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COMMISSIONING AND EARLY OPERATION EXPERIENCE OF THE NSLS-II STORAGE RING RF SYSTEM*

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Abstract

The National Synchrotron Light Source II (NSLS-II) is a 3 GeV electron X-ray user facility commissioned in 2014. The storage ring RF system, essential for replenishing energy loss per turn of the electrons, consists of digital low level RF controllers, 310 kW CW klystron transmitters, CESR-B type superconducting cavities, as well as a supporting cryogenic system. Here we will report on RF commissioning and early operation experience of the system for beam current up to 200mA.

INTRODUCTION

The NSLS-II storage ring was designed to maintain a 3GeV, 500mA circulating electron beam with very small horizontal (down to 0.5 nm-rad) and vertical (8 pm-rad) emittance [1]. There are fifteen 9.3 m straights and fifteen 6.6 m straight in the ring, where two of the 9.3 m straights were allocated for RF cavities. The fully built-out RF system is expected to have two CESR-B type 500 MHz superconducting cavities and one passive 1500 MHz superconducting Landau cavity on each RF straight.

To operate these superconducting cavities, an 840 watt liquid helium (LHe) refrigeration system has been commissioned [2]. Currently NSLS-II has two 500 MHz CESR-B type cavities on site, one of which is in the ring for daily operation, while the other is in the blockhouse (a test setup) for conditioning and studies. A prototype passive 1500 MHz Landau cavity is on site, whose construction is pending a cold test with LHe. Two 310 kW klystron transmitters, driven by FPGA based cavity field controllers (CFC) [3], have been commissioned to power the two 500MHz cavities. We will first briefly describe the status, then discuss a few interesting cases we have experienced, and finally the future plan and summary.

CURRENT STATUS

Figure 1 shows a simplified diagram of the storage ring RF system. The 500 MHz cavitiy design was optimized with flexibility for various scenarios with one to four operating cavities, and both first built cavities have measured Qext of 79,000. To reduce power reflection under operation with low beam current (< 200 mA), a 3-stub tuner has been added to raise the Qext of the cavity to 200,000. A cavity frequency tuner PLC was implemented to adjust tuner position based on the phase difference between the cavity field and the forward field.

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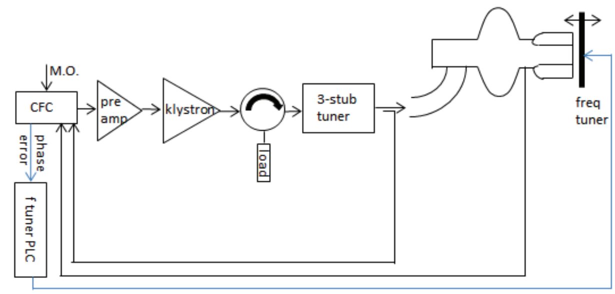

Figure 1: Simplified diagram of the NSLS-II storage ring RF system.

This PLC also monitors vacuum and water temperatures.

Table 1 shows typical operation parameters as of early April, 2015. The first cavity had been partially conditioned to 1.4 MV in the blockhouse before being moved to the ring. It then experienced frequent vacuum trips forcing the voltage to be lowered to 1.2 MV for reliability to accommodate optimization of other systems. In January 2015 the cavity was pulse conditioned to 1.87 MV with increasing duty cycles to CW, then the voltage was lowered to 1.778 MV for early operation.

Table 1: A Typical Set of Early Operation Parameters

M.O. frequency (MHz)	499.6815
r/Q (Ω)	89
Q0	2.7e+8
QL and Qext with 3-stub tuner	2.0e+5
Cavity voltage Vc (MV)	1.776
Cavity power (W)	131
Beam energy (GeV)	3.0
Beam energy loss per turn Va (kV)	288
Beam current (mA)	200
Revolution frequency (kHz)	378.55
Cavity detuning frequency (kHz)	-2.47
Momentum compaction	3.7e-4
Momentum acceptance	2.42e-2
Synchrotron frequency (Hz)	2550
Beam power (kW)	57.6
Forward power (kW)	77.8

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Although the cavity demonstrated Q0 = 6.8e+8 at a voltage of 3 MV during the vertical test, once assembled with copper plated thermal transitions and HOM dampers it shows a lower Q0 of 2.7e+8 at 1.778 MV. It is not yet clear what the cause might be. The cavity will be fully warmed up to room temperature in the May shutdown and the Q0 will be re-measured after restart. Heaters inside the LHe vessel were used to measure Q0. When RF was on and the heaters were off, the cold gas return flow of the cryomodule was recorded; then the RF was turned off and the heaters were turned on with gradually increasing power. When the cold gas return flow of the latter matches that of the former, the heater power should be equal to the cavity power previously dissipated on the wall. The Q0 can then be obtained.

Figure 2 shows the RF traces at the first 200 mA injection. Two loops are keeping cavity RF stable: a closed-loop CFC maintains a preset cavity field phase and amplitude with respect to the master oscillator; and the frequency tuner maintains the phase difference between the cavity field and the forward field, i.e. cavity detuning is being adjusted based on the field induced by the beam. During injection the forward power goes up while the reverse power goes down, and the increasing gap is equal to the beam power.

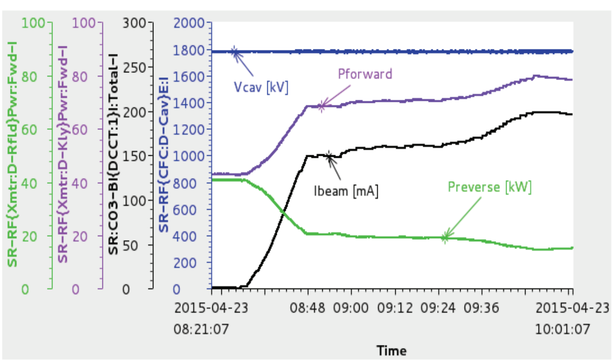

Figure 2: RF behaviours when beam current was ramped to 200 mA for the first time.

CASE STUDIES

While it has been mostly straight forward to operate the storage ring RF system, we did experience interesting cases, based on some of which we have improved the system.

Interference Between the Transmitter HVPS Switching Harmonics and the Synchrotron Frequency

Figure 3 shows the interference between the transmitter HVPS switching harmonics and the synchrotron frequency. Although the data was taken with a temporary 7-cell PETRA III cavity at the early stage of ring commissioning, the same principles apply to the superconducting cavities as well. The switching frequency of the klystron supply unit was 112 kHz with 86 switching modules, which yielded a switching sub-harmonic of about 1.3 kHz. The switching sub-harmonic is adjustable by design to avoid overlap with other spectrum peaks.

In the top screenshot of Figure 3, the synchrotron frequency was 2.715 kHz at the given cavity voltage at that time, and there was some distance between it and twice the switching sub-harmonic, therefore they didn't interfere with each other and the beam was stable. In the bottom screenshot, the cavity voltage was intentionally lowered so that the synchrotron frequency went down to 2.67 kHz which was almost identical to twice the switching sub-harmonic. Then the synchrotron peak was widened due to beam instability, in the meantime large beam horizontal oscillation in a dispersive section was observed. Recently the switching frequency was raised to 137 kHz, yielding a switching sub-harmonic of 1.6 kHz, so that for a wide range of cavity voltage the synchrotron frequency always sits between 1.6 kHz and 3.2 kHz with safe distance between them.

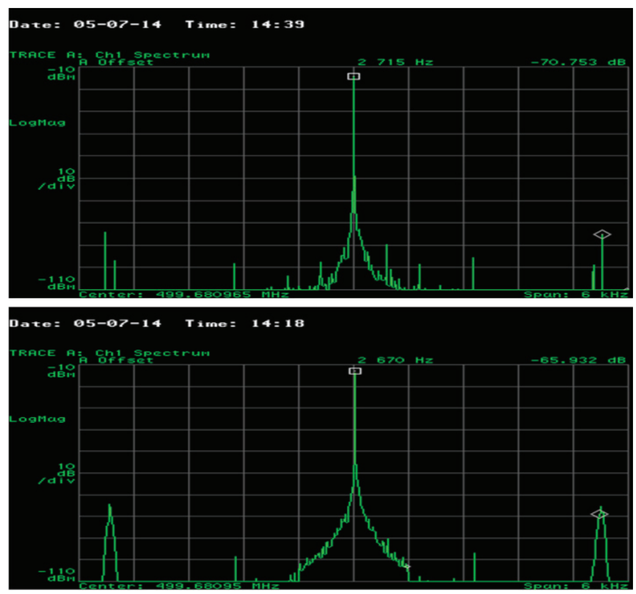

Figure 3: Top: The synchrotron oscillation peak 2.715kHz is clean when away from two times the switching harmonic 2.65kHz; Bottom: The synchrotron oscillation peak 2.67kHz is widened due to beam instability. Large beam horizontal oscillation is observed with a BPM.

Quench Protection and Prevention

The 500 MHz niobium cavity is cooled to 4.5 K by LHe at 1.26 bar vapour pressure. There are two dedicated pressure sensors to detect sudden pressure rise inside the LHe vessel, and once the pressure is above 1.35 bar, the RF will be tripped off by the quench detection circuit. In addition, the LHe supply valve will be closed, and the warm gas return valve will be fully opened to direct helium gas to the compressor suction side via an ambient heater. If the LHe vessel pressure drops to below 1.05 bar which is the normal compressor suction side pressure, all valves on the cryomodule will close to avoid contamination. If the pressure builds up to 1.35 bar again the warm gas return valve will open again.

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Figure 4 shows a quench trip caused by abrupt cavity voltage ramp-up. At 19:22 effort was made to bring RF up from zero. First it ran in the feed forward mode then was switched to the feedback mode with the same 50 kV voltage, after which the cavity voltage was brought to 250 kV and the forward power rose to 75 kW accordingly. Then the cavity was manually brought back to near resonance and the forward power dropped to only 2 kW. An attempt was made at 19:30 to raise the voltage abruptly, although the resulted sudden rise on both the cavity voltage and the forward power might not been caught by the relatively slow logging system. What can be seen from Figure 4 is that the gas pressure jump to more than 1.35 bar and the transmitter was tripped. Since the warm gas return was opened, both gas pressure and liquid level dropped quickly. Manual control took over after about 10 minutes and the cyromodule went back to operation after another 20 minutes. During recovery the LHe sensor was cycled a few times to avoid reading hang-up. Around 20:16 the 1778 kV cavity voltage was re-established to 1778 kV.

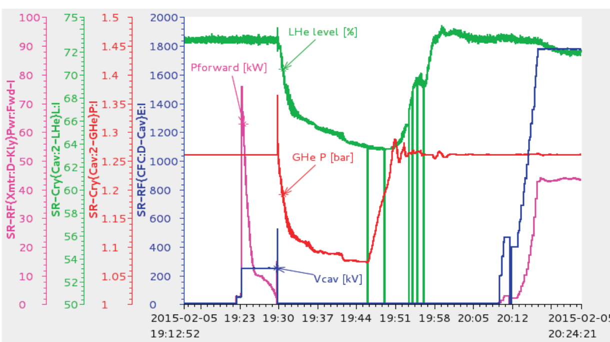

Figure 4: Quench caused by abrupt cavity voltage ramp-up and its protection.

Slow Drift on Tuner Position

It has also been noticed the tuner position starts to drift after a cold start (after more than a few hours of shutdown), then stabilizes after days of operation. The “cold position” for resonance is always different from “warm position”, as shown in Figure 5. The difference is on the order of 10 kHz. Temperatures at difference spots, including the He HEX, the N2 elbow, the beam pipe thermal transitions, and the coupling port tongue have been checked, however it is not clear yet what has directly caused the tuner position shift.

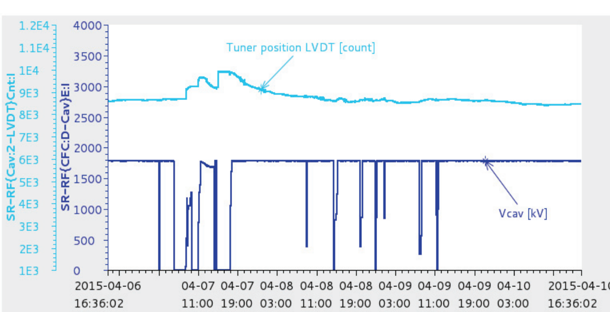

Figure 5: Slow tuner position drift from a cold start.

Cavity Field Spectrum Shows ±37 Hz Side Peaks Near the Central Frequency

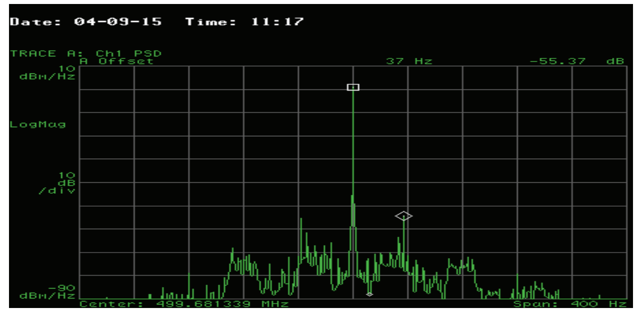

Figure 6: The cavity field spectrum has ±37 Hz side peaks near the central frequency.

In operation the cavity field spectrum shows ±37 Hz side peaks near the central frequency, as in Figure 6. Frequency in this range is often related to mechanical vibration. It is possibly contributed by the compressor motor which runs at 65% of the 60 Hz full frequency. However we have not had the opportunity to vary the compressor motor frequency to confirm it. Other possible sources are the frequency tuner motor and the building HVAC. Although not fully understood, these side peaks did not prevent the beam from meeting the specification, in terms of emittance and stability, etc.

FUTURE WORK AND SUMMARY

The prototype passive 1500 MHz harmonic cavity was constructed in 2011 and the early cold test showed a lower Q0 than expected, possibly due to interference with a transverse mode. This cavity is being tested again with an improved setup which is much like that of a vertical test, except that the cavity has its own cryostat thus it can be positioned horizontally. An on-axis plunger was made to mount an antenna for better coupling, while reducing the effect of the transverse mode. Once the Q0 is understood with this dewar test, the cavity will be modified to allow an interface with the existing cryogenic plant. HOM dampers and a frequency tuner will also be constructed accordingly to complete the cavity.

Higher beam current is being desired by beamline physicists for commissioning their systems. In the beam current range of 300 – 500 mA, to compensate extra energy loss resulted from damping wigglers and insertion devices, the second 500 MHz cavity needs to be installed. The projected time frame for this work is August to September 2015, with preparation work already on going.

To summarize, the NSLS-II storage ring RF system has met the needs for NSLS-II commissioning and early operation. The team is optimizing and improving the system to accommodate future higher current operation.

REFERENCES

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[2] Jim Rose, et al., WEPWI058, Proc. IPAC2015, http://jacow.org/.

[3] Brian Holub, et al., MOPTY038, Proc. IPAC2015, http://jacow.org/.