Status and highlights of the NSLS-II and the 3rd RF system Upgrade and future plans


*Now at the VLA radio telescope in Socorro, NM
Overview

• Overview and highlights of the NSLS-II storage ring RF systems
• Recent problems and motivation for 3\textsuperscript{rd} and 4\textsuperscript{th} RF systems
• Third RF System project and status
• Early plans for Fourth RF system and Harmonic Cavities
• A Bright Future
NSLS II overview

• National Synchrotron Light Source (NSLS-II) is a new 3 GeV, 500 mA, high-brightness synchrotron light source facility at the Brookhaven National Laboratory, funded U.S. Department of Energy (DOE).

• SR circumference is 792 m with 1 nm-rad horizontal and 8 pm-rad vertical emittance.

• NSLS II provides with:
  • wide spectral range
  • high average spectral brightness
  • high flux density
  • 60~80 beamlines

• 26 beamlines in routine top off operation at 375 mA. 400mA operation begins in July
• Beam emittance and beam orbit stability met the goals.
RF straight layout

- Two RF straights reserved in NSLS-II lattice
- One is populated with two 500 MHz CESRb cavities (Project funded)
- Space reserved for passive SRF 3\textsuperscript{rd} harmonic cavity
- Currently building out second RF straight with 3\textsuperscript{rd} CESRb cavity (AIP funded)
- Component production for third cavity is \(~90\%\) complete
- Cryomodule Integration performed at NSLS-II
Storage Ring: Superconducting Cavity

• 2 (of 4) 500MHz Cornell type SRF cavities installed

• Redesigned coupling iris for $Q_{\text{ext}} = 79,000$ (from 200,000)

• BNL assisted AES in assembly of first 2 cryomodules; complete knowledge base for refurbishing cryomodules
Storage Ring Transmitter

540 kVA klystron solid state switching power supply with mod-anode, filament supplies, interlocks and controls

Operating since 2012, only four failures: 1x PLC I/O module failed, 2 x HV capacitor in output filter, 1 x secondary winding in HV transformer- this latter did not cause downtime due to redundant switching modules
The klystron High Voltage PS is a switching PS with 86 switch modules. The switching frequency is programmable as $N$ times $3.125$ kHz, and is typically run at values of $N$ between 30 and 120 for switching frequencies of $93.75$ kHz to $375$ kHz. There is a subharmonic at the switching frequency divided by the number of modules which places the subharmonic in the vicinity of the synchrotron frequency - we occasionally have to change the switching frequency as RF voltage is raised and the beam potentially driven by the switching sub-harmonic.

Carlos Marques, John Cupolo
The klystron HVPS is a switching power supply with 86 switch modules, 82 typically active at any time- with 4 redundant spares. An algorithm for switching sequence allows us to select weights for reducing the amplitude of the AC power harmonics: 60, 120, 180, 240, 360 and 720 Hz. This can be performed “live” with beam.
Very Good Diagnostics and Tools in LLRF

Field Probe failed, backup has high beam to RF field ratio, sees ion gap transient

Created FIR filter to compensate
Equench: detect “lost” rf power, trip RF

$0.8 \times (P_{Fwd} - E_{Loss\text{max}} \times I_{beam}) < P_{Rev} < (P_{Fwd} - E_{Loss\text{min}} \times I_{beam}) \times 1.2$

Plot of the Forward power minus the Reverse power minus the power distributed to the Beam versus time in the event of a quench at 250mA beam current. Integration of this plot yields the total energy into the walls of the cavity in the form of heating which is roughly 13.6kJ and vaporization of ~4 liters of LHe.

Equench event during conditioning the superconducting cavities. The recovery of the RF systems from an Equench trip is dramatically easier since the cryoplant does not need to be recovered, only the RF power.

From Belomestnyck
300 kW, 5 CHANNEL NETWORK ANALYZER

Frequency sweeps with different tuner positions

Varying $k_p$, $k_i$ constant

Varying $k_i$, $k_p$ constant

Cavity and beam responses
Quiet and Stable RF systems
RF frequency plot with global (RF) correction on

Very slow orbit (circumference) feedback with RF frequency adjustment is correlated to the phase of the moon due to tidal forces
Motivation for Third RF System

Running out of RF power by 2021: Planned addition of SC wiggler puts us over the power limit of two systems

Reliability: Up until very recently the cavity vacuum trips dominated machine downtime. A real failure on one of the RF systems would mean reducing operations beam current.
A general upward trend in reliability was reversed on November 8, 2018. During a two-day maintenance an RGA was installed/baked by the vacuum group immediately downstream of cavity gate valve and independently a partial warm-up of the cryomodule to 50 K was performed due to coldbox repairs.

<table>
<thead>
<tr>
<th>Operaions period</th>
<th>#Faults</th>
<th># Dumps</th>
<th>Downtime (hr)</th>
<th>MTTR (hr)</th>
<th>MTBF (days)</th>
<th>Comments</th>
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<tr>
<td>RF-p0 (May-Aug)</td>
<td>13</td>
<td>7</td>
<td>4.66</td>
<td>0.67</td>
<td>7.89</td>
<td>1293 hrs</td>
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<tr>
<td>RF-p1 (Sep-Dec)</td>
<td>25</td>
<td>16</td>
<td>7.25</td>
<td>0.45</td>
<td>3.71</td>
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<tr>
<td>RF-p1 (Oct-Dec)</td>
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<td>14</td>
<td>4.75</td>
<td>0.34</td>
<td>3.05</td>
<td>1102.5 hrs</td>
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<tr>
<td>RF-p2 (Jan-Apr)</td>
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<td>3.89</td>
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<td>RF-p3 (Jun - )</td>
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<td>0</td>
<td>0.00</td>
<td>--</td>
<td>15.72</td>
<td>377.2 hrs</td>
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</table>

Full warm-up of cavity, replacement of pump-out box ion pump+ elbow, downstream shielded bellows and cleaning of BPM assembly during May shutdown has fixed the problem.
CESRb 500MHz Superconducting Cavity
Vacuum trips dominate RF system performance

After November 8th maintenance day were not able to run Cavity D at 1500kV with 375 mA. Voltage reduced to 875kV, still frequent trips

After full warmup during May shutdown, Cavity D conditioned to 1800kV, runs reliably at optimum voltage of 1500kV
Cavity D transients, Trips

Rare capture of cavity riding through transient, then tripping. Normally we just see trip since buffer is triggered by trip, not transient.
3rd RF SYSTEM PROJECT

- Valve box on tunnel roof cell 22
  June 2019

- Cryomodule in tunnel cell 22
  Horizontal test
  December 2018

- Existing manifold valve box in RF Bldg

- MCTL to cryomodule

- Multi-channel transfer line (MCTL) from Manifold box to Valve box
  May 2019 (?)

Approaching limit of two RF systems by year ~2020
Need redundancy as well

- 300 kW 500 MHz Transmitter
  ~October 2019
  (still reviewing bids)
Typical design $Q$ is $1 \times 10^9$ at 10MV/m at 4K.

Previous reported $Q_0$ were $(1 \pm 0.2) \times 10^9$ at 10MV/m at 4K (S. Bauer et. al., EPAC04).

NSLS-II cavies 1, 2 and 3 superimposed on earlier results. Cavity 3 was N2 doped.
Third Cryomodule in final assembly at BNL/NSLS-II

Cavity String Assembly

Window High Power Test Assembly
Can only test during shut-down when 310kW transmitter is available
The Third NSLS-II Transmitter*

*Coming soon to CWRF 2020
Future plans in priority order

• Fourth RF system
  • Cryomodule and transmitter installed in second RF straight
• Fifth Cryomodule as spare
• Complete Harmonic cavity cryomodule with HOM dampers and tuner
• Second Harmonic cavity
Landau Cavity

First horizontal cold test complete completely validates $0-\pi$ mode tuning over 1 MHz bandwidth. Low Q loaded (6e7 vs. 2e8) explained by trapped TE mode when tested without dampers.

Need to design and fabricate new vacuum jacket, instrumentation, ferrite dampers, tuner mechanism.
SUMMARY

• NSLS-II has been running with user beam for 4 years now, and has met all design goals with the exception of 500mA operation, and it is methodically approaching full current as well.

• Operations with 2 cavities point out the risks to both performance and reliability, management has finally started down the road to full build out.

• Construction of 3rd RF system underway, completion in FY2020.

• Future options buildout to include 4th RF system + harmonic cavities + spare CESRb.
RF conditioning with glass viewport to try and identify arc locations. Arc locations were inside glass from 1.5 MV field emitted electrons.