative to other light sources. Unused bending magnet radiation is intercepted by discrete absorbers at normal incidence, to shield and protect un-cooled downstream flanges, bellows, etc.. There are three types of ABS in the storage ring: the crotch ABS at end of dipole chambers with opening for the exiting ID/BM photon fans; stick ABS that trim the edge of the bending magnet fan; and flange ABS. Crotch and stick ABS are made of GlidCop [3] and are inserted horizontally from the ante-chamber side into the photon exit gap with tips of the ABS ranging from 20 to 25 mm from nominal beam center. The flange ABS also made of GlidCop has a tapered opening of 64 mm (H) x 21 mm (V) to protect bellows, kicker chambers, etc. from large mis-steered beam.

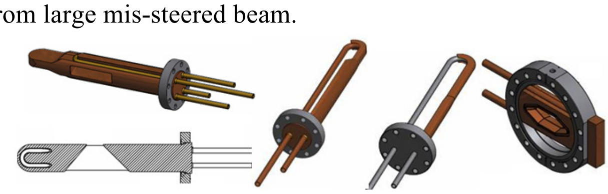

Figure 6: Models of photon absorbers (from left): crotch ABS, crotch ABS with zero opening, stick ABS with stainless cooling tube, and flange ABS.

The crotch ABS intercepts less than 1.8 kW with power density < 57 W/mm^2 and T < 180^o C at the tip and < 130^o C at cooling tube surface. The stick ABS intercept less than 700 W with power density < 5 W/mm^2 and T < 130^o C at the tip and < 120^o C at cooling tubing surface. These temperatures are well within the allowable limits for GlidCop and for water boiling under the planned water flow and pressure condition. The ion pump and titanium sublimation pump are mounted directly underneath each ABS to pump the desorbed gas. All three ABS are presently under fabrication by commercial vendors.

RF Shielded Bellows

RF shielded bellows join the adjacent cell chambers to form the complete vacuum sectors. The requirements are lateral offset of ±2 mm, compression & expansion of -15 and +10 mm, and angularity of ±15 mrad. They accommodate manufacturing tolerances, flange assembly, BPM alignment and thermal expansion during in-situ bake. The bellows has to have low impedance and losses with the intense electron beam under these adverse mounting conditions [4]. We selected an outside RF finger [5] design over inside RF finger design [6] for its lower impedance with those lateral and angular offsets. Several sets of RF bellows with wider (and fewer) fingers were fabricated and mechanically tested. Beam test at APS continues while the bellows production has started.

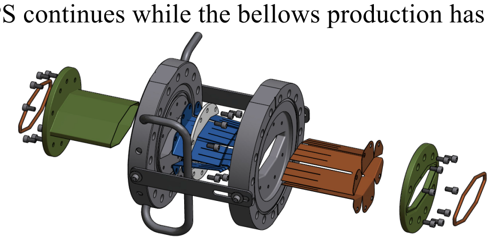

Figure 7: Model of NSLS-II RF bellows shows (from left) coil spring (gold), Rd plated stainless sleeve (green), inconel springs (blue), Ag plated GlidCop fingers (brown), stainless mounting plate (green) and coil spring (gold). The bellows are removed for ease of viewing. The GlidCop fingers are captured between inconel springs and stainless sleeve.

NEG Strips and Supports

NEG strips (St707 alloy from SAES Getters) are mounted at the top and bottom of the ante-chambers (Fig. 8) as distributed pumping for active gases. They have pre-punched holes and are riveted, with alumina insulators at 10 cm intervals, onto stainless steel carrier plates, which ride in extruded channels in the ante-chamber.

In-Situ Bake

The cell vacuum chambers and other appendage components are in-situ baked to ~130^{o}C for fast conditioning during initial commissioning and after interventions. A long 10 mm ϕ cal rod heater is inserted into one 12mm ϕ unused cooling channel at ante-chamber side, as main chamber heater. More than 1 kW/m power is attained with these low cost commercial heaters. Temperatures over 100^o C is achieved without thermal insulation around the chamber. NEG strips powered at low current supplement the cal rod and bring the chamber to over 130^o C. Ion pumps have their own built-in heaters. Additional removable silicone heaters are used at RF bellows, tees, elbows, gate valves and large flanges to achieve overall temperature uniformity during bakeout.

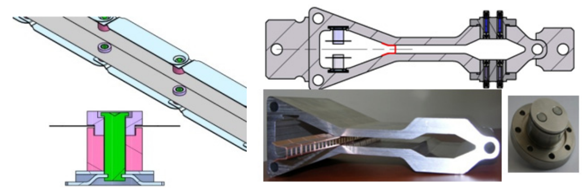

Figure 8: Top & bottom NEG strips (gray) with stainless rivet (green) and alumina bushings (pink and purple) on stainless carriers (light blue) at 10-cm intervals; and the BPM buttons (right) and Be-Cu RF screen (red and gold) to shift the rogue mode frequencies away from 500 MHz.

Mitigation of BPM Rouge Modes

BPM signals could have been compromised by the transverse electrical (TE) mode type resonances with frequencies ranging from 400 MHz to 1.5 GHz measured in NSLS-II multipole chambers [7]. Simulation using GdfidL Code has identified these resonance modes are those due to the electric field inside the photon exit gap into ante-chamber volume. To this end, Be-Cu type screen [8] is installed in the extraction gap of the multipole chambers to provide partial RF shielding in the ante-chamber, thus shifting the starting frequency to over 550 MHz, well above the 500 MHz RF frequency.

ACKNOWLEDGEMENT

The authors thank colleagues at many light sources for their valuable assistance in the design and fabrication of NSLS-II vacuum systems; in particular, Joe Gagliano and George Goeppner of APS, Roberto Kersevan of ESRF, Gao-Yu Hsiung, Che-Kai Chan and Jun-Rong Chen of NSRRC, Nadine Kurita of SPEAR-3, and many others at NSLS-II Project.

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