OAK RIDGE NATIONAL LABORATORY SPALLATION NEUTRON SOURCE ELECTRICAL SYSTEMS AVAILABILITY AND IMPROVEMENTS*

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Abstract

SNS electrical systems have been operational for 4 ½ years. System availability statistics and improvements are presented for AC electrical systems, DC and pulsed power supplies and klystron modulators.

INTRODUCTION

The Electrical Systems Group at the SNS has responsibility for DC power supplies, pulsed power systems and modulators, and for AC power distribution on site. These systems have been in operation for 4 ½ years since initial commissioning in 2006 and have had numerous upgrades and improvements to increase overall accelerator availability. This report lists these upgrades and improvements and their effect on availability. In this report, availability is presented as total downtime hours per system. Figure 1 shows the down time for each of these systems for FY 2007, 2008, 2009, 2010 and 2011 (2011 extrapolated from ½ year of operation) for the scheduled 3779, 4032, 4916, 5310, 5500 hours of beam delivery for each year respectively. Fiscal year starts October 1.

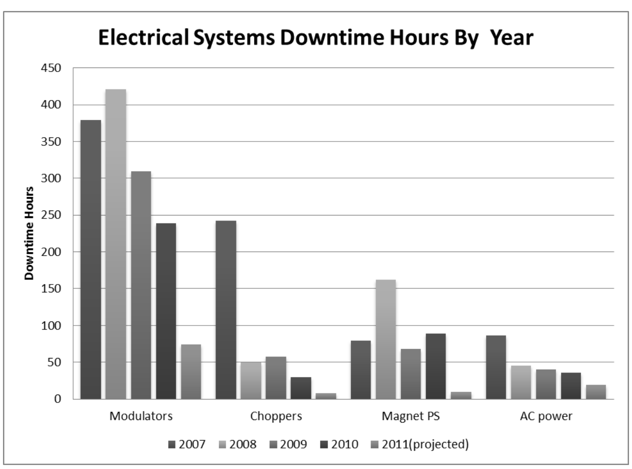

Figure 1. Downtime by system for FY 2007 to FY 2011

DC POWER SUPPLIES

[1] There are 474 dc magnet supplies used at SNS. These can be divided into 2 types: unipolar (114) supplies used as the main magnet supplies and bipolar supplies used for corrector magnets. The unipolar supplies are largely water cooled and of 15 types ranging from 185 to 6000 amperes. The bipolar supplies (360) are air cooled 20 A units that can be connected in parallel to provide up to 140 A. All power supplies were commercially purchased. Power supplies all include DCCTs (Direct Current Current Transformers) for current monitoring. All power supplies (except for the 6000 A, 440 V main ring power supply) were tested at the vendor into a full resistive load. These dc power supplies have proved to be very reliable and do not contribute much down time. Failures that have occurred have been individualized occurrences that are not systematic. In FY 2010, an intermittent fault in a 6000 A supply accounted for over 1/2 of the downtime for magnet power supplies.

A separate power supply interface (PSI) chassis is used to provide computer interfacing and control of the power supplies. In the last few years, 2-3 failures per year of the fiber optic drivers in these units have occurred.

PULSED POWER SUPPLIES

There are four types of pulsed power supplies used at SNS: Injection Kicker Magnet power supplies, Extractor Kicker Magnet power supplies, Low Energy Beam Transport (LEBT) fast electrostatic deflector supplies and, Medium Energy Beam Transport (MEBT) fast electrostatic deflector supplies.

[2] There are 8 injection kicker magnet power supplies that produce pulses with a rise time of 2 ms, a programed pattern of 1 ms, and a fall time of 0.25 ms. The programed pattern can be any monotonically decreasing pattern within a 120 kHz bandwidth. The injection kicker magnets “paint” the beam from the linac into the ring and different patterns may be used. The injection kicker magnet power supplies are operated in pairs and outputs of each member of the pair must track each other within 0.5%. These power supplies are bipolar +/- 800 V at 1400 A and operate at 60 Hz. Few problems occurred with these units.

[3] The 14 Extractor Kicker magnet power supplies are all identical and are each Blumlein configured PFNs (Pulse Forming Networks) switched by Thyratrons. They were developed in collaboration with Brookhaven National laboratory. They have a rise time of <200 ns (1%-95%) and a flat top of at least 700 ns and operate at 60 Hz. The pulse output is 2.5 kA at 35 kV with a

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maximum of 5% ripple (peak-to-peak) on the flat top.

The extraction kicker power supplies have had a number of issues that have been resolved. The original commercial Thyratron trigger board was not properly matched to the Thyratron, leading to excessive jitter, over currents in the grid circuits and cable failures as well as decreased Thyratron lifetimes. These boards were replaced by a different commercial trigger board that met requirements and resolved these problems. The commercial PFN charging supplies experienced early failures due to output capacitor failures. These capacitors were replaced with an improved capacitor and no further failures occurred. There were a spate of PFN charging cable failures – shields were added and cables are inspected yearly to minimize this problem. These extraction kicker problems all started occurring in FY 2008 and were resolved in FY 2009.

LEBT PULSERS AND MEBT PULSERS

The LEBT pulsers chop the 1 ms, 65 kV beam from the ion source at 1 MHz with 700 ns on, 300 ns off to provide an extraction gap in the ring. The 4 channels are each +/- 3 kV with 50 ns rise times. These LEBT pulsers are capacitively coupled to a dc -65 kV lens element within the LEBT which occasionally arcs down. These arcs were responsible for multiple failures of the LEBT pulsers in FY 2007. Since then, additional levels of protection have been added to the pulser circuitry to reduce downtimes from 242 hours in FY 07 to an annualized rate of 9 hours in FY 11.

The 2 MEBT pulsers are unipolar but are otherwise have a similar function to the LEBT pulser. They feed deflection plates following a 2.5 MeV RFQ and serve to sharpen the extraction gap. These pulsers are 3 kV with a 10 ns rise time. These are commercial units that have not contributed to downtime.

MODULATORS

[4] [5] There are presently 15 installed modulators that provide power to 92 klystrons for the SNS linac. The modulators all are rated at 11 MW peak, 1 MW average power with maximum operation at 1.35 ms at 60 Hz. These modulators were designed in collaboration with Los Alamos National Laboratory for the SNS project and are of a resonant 20 kHz polyphase boost inverter design. While all 15 the modulators are of a similar design, there are three different models of modulators, each with a different voltage and output current to match to their klystron loads.

As delivered, the modulators had severe operational problems, mostly due to component selection issues. In FY 2007, the modulators had 380 hours of down time, despite being operated at low duty cycles (30 Hz, 500-800 us). In 2008, when we went to 60 Hz, downtime increased to 420 hours. Since then, the down time has decreased each year despite increasing duty cycles (from 800 us to 1200 us pulse length at 60 Hz). In FY 2011 the modulators have had 36 hours of down time in 2400 scheduled hours of beam delivery so far for an annualized rate of 79 hours.

Components replaced include all inductors, transformers, insulators and voltage dividers; most capacitors, resistors, electrical connectors, and cabling (both due to sizing issues and flammability ratings). The cooling systems (air, water and oil) were all upgraded. The capacitors led to the most down time as some oil-filled capacitors would rupture on failure, spewing highly flammable fluids in the modulator enclosure, causing extensive damage to the modulator.

While the basic topology was retained, an important change was made in FY2009 to the firing of the IGBTs. Previously, a macro pulse ended at random times during the IGBT firing cycle, causing possible termination of the pulse at a voltage peak. This caused high voltage ringing that ultimately damaged the IGBTs. This was change to insure that the macro pulse ended near a voltage zero crossing. Since this change was instituted, IGBT failures have decreased by a factor of 50.

A more detailed description of these changes is contained in reference [6], these proceedings.

AC ELECTRICAL SYSTEMS

[7] Electrical power for the site is provided by dual 161 kV transmission lines to two, 70 MVA, 161 kV to 13 kV transformers. One of these transformers is used to provide 100% redundancy. These transformers are connected to 47 substations on site, of which 29 are used directly for accelerator systems. The transformers in turn are connected to about 100 transformers, 100 motors (over 50 HP) and 12,000 circuit breakers. There are 8 diesel engine powered, back-up generator systems and 13 Uninterruptable Power Systems (UPSs) on site with capacities of 2300 kVA and 345 kVA, respectively. Present site power usage during accelerator operations is about 24 MW.

Most of the down time assigned to AC electrical systems is due to power fluctuations that trips off any system that can affect the beam delivery. Typically the power disturbance is 5-7 cycles long with about a 20% voltage sag. These are usually associated with lightning strikes or faults on the external power grid. The time to recover from these trips has been as much as 12 hours. While there is little that we can do about these disturbances, we have been able to minimize their effects on equipment. Especially sensitive equipment has been moved to UPS power. Trip levels for other equipment such as motors have been set at the maximum level allowed by their specifications. These actions have significantly reduced downtimes. No power failures have occurred that have triggered the starting our back-up generators. Other notable causes of downtime for AC electrical systems are circuit breaker trips/failures and loose wiring. Electrical wiring issues have been addressed by an inspection program on a 4 year cycle. Circuit breaker trips have resulted from improper breaker coordination, breaker failures and critters getting into electrical cabinets.

In addition to the above failures, we have experienced two 13 kV switch failures, one 13 kV/480V transformer failure, and numerous motor starter failures that did not contribute to beam downtime as they either occurred during a maintenance outage or had a redundant back-up. The 13 kV switches have been upgraded, and spares are maintained for transformers and switches. The motor starters were replaced under warranty by the manufacturer.

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