ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPHA013

SUPERCONDUCTING RADIO FREQUENCY CAVITY DEGRADATION DUE TO ERRANT BEAM*

C. Peters, A. Aleksandrov, W. Blokland, M. Crofford, D. Curry, C. Deibele, G. Dodson, J. Galambos, G. Johns, A. Justice, S. Kim, T. Pelaia, M. Plum, and A. Shishlo, Spallation Neutron Source, Oak Ridge National Laboratory, Oak Ridge, TN, 37831, USA

Abstract

In 2009, the Superconducting Radio Frequency (SRF) cavities at the Spallation Neutron Source (SNS) began to experience significant operational degradation [1]. The source of the degradation was found to be repeated striking of cavity surfaces with errant beam pulses. The Machine Protection System (MPS) was designed to turn the beam off during a fault condition in less than 20 μseconds [2] as these errant beam pulses were not unexpected. Unfortunately an improperly operating MPS was not turning off the beam within the designed 20 μseconds, and the SRF cavities were being damaged. The MPS issues were corrected, and the SRF performance was restored with cavity thermal cycling and RF processing. However, the SRF cavity performance has continued to degrade, though at a reduced rate compared to 2009. This paper will detail further study of errant beam frequency, amount lost per event, causes, and the corrective actions imposed since the initial event.

INTRODUCTION

The SNS Linac consists of an ion source, Low Energy Beam Transport (LEBT), Radio Frequency Quadrupole (RFQ), Medium Energy Beam Transport (MEBT), Drift Tube Linac (DTL), Coupled Cavity Linac (CCL), and Superconducting Linac (SCL). This paper will focus on the ion source, LEBT, RFQ, DTL, CCL, and SCL. The DTL and CCL will be referred to as the Normal-conducting Linac (NCL).

ERRANT BEAM

An errant beam is a beam pulse that is not normal. The beam current may be higher or lower than expected, or the beam pulse may be shorter or longer than expected. Errant beam produces beam loss. The beam loss can be abrupt from a fast shift in beam parameters or slow with small amounts of beam loss over an extended period of time. The beam may hit cavity surfaces causing gas or particulate desorption. The gas or particle desorption can create an environment for arcing, multipacting, or field emission.

MACHINE PROTECTION SYSTEM

The major task of the MPS is to turn off the beam. Individual equipment detects fault conditions and send a signal to the MPS to interrupt beam operation. The MPS does this function by turning off the ion source RF timing gate (the ion source decays in about 20 μseconds) and the RFQ timing gate (the RFQ decays in about 1 μsecond), and the entire beam is deflected outside the entrance aperture of the RFQ for 20 μseconds (the response for beam deflection is about 1 μsecond). The design maximum turn off time for the MPS is 20 μseconds [2]. This does not include the time for fault detection by individual equipment.

INITIAL EVENT

In 2009 the SCL began experiencing increased amounts of downtime [1]. Multiple cavities required running with reduced gradients, and some had to be turned off completely. This reduction in gradient significantly impacted the overall beam availability as well as the peak beam energy. The initial investigation determined that there were significant amounts of beam loss in the SCL near the cavities that experienced operational issues. Experts suspected the MPS was not working properly.

Measurements were done to verify the proper turn off time of the MPS. It was found that it was not working properly, and in some cases entire beam pulses were transported during fault conditions. The issue was found quickly and repaired, and SCL operation was restored with thermal cycling and RF processing.

CONTINUED DEGRADATION

Though the problems with the MPS in 2009 were corrected the SCL cavity performance continued to degrade due to errant beams, although gradients could be restored to their original values by thermal cycling and RF processing during maintenance periods. Figure 1 shows the short beam trip rate and beam energy from October 2010 to October 2012. It shows that there were typically 40 short trips per day, but in some cases up to 80 trips per day. Much of these trips were errant beam trips. It also shows that the beam energy decreased during the same time. Twice during 2012 the beam energy had to be reduced due to issues with SCL cavity performance. Some cavities had to be removed from the Linac to be repaired.

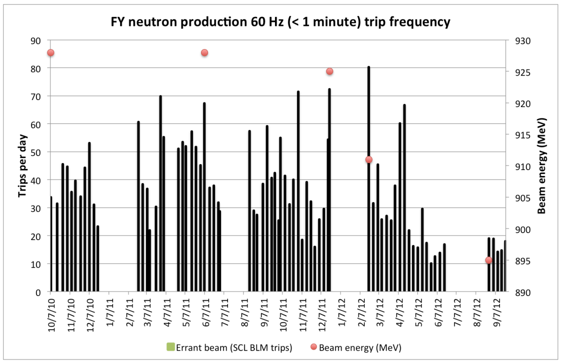

Figure 1: Weekly short beam trip rate and beam energy 2010-2012.

In order to achieve stable beam operation at high beam power the trend of decreasing beam energy had to be understood and corrected.

MEASURING ERRANT BEAM

The first task was to verify that the MPS was working properly. In order to determine the frequency and beam loss per event a differential beam current monitor measurement system was created using existing Beam Current Monitors (BCMs) in the MEBT, CCL, and end of the SCL.

An example of the Differential Current Monitor (DCM) system is shown in Fig. 2 [3]. It shows that the MPS was working properly and was turning off the beam within about 20 μseconds. It also shows that losing 20 μseconds of beam still is too much to lose in order to maintain nominal SCL operation and beam energy.

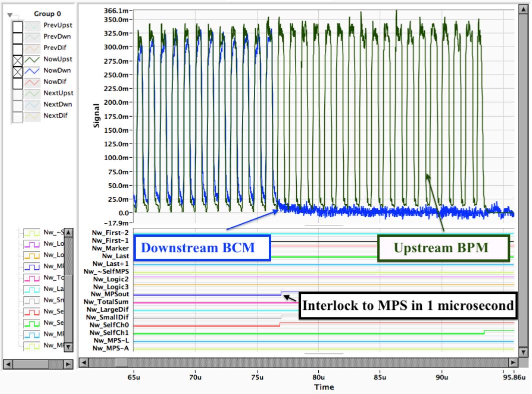

Figure 2: Snapshot of new Differential Current Monitor detecting an NCL fault.

The frequency of errant beam was found to be about half of the trip rate shown in Fig. 1. That means 20-30 errant beam pulses per day during neutron production.

SOURCES OF ERRANT BEAM

In addition to measuring errant beam the major sources of errant beam were identified.

Ion Source and LEBT

Within the ion source and LEBT there are two mechanisms for causing errant beam. The first was unstable ion source plasma ignition. Figure 3 shows an example of a beam pulse with delayed ion source plasma ignition. The ion source plasma starts 200 μseconds later than expected.

The other mechanism is arcing in the ion source or LEBT. Figure 4 is an example of an arc occurring in the LEBT producing a poorly chopped low current beam pulse.

The ion source was not found to be the major source of errant beam. Only about 10% of the errant beam trips were found to be due to ion source or LEBT malfunctions.

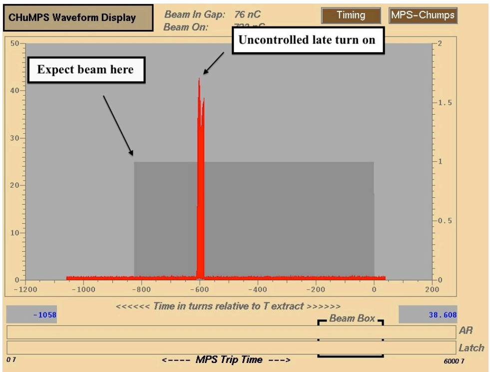

Figure 3: Example of late ion source turn on.

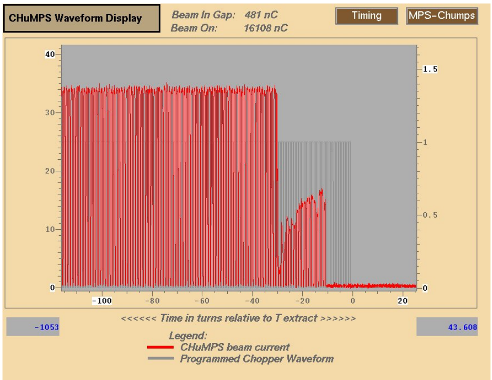

Figure 4: Example of a LEBT high voltage malfunction.

Normal-conducting Linac

The NCL cavities have experienced many operational issues. The most important issue has been vacuum performance. Many of the cavities have vacuum leaks that are very difficult to diagnose. Both the DTL and CCL tanks are pumped using ion pumps and the RF windows are pumped with Non-Evaporable Getter (NEG) pumps. Baseline vacuum pressures are typically very good reaching about 3e-8 Torr, but the pumps are always pumping on air leaks and become contaminated quickly. Once contaminated the pumps begin bursting gas. The bursts increase the probability of arcing and field collapse. If the cavity field collapses when beam is present in the cavity there will be beam loss.

---

*Work supported by ORNL/SNS through UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the U.S. DOE #peterscc@ornl.gov

After recording statistics for errant beam faults it was clear that the majority of trips were due to NCL malfunctions.

REDUCTION IN ERRANT BEAM

After reaching the conclusion that the NCL was the cause for the majority of errant beam pulses significant time was spent to try to reduce NCL faults.

NEG Regeneration

As stated earlier the main issue with the NCL is vacuum performance. A preventative maintenance plan was set up to proactively regenerate NEG pumps on the RF windows of the NCL. Figure 5 shows an example of NEG pump regeneration and the reduction of faults.

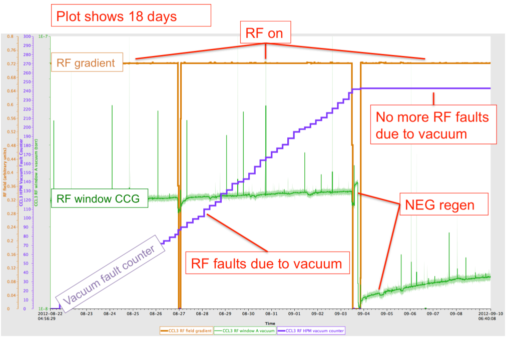

Figure 5: Reduction of RF cavity faults by reducing baseline pressure.

Change of RF Frequency to Reduce Multipacting

Another issue with the NCL is multipacting near the RF window. This was not only a cause of errant beam, but it was a significant source of downtime. The cavities were adjusted to run slightly off resonance to move outside of the multipacting band. The effect is shown in Figure 6. Initially in the figure there were many faults. After the shift in frequency the RF window vacuum decreased slightly, and the fault frequency decreased significantly.

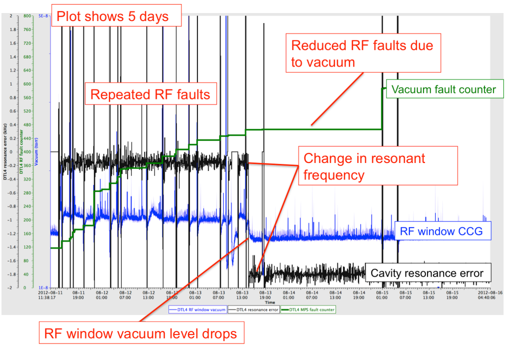

Figure 6: Reduction of RF cavity faults by running cavity slightly off resonance.

CONCLUSION

SCL cavity performance degradation has continued, but the rate of degradation has slowed due to improved performance of the NCL. Additionally, cavity performance can be restored with thermal cycling and RF processing. Figure 7 is an updated plot of Fig. 1 extended to 2015. The short trip rate has been reduced down to about 10 trips per day. Of those trips only about 5 per day are due to errant beam.

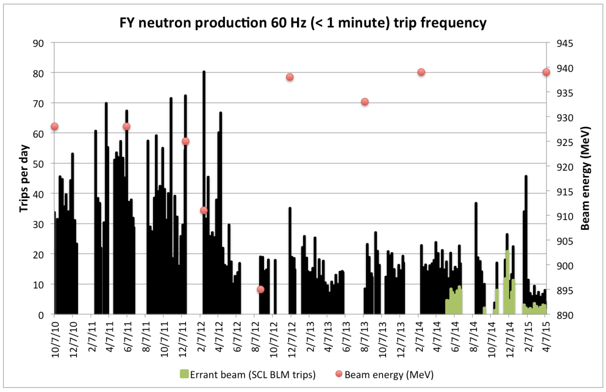

Figure 7: Reduction in errant beam trips since 2010.

To further improve NCL performance the vacuum system for the NCL is currently undergoing an upgrade.

Additionally, to further reduce the impact of errant beam, the DCM system has been connected to the MPS. The current turn off time is ~14 µseconds, but has the potential to reduce the beam turn off time down to about 6 µseconds [2].

ACKNOWLEDGMENT

The authors would like to thank all of the Accelerator Operations members that participated in data collection, and productive conversations.

REFERENCES

[1] S. Kim Et Al, "The status of the Superconducting Linac and SRF Activities at the SNS," 16th international conference on RF superconductivity, Sep 23-27, Paris, 2013

[2] C. Sibley, "Machine protection strategies for high power accelerators," Particle Accelerator Conference, 2003, May 12-16, Portland, OR, 2003

[3] W. Blokland, "A New Differential and Errant Beam Current Monitor for the SNS Accelerator," IBIC 2013, Oxford, Sep 16-19, 2013