VACUUM SYSTEM DESIGN AND SIMULATION FOR CHESS-U*

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Abstract

A major upgrade project (dubbed CHESS-U) is planned to elevate performance of Cornell High Energy Synchrotron Source (CHESS) to the state-of-art 3rd generation light sources. As a critical part of the CHESS-U project, about 80-m of Cornell Electron Storage Ring is to be replaced with double-bend achromat lattice to significantly reduce electron beam emittance. In this presentation, we will describe the designs of the CHESS-U vacuum system, including new beam pipe extrusions and chambers, sliding joints, and crotch absorbers. The vacuum pumping system consists of distributed pumps in the form of non-evaporable getter strips in the dipole chambers and compact, discrete NEG/Ion pumps in the quad straight and undulator beampipes. A test-particle Monte-Carlo simulation program, MolFlow+, is employed to evaluate pumping performance of CHESS-U vacuum system in two aspects. First, we demonstrate that the planned vacuum pumping system can achieve and sustain required ultra-high vacuum level in CHESS-U operations after an initial beam conditioning. Second, we will explore beam commissioning processes of the new vacuum chambers, and simulate the saturation of the NEG strips during the commissioning. These simulations will aid continuing design optimization for the CHESS-U vacuum pumping system.

INTRODUCTION

The Cornell High Energy Synchrotron Source (CHESS) is a national user facility with 11 experimental stations funded by NSF. Historically, CHESS ran as a parasitic light-source to the electron-positron colliding beam High Energy Physics (HEP) research program, sharing the Cornell Electron Storage Ring (CESR). At the end of HEP-era in 2008, many accelerator upgrade programs took place to optimize CESR for CHESS operations, especially with recent development of the CHESS Compact Undulator (CCU). The CHESS-U project is the first major upgrade to both the CESR and the CHESS X-ray beamlines. CESR will be converted to single beam operation, with higher single beam current (120 mA to 200 mA) at higher beam energy (5.3 GeV to 6.0 GeV). The south arc (~1/6th, or ~80 m) of CESR will be replaced with 6 double-bend achromat (DBA) cells [1], populated with new magnets and vacuum beampipes. The new lattice is designed to minimized beam emittance to boost the X-ray beam brightness. Fig 1 illustrates one CHESS-U DBA cell, which includes two combined function dipole (CDF) magnets and four quadrupole magnets.

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VACUUM CHMABERS & COMPONENTS

New CHESS-U vacuum chambers in each DBA cell, as shown in figure 1, consist of two long dipole chambers (with integrated quad straights). A majority of the new CHESS-U vacuum chambers will be constructed from type 6063/6061 aluminum alloy in three forms of extrusions with their cross-section depicted in figure 2. These extrusions are designed to provide prescribed CHESS-U beam aperture of 22-mm (V) by 52-mm (H), and to have adequate clearance to the CHESS-U magnet poles. The beampipes made from these extrusions will also serve as distributed absorbers of synchrotron radiation (SR) generated from dipole magnets. Finite-element analysis (FEA) were done to ensure a sufficient safety margin when these water-cooled extrusions are subject to thermal stress induced by the SR power at 250 mA beam current at 6 GeV. Fig.3 displays the fit between the extrusions and the magnets.

Dipole B Vacuum Chamber

The body of the dipole B vacuum chamber is made of ~2.35m of type B aluminum extrusion (see fig.2) with center-line bending radius of 31.38m. The prescribed bending geometry is achieved by 'stretch forming' method, which involves stretching the extrusion beyond its yield and then forced it onto a die to form the required bending radius. To facilitate the process, the extrusions are ordered in –T1 temper and then heat treated after forming to –T5 for required strength. The dipole B chamber is completed by welding quad extrusions (type A in fig.2) on both ends of the bend and terminating with UHV flanges, with a total length of ~4.7m.

Dipole A Vacuum Chamber

Dipole A is much more complex, as it serves as the egress for the X-ray beam from the insertion devices. The main body of the chamber have to be made by welding two machined halves (6061-T6 aluminum), as shown in fig.4. Similar to the dipole B chamber, quad extrusions are welded to both ends of the main body for the particle beam, and a copper beampipe is welded to the main body via explosion-bonded bi-metal transition for the X-ray egress. The total length of the dipole A chamber is ~4.7m. A flanged port on top the main body allows for an insertable crotch absorber (description below).

ID Vacuum Chamber

CHESS-U will use the canted CCUs as the main insertion devices (IDs). One pair of canted CCUs has been in operation for CHESS since 2014. The ID vacuum chambers will be made from 3.35m long aluminum (6061-T6)

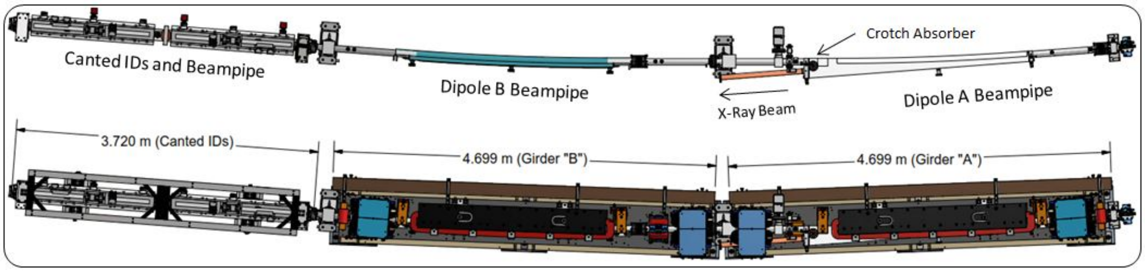

Figure 1: Illustration of one Double-Bend Achromat cell, constructed in two magnet/vacuum girders and a straight for two canted insertion devices (IDs). The upper assembly shows only the vacuum chambers only.

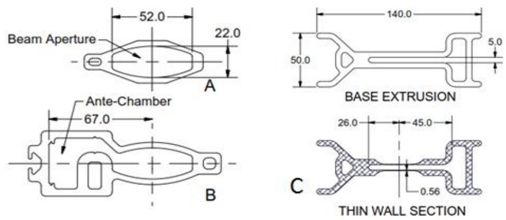

Figure 2: CHESS-U extrusions (dimensions in mm). Type A – quad extrusion; Type B – dipole extrusion with ante-chamber; Type C – undulator extrusion.

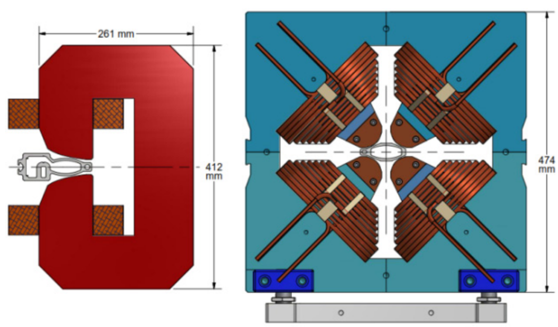

Figure 3: CHESS-U beampipe extrusions installed in a dipole (left) and a quadrupole (right) magnet.

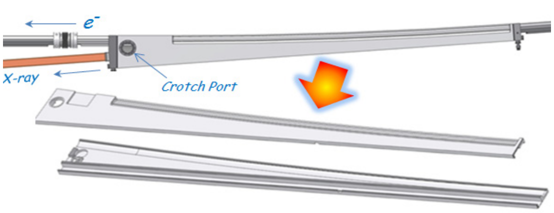

Figure 4: Dipole A chamber design. Two machined halves allow beam path and aperture, X-ray egress and clearance to the dipole magnet.

extrusions (Type C in fig.2), with a nominal vertical beam aperture of 5mm. To clear the 6.5-mm CCU gap, center portion of top and bottom extrusion walls were machined to 0.56mm in thickness. Vertical tapers are welded to the ends of the ID extrusion for transition to the 22-mm CHESS-U vertical aperture. The thin-wall ID chamber and the end tapers are the same design as the ID chamber currently in CESR for over 2 years.

Crotch Absorber Design

Crotch absorber is needed to safely shadow the X-ray egress port from the bend SR, though itself is exposed to extremely high SR power density. A design adapted from current CHESS crotch is shown in fig.5. The crotch absorber consists of a water-cooled copper cylinder and a 5-mm thick outer beryllium tube. The beryllium tube diffuses and scatters impinging SR power to reduce SR power on the inner copper surface to a safe level. Detailed thermal FEA (including spectral SR scattering and absorption in beryllium) has been done and compared to the CHESS crotch, that was subjected higher SR power during the HEP-era. A summary of FEA results for both CHESS and CHESS-U crotches are given in Table 1. As expected, simulated maximum temperature and thermal stress are located near outer surface of the beryllium tube. The FEA results showed slightly lower level of thermal stress on the CHESS-U crotch, as compared to the CHESS crotches had experienced during the CESR HEP-era without any sign of failure. As a confirmation, one of the CHESS crotches was replaced from CESR for close inspection during 2016 Summer Shutdown, and no any sign of damage was detected on this CHESS crotch.

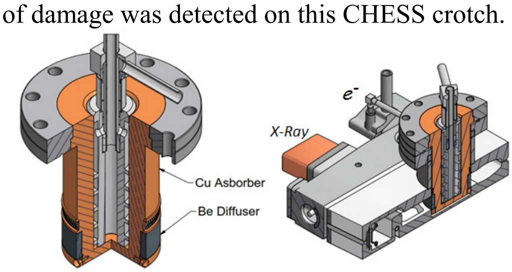

Figure 5: CHESS-U crotch absorber design (left) and its installation on the dipole A vacuum chamber.

Table 1: FEA results for CHESS and CHESS-U Crotch

	CHESS	CHEE-U
Beam Parameters	5.3GeV 400mA	6.0GeV 250mA
Total SR Power (kW)	5.7	5.1
Absorbed Power (kW)	4.9	3.8
Max. Temperature (Be)	337°C	325°C
Max. Stress (Be) (MPa)	1.2×10^3	0.97×10^3

RF-shielded Sliding Joint

Each DBA cell is equipped with two RF-shielded sliding joints (SLDJTs). Design of the CHESS-U SLDJT, shown in fig.6, is based on a SLDJT in CESR. These SLDJTs provide flexibility for vacuum installation, and accommodate beampipe thermal expansions during *in situ* hot-water bakeout and in operations. Beam impedance property of the SLDJT was simulated with T3P codes [2], and the calculated loss factor (5×10^{-3} V/pC) and vertical

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kick (2.79 V/pC-m) were found to be acceptable [3]. SLDJTs are directly welded to beampipe extrusions due to limited space for flanges. With a 250mA beam at 6.0 GeV, the calculated (by FEA) highest temperature and maximum thermal stress from SR are 140°C and 138 MPa, respectively, with sufficient safety margin for 6061-T6 material used for the SLDJT.

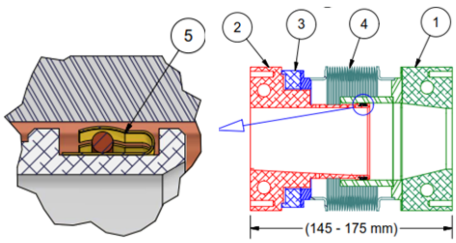

Figure 6: CHESS-U RF-shielded sliding joint design. 1-Female flange made of explosion-bonded aluminum to stainless steel plate; 2-Aluminum male tube; 3-Bi-metal transition ring; 4-Edge-weld bellows; 5-RF contact stock.

VACUUM PUMPING & SIMULATION

Vacuum pumping for the new DBA cells include discrete (or lumped) pumps in the quad straight and distributed pumps in the dipole chambers. Existing ion pumps in CESR will be re-used as lumped pumps in the DBA cells. However, distributed ion pumps in CESR are no longer suitable due to much smaller (and non-uniform) dipole magnets in the DBA cells. Non-evaporable getter (NEG) strips will be inserted into dipole ante-chambers for distributed pumping. The NEG strip structure (fig.7) is based on a APS design, except the base holding strip is made of a single continuous stainless steel strip.

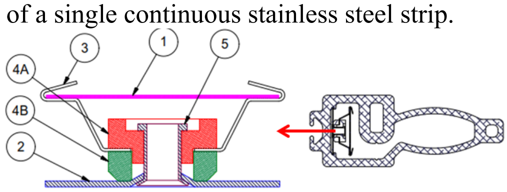

Figure 7: NEG strip carrier. St707 NEG strip (1) is supported onto a base stainless strip (2) with periodic stainless steel clips (3), which are electrically insulted by a pair of ceramic spacers (4) secured by custom rivets (5)

A NEG strip option was also explored for ID chambers, but it complicates interface with the ID magnets. Instead, the 3.8m long ID chamber is pumped by six compact NEG pumps (SAES NexTorr® and CapaciTorr®). This is the same pumping configuration as the present CCU chamber in CESR [4].

To validate vacuum pumping design, the test-particle Monte-Carlo program, MolFlow+, is employed to simulate pressure profile along one DBA cell. SR-induced desorption is the dominating gas load, with SR flux shown in fig.8. Based on measurements at CESR, SR desorption yield (η_{SR}-molecule/photon) decreases with photon dose (D_{SR}-photon•m)) as: $\eta_{SR} = 10^{16.28} \bullet D_{SR}^{-0.88}$. Using NEG strip pumping speed and capacity data from Benvenuti [5] *et al*, a simulated pressure profile after 200 Amp-hr beam conditioning is shown in fig.9. Fig 10 illustrates the combined vacuum beam conditioning and the NEG strip saturations. It clearly indicates that multiple NEG strip activation cycles are needed during the CHESS-U commissioning. To reduce initial NEG strip saturation, we plan to perform in situ hot-water bakeout, using build-in cooling channels in the extrusions.

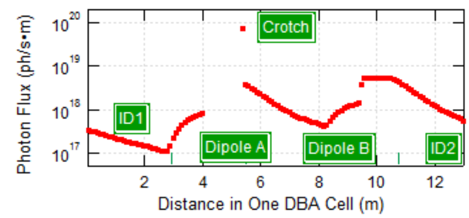

Figure 8: SR Flux impinged on vacuum chamber in one DBA cell, for 200 mA beam at 6 GeV.

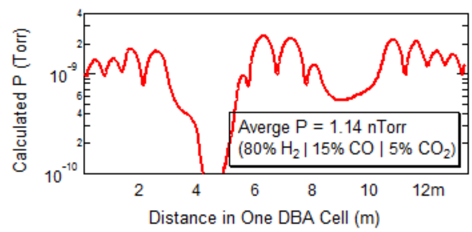

Figure 9: Simulated pressure in one DBA cell at 200 mA with 200 Amp•hr beam dose, and 'fresh' NEG strips.

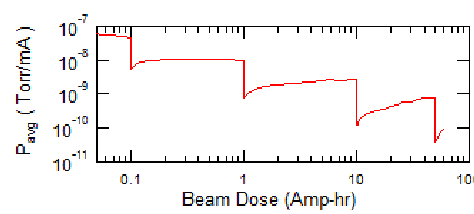

Figure 10: Simulated vacuum processing in CHESS-U with dips in P_{avg} corresponding NEG strip re-activations.

CONCLUSIONS

Tremendous progress has been made in CHESS-U vacuum system design and engineering. Designs of key components are approaching completion and many of them are transitioning toward production. We are aiming at the completion of CHESS-U in December 2018.

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