SNS Beam Chopping and its Implications for Machine Protection *

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Abstract

The SNS front end has a high speed chopping capability, which has the primary purpose of creating the 250 ns beam gaps essential for safe ring kicker operation. This chopper is also predicted to be capable of extinguishing the beam completely, and holding it off indefinitely, without damaging or activating any hardware, and without even changing the thermal equilibrium of any RF gear. It is, however, an intrinsically non-fail-safe approach to blanking a potentially 2 MW average power H^- beam. This paper will describe the front end chopping process, and the interlock systems that will allow it to be used as a convenient initial mechanism for on-demand beam blanking. It will also describe the instrumentation that will detect faults and initiate slower, more reliable, and less operationally desirable means of turning off the beam.

1 INTRODUCTION

One category of shutdown command from the SNS Machine Protection System (MPS) requests an immediate shutdown for the rest of the 1 ms nominal beam pulse, but the machine should continue to operate, starting at the next scheduled (60 Hz nominal) pulse. A typical use of this mode is for when a beam loss monitor exceeds a threshold. The shutdown mechanism should be as fast and minimally invasive as possible, so the machine's operability on the next pulse will not be jeopardized. This implies that neither cavity RF nor the source plasma should be turned off.

As described below, the LEBT chopper can deflect at least 98% of the beam into the 65 keV "dump". Because of the vagaries of this chopper, there is no possible way for it to be considered a fail-safe shutoff. The trick to effectively using this mechanism is to have fast and reliable means of detecting its failure, and to have a fast and reliable backup method to kill the beam. Fast in this case means the total time from primary shutdown input to beam shutdown, through the secondary channel, needs to be less than about 10 μs.

The RFQ provides a satisfactory means to shut down the beam reliably. A kill switch in the RF drive line will reduce the field to a non-propagating level in about 5 μs. If the system resorts to this backup method, the fault shifts to the "latching" category, because the thermal equilibrium in the RFQ is disturbed. Figure 1 shows the architecture schematically.

* Work supported by the Director, Office of Science, Office of Basic Energy Sciences, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098

2 SECOND STAGE BEAM SHUTOFF

The primary means of detecting failure of the LEBT chopper is to measure and fault-check eight signals at 32 MHz: the four deflection electrode voltages, and the four split-electrode current signals. The process of digitizing waveforms of current and voltage is fail-safe: the chance that broken wires, changes in gain, and extraneous random noise can take an invalid signal and make it pass a long series of window tests is vanishingly small. All obvious hardware failure modes are detected by this arrangement. These include failures in the ± 3 kV power supply, the high voltage switch, the capacitive coupling network, the timing generator, and cables between the above components The split electrode measurement is designed to detect small amounts of mis-steering. It is also true that, by looking at the simple sum signal, mis-steering that is sufficient to let beam through during the intended chop times can also be detected.

The signal processing has to happen with latency less than a few microseconds, since the time to melt beam line (especially at the 2.5-7.5 MeV segment of the machine) is in that range. Time to clear the beam. Conventional computer technology (microcontroller, DSP, RISC, and multi-CPU collections of the above) may reach very high throughput and average speed, but guaranteed latency behavior is not so good. The current generation of FPGA chips can, when carefully used, cycle at 50 to 200 MHz, and perform simple computations with a few cycle latency. Parallel, adjustable window comparisons of four to eight channels count as simple computations.

FPGAs are uniquely testable, and all logic circuits and wires on the chip are fully tested at the factory. Within limits, the firmware that runs the FPGA can be tested in a software simulator (this is one of the big reasons Verilog and VHDL design methods are so popular). With the addition of bench-test design verification, using such time honored methods as temperature and frequency guard band testing, we expect to meet standards of sound engineering suitable for the project's QA-2 level.

3 LEBT CHOPPER OPERATION

LEBT Chopper operation is explained in more detail elsewhere. High speed chopping waveforms are capacatively coupled onto electrodes whos D.C. potential sets the static steering and focusing behavior. Because of that A.C. coupling, the chopping waveforms have to be designed to have zero D.C. component. The waveforms shown in figure 2 have that property. The only time a small amount of beam

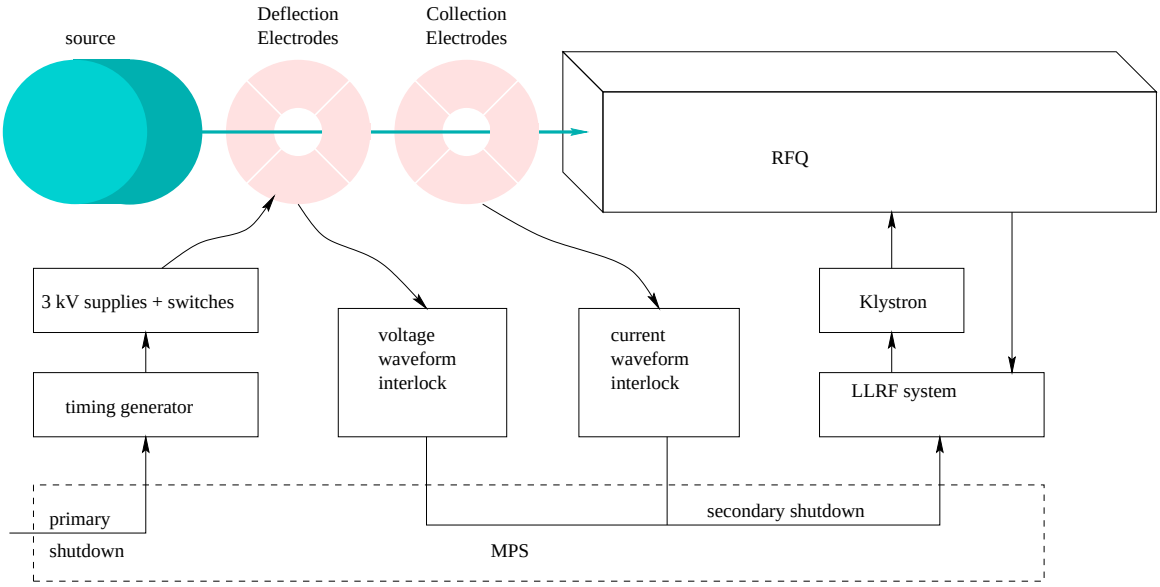

Figure 1: Schematic of the beamline and redundant cutoff mechanisim.

might leak through the chopper is during the 40 ns transitions between dwell points, when the deflection is $1/\sqrt{2}$ of the design point. These events happen at roughly 1 MHz, suggesting that the overall chopping ratio is at least 98%.

The LEBT chopper target (onto which the chopper electrodes deflect the beam) are designed to accept the full 150 Watts of beam power that would arise from a having the whole 1 ms pulse land on the target at 60 Hz. The MEBT chopper, on the other hand, can only accept The heat load on the MEBT chopper target under cutoff conditions is no more than that during normal operations, so it is possible to use the combination of choppers to achieve full (better than 10^{-4}) extinction of the beam in the linac using the choppers, while leaving all RF systems running.

4 MPS INTERACTION

The Chopper controls need to be able to shift to mode 1 with microsecond latency, so the FPGA that controls these waveforms must have a direct connection from the MPS. The fault detection subsytems also need such a direct connection. Finally, the fault detection subsystems need to be able to communicate back to the MPS, with a similar low latency, so that backup shutoff can be triggered if this method fails. Additional levels of protection can be incorporated into the MPS, such as from the current transformers and beam position monitors installed in the MEBT.

5 REFERENCES

[1] J.W. Staples et al., “The SNS Four-Phase LEBT Chopper,” Proceedings of the 1999 Particle Accelerator Conference, New York, 1999

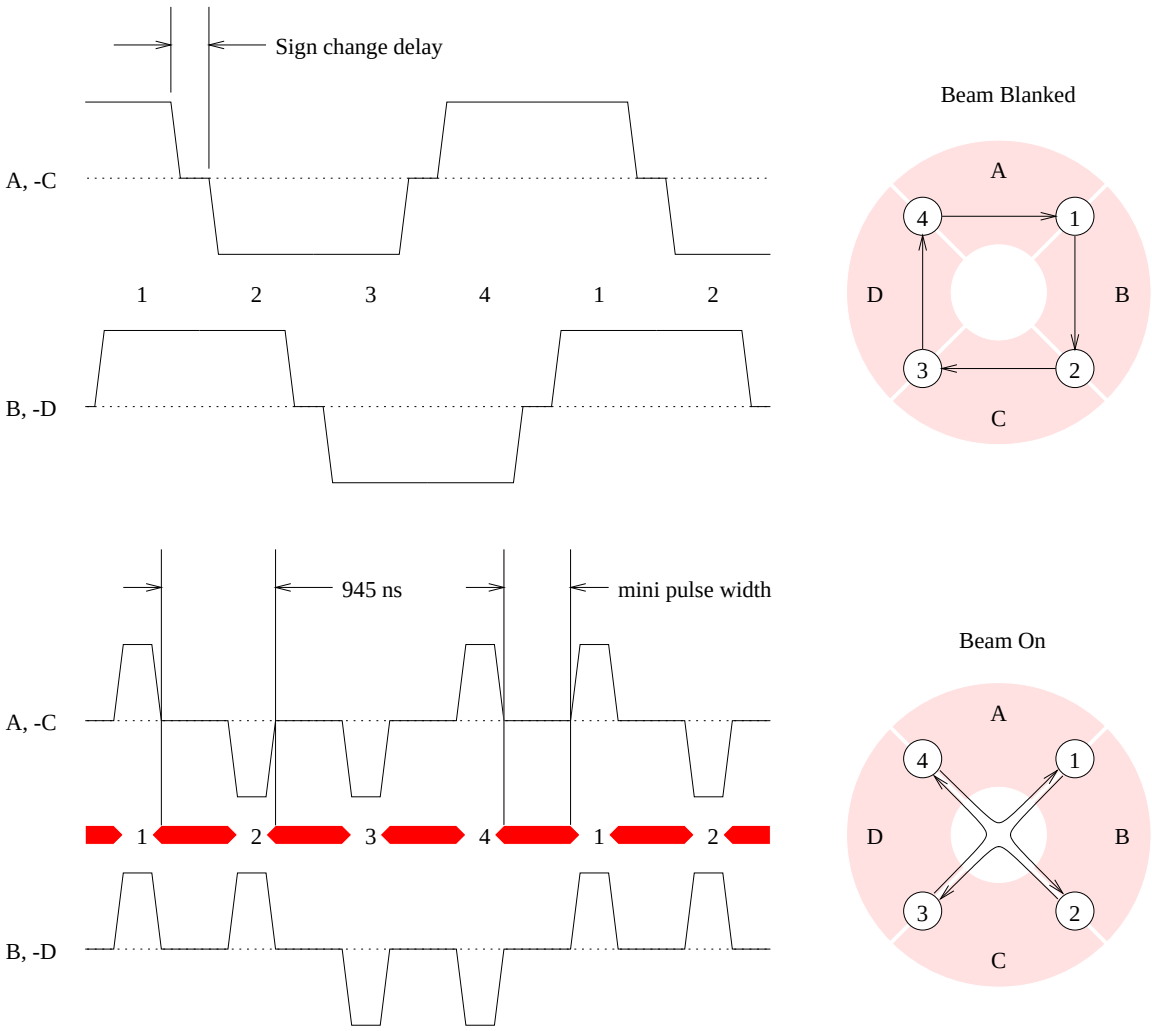

Figure 2: LEBT chopper waveforms at the mini-pulse scale..