HIGH-DYNAMIC-RANGE CURRENT MEASUREMENTS IN THE MEDIUM-ENERGY BETA TRANSPORT LINE AT THE SPALLATION NEUTRON SOURCE*

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Abstract

It is desired to measure the effectiveness of the LEBT (low energy beta transport) chopper system. Since this chopper is required to chop the H- beam to a 1% level, it is, therefore, required to accurately measure the beam during the chop. A system is developed with a high dynamic range that can both accurately measure the beam to tune the chopper system as well as provide an input to the MPS (machine protection system) to stop the beam in the event of a chopper system failure. A system description, beam based calibration, and beam measurements are included.

SPALLATION NEUTRON SOURCE

The Spallation Neutron Source (SNS) is a third generation pulsed neutron source recently completed at the Oak Ridge National Laboratory in Oak Ridge, Tennessee. An ion source produces 1 millisecond macropulses of H^- ions. The Radio Frequency Quadrupole (RFQ) creates micropulses at 402.5 MHz. Choppers are used to create 300 nanosecond gaps from the macropulse for clean extraction from the ring. The resulting 645 ns minipulse is accelerated to 2.5 MeV and injected into the main accelerating structure. Drift Tube Linac (DTL) and Couple Cavities Linac (CCL) structures are used to accelerate the beam to 186 MeV. The superconducting linac accelerates to 1 GeV. The resulting protons are accumulated in the ring and delivered in 1 microsecond pulses to the liquid mercury target.

LEBT Chopper

The LEBT chopper is located before the RFQ and provides a preliminary chop in the beam that lowers the beam power to the MEBT chopper. The LEBT chopper uses four electrostatic plates to create gaps by deflecting the beam out of the beam path. Figure 1 shows the bunching structure for SNS. The proposed system will allow operators to analyze the efficiency of the LEBT with greater precision as well as allow a mechanism for machine protection. In the event of a chopper failure, the beam in the gap will be accelerated to the ring and strike components during extraction potentially causing excessive radio activation and costly downtime. For the accelerator to run at its design power the chopper system must be running as efficiently as possible.

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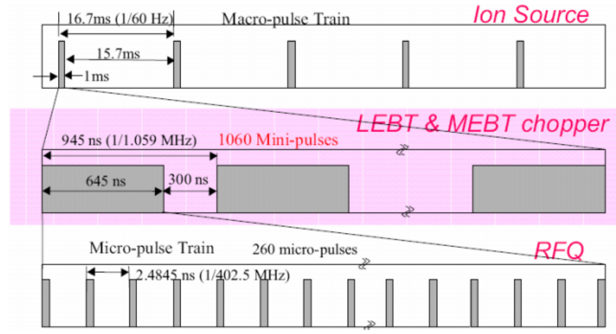

Figure 1: SNS bunching and gap structure. [1]

CHOPPER MPS SYSTEM

System Requirements

The main requirement of the Chopper MPS system (ChMPS) is that it be able to measure the beam-in-gap currents. The previous method of analyzing the beam in gap consisted of using beam current (BCM) monitors to visually determine the efficiency of the LEBT chopper. The BCM method has been shown to only resolve the signal to about 2 to 4 mA. The ChMPS system presented seeks to provide an analytical method of measuring chopper efficiency with a much higher dynamic range. It was determined that a range of 50 dB would be adequate. Furthermore, the proposed system would allow for a mechanism that can be added to the MPS of the machine that will disable beam if the beam-in-gap current rises above a preset threshold.

Hardware Description

Beam position monitor (BPM) data is taken from the BPM immediately after the LEBT chopper. The BPM's used in SNS house four microstrip electrodes to measure beam position and phase by measuring the voltage on a particular electrode and comparing it to the other three. Figure 2 is a cutaway of the type of BPM used to collect data for this system.

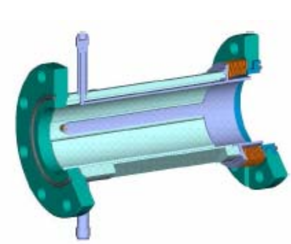

Figure 2: Cutaway BPM assembly.

Figure 3 shows a diagram of the ChMPS system hardware.

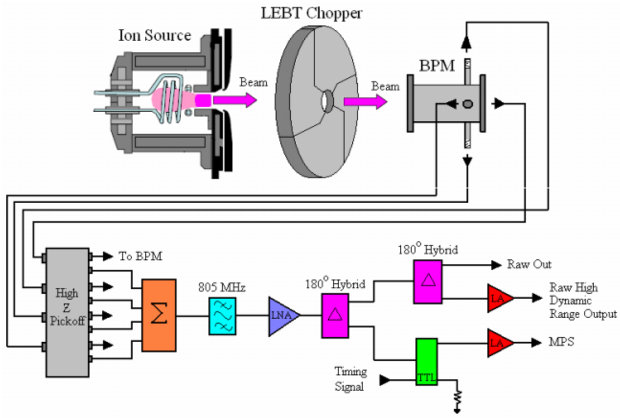

Figure 3: ChMPS hardware layout.

SMA cables are used to transfer signals from all four BPM electrodes to the ChMPS system. One of the requirements of this system is that it not disrupt the BPM system. Therefore, the individual data lines are put through a high impedance pickoff box. The high impedance pickoff uses a parallel 1 kΩ to sample approximately 5% of the BPM signal and send it to the rest of the ChMPS system before sending the rest of the BPM data to the BPM electronics. The signals are then put through a summing hybrid so the beam data is insensitive to the beam position. One band pass filter is used to ensure that only the 805 MHz component is analyzed. The signal is amplified by 33 dB with a low noise amplifier. The signal is then split with a 180˚ Hybrid. One of the signals is then split with another 180˚ Hybrid and used for a raw data output which is used to measure the rise and fall time of the chopper while the other is put through a log amp which provides a high dynamic range output. The other signal from the first split uses a TTL logic circuit triggered from the machine timing to analyze data for the MPS system. The installed ChMPS can be seen in Figure 4.

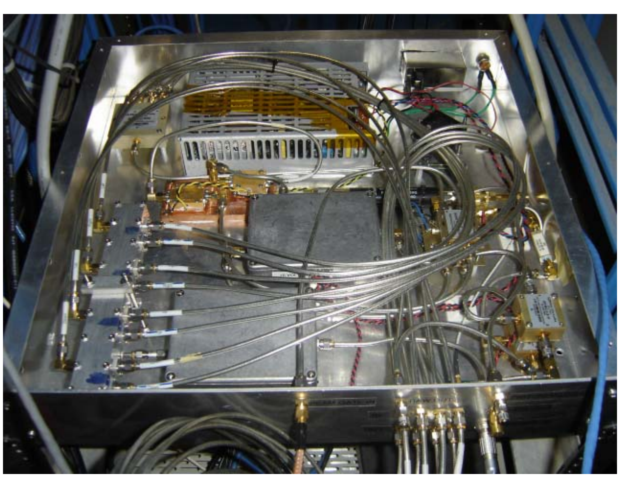

Figure 4: Installed ChMPS hardware and housing.

Log Amp

The log amp chosen for this system is the Analog Devices AD8318. It has a minimum usable input power of -60 dBm and a maximum input power of 0 dBm. The characteristic curve of the log amp used can be seen in Figure 5 and shows that, with attenuators to keep the input power within range, the log amp has 50 dB of dynamic range. This corresponds to the ChMPS system requirement to be able to resolve 50 μA. The log amp measures the power of an incoming spectrum and returns a corresponding voltage. When there is no signal it has an output of 2.1 volts, which can be used as a fail-safe threshold for the MPS system.

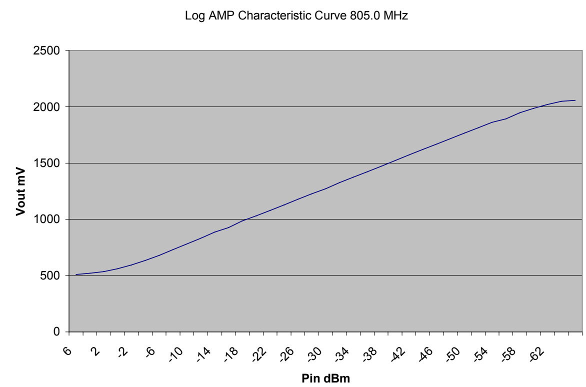

Figure 5: Log Amp characteristic curve.

MPS and Timing

For the purpose of protecting the machine against a LEBT chopper failure, it is important to only analyze the chopped portions of a pulse. The TTL switch in the ChMPS system is triggered by the timing signal from the chopper and is set to be in the on position in the gaps between mini-pulses. The log amp then analyzes data only when there should be no beam. If there is beam in the gap the log amp will read the voltage and if it is above a predetermined threshold the MPS will shut off the beam. The bottom waveform in Figure 6 is the raw BPM data and the top is the ChMPS output voltage which shows the measurement of a single mini-pulse in which one of the LEBT chopper plates had failed leaving beam in the gap.

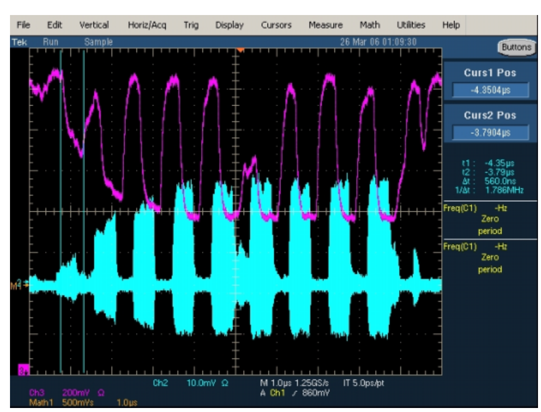

Figure 6: ChMPS measurement of a mini-pulse with failed chopper.

Software

The voltage output of the log amp is not directly usable to the operators and physics. Therefore, once the data is received from the log amp it is processed to output the data as a current. A script written in MATLAB was written to do the conversion.

The data is first run through a moving average filter with a span of 100 points. Using the log amp characteristic curve in Figure 5 each voltage point is converted to power in dBm which is then converted to power in watts using

$$P = 0.001 \cdot 10^{\frac{P_{dBm}}{10}} . \quad (1)$$

The peak voltage is found by

$$V_{peak} = \sqrt{100 \cdot P} . \quad (2)$$

The current is then

$$I = V_{peak} \cdot Scalefactor, \quad (3)$$

where the *Scalefactor* is found by dividing the known current of the beam by the minimum V_{peak} measured from the ChMPS at that current.

RESULTS

The waveforms in Figure 6 show that the ChMPS is indeed capable of characterizing the beam. Figure 7 shows another example of the ChMPS showing a more detailed representation of the chopper efficiency. The case in Figure 8 had the choppers set to chop all but one

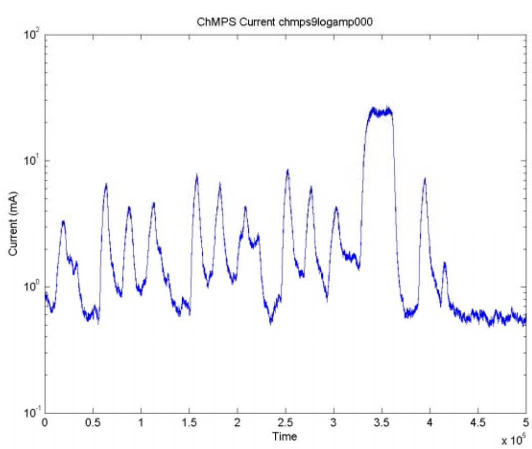

Figure 7: Current waveform of data in Figure 8.

mini-pulse and shows the current waveform. The case in Figure 8 shows a current plot of beam analyzed with the ChMPS where the timing has been implemented. The TTL is only switching when there is no beam. The spikes on each pulse suggest the timing needs to be adjusted to avoid catching the rise and fall of each pulse. The minimum current measured in Figure 8 is 10 µA.

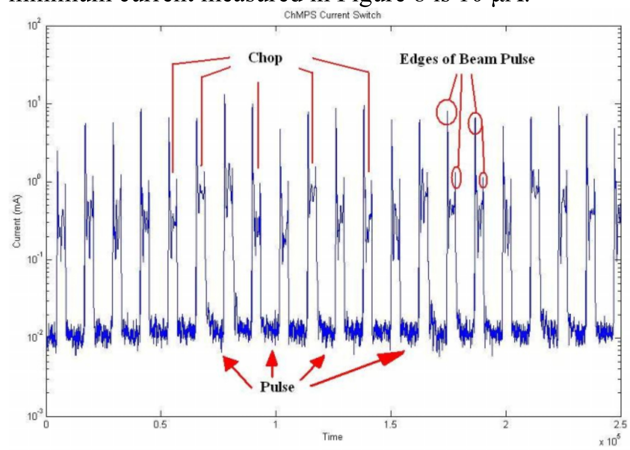

Figure 8: ChMPS with timing switch analyzing beam gaps.

CONCLUSION

The ChMPS system designed to measure chopper efficiency with high dynamic range succeeded in delivering a more precise method of measuring the beam in the gap with a measurement floor of 50 µA. Future developments to this system will include; full integration with the chopper timing allowing analysis of only the chopped portions of the beam, integration into the MPS system allowing for automatic beam shutoff in the event of a chopper failure, further development of the software that will allow a GUI driven interface, and addition of a digitizer that will allow the ChMPS data to be viewed in real-time from the accelerator control room. The usefulness of the ChMPS can also be expanded to measure the efficiency of choppers in other areas of the accelerator. This system will allow for a more efficient and safer method of neutron creation and accelerator operation in the Spallation Neutron Source.

REFERENCES

[1] Stockley, Martin P., “The SNS Chopper System”, Lecture given at the Spallation Neutron Source, Oak Ridge, Tennessee, November, 2002.