Direct Geometry Spectroscopy on a Nearly Constant Frequency Source

G. E. Granroth, J. D. Galambos, A. A. Parizzi, W. M. McHargue, J. A. Kohl, X. Yao, A. I. Kolesnikov, and T. E. Sherline

Neutron Sciences Directorate, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831 USA

E-mail: `granrothge@ornl.gov`

Abstract. The Spallation Neutron Source (SNS) at Oak Ridge National Laboratory (ORNL) typically operates on a clock that closely follows the input power line frequency. For most experiments, the variation in the line frequency is so much smaller than other resolution effects that it can be ignored. However for fine resolution direct geometry spectroscopy the monochromating chopper may produce a time width of a few μs. Therefore the ability of the chopper to follow the source clock is crucial. To understand the sensitivity of the data and the chopper phase to the variability of the source, we embarked on the study summarized here. Two novel concepts were used in this study: 1) the accelerator was operated at fixed frequency and 2) The top dead center positions of each chopper were recorded as an event list in the raw data. Point 1 is novel because the accelerator was specified to operate close to the line frequency instead of at fixed frequency. Thus many of the accelerator components are operating in a manner for which they were not designed. Point 2 allows for precise correlation of the chopper phase with the neutron events. Specifically, measurements of the incoherent scattering from V were measured on the SEQUOIA spectrometer using $E_i = 100\ meV$ neutrons. This monochromatic beam was produced by the fine resolution Fermi chopper spinning at 600 Hz resulting in $\Delta E = 2\ meV$ at the elastic line. During this acquisition, the source was operated for 14000 s at a variable frequency, then 4000 s at fixed frequency, and finally 4700 s at variable frequency. The resultant data shows no noticeable change in energy resolution assuming no pulses are vetoed. Operational implications of this study will be discussed. One of which is that we have demonstrated a method for users to decide the chopper veto window post acquisition.

1. Introduction

The Spallation Neutron Source (SNS) at Oak Ridge National Laboratory (ORNL) is an accelerator base pulsed neutron source. There are many types of operating instruments at the SNS of which the Direct Geometry Chopper Spectrometers, ARCS[1], CNCS[2], SEQUOIA[3, 4], and HYSPEC[5] are the most sensitive to variation of the accelerator phase. For these instruments, the minimum designed time pulse width is 1.33 μs. For this case the phase stability must be better than 230 ns. Though this is the tightest requirement, the chopper that produces this tight time pulse is rarely used. The tightest most frequently used chopper is designed to produce a 5.4 μs pulse which requires 1 μs phase stability. This latter chopper is the focus of this study. Both of these cases show that tight time control is necessary.

There are multiple possible causes of instability to this center. One possible source is the stability of the chopper phase with respect to when the neutrons are generated in the source.

Traditionally this contribution to the phase stability has been minimized by fixing the source frequency. IPNS was synced to the clock of one of the Fermi choppers[6], ISIS filters the line frequency through a fly wheel[7], and J-PARC operates at fixed frequency[8]. Before the SNS, LANSCE was the only neutron source to follow the line frequency. This choice was made because of accelerator technology limitations at the time of its design and construction[9]. Therefore any narrow time width choppers must closely follow the line. The successful experiments from the instrument Pharos[10] show that this choice was OK. Therefore the design choice for the SNS accelerator was to operate at the line frequency smoothed so it changes no faster than 1 mHz/s [11]. However, technology improved from the time of this design choice to the time of procurement of many components in the accelerator, and a review of these components revealed that they could operate within their parameters and the whole system operate at fixed frequency. This report details an accelerator fixed frequency test run and a study to see if there is a benefit for the instruments that are most sensitive to it. The specific study used the SEQUOIA spectrometer because its long final flight path makes it the SNS's direct geometry spectrometer that is the most sensitive to timing variations. After this discussion, comments related to the high speed disc choppers on CNCS and mechanical bearing T_0 choppers will be made. These two chopper types are the others that are the most sensitive to variations in the line phase.

2. Accelerator Description

The SNS accelerator was designed to operate at the electrical grid frequency of 60 Hz, and to follow a targeted phase of the AC line voltage with a slew rate limited to 1 mHz/s. So the accelerator is not precisely fixed to a phase of the AC line. Generally no adverse effects on beam production were noticed during the periods when beam pulse generation strayed from the targeted AC line phase. This motivated the attempt to try and run the SNS at a fixed frequency.

A primary accelerator technology consideration , that is potentially impacted by variation of the beam pulse timing with respect to the grid phase, is the stability of DC power supplies (e.g. magnet, and high voltage power supplies for RF generation). This equipment has design output stability requirements of 10^{-3} (10^{-4}) for linac (ring) magnet power supplies, which is sufficient for stable beam operation. However an assumption in the design phase was that the beam operation would be fairly stable with respect to the AC line phase. Regardless, modern power supply switching technology used in the SNS power supplies is able to provide this stability level, independent of time relative to the AC line. Another concern is AC elements in the accelerator equipment. For example the klystrons that generate the high power RF for particle acceleration use hot cathodes, heated by AC power. The SNS klystron cathodes were designed with sufficient mass to avoid the small thermal transients resulting from the AC input variation (which is problematic at some older facilities). Finally, care must be taken to avoid introduction of slight signal ripple in equipment throughout the accelerator from inadvertent poor quality low power AC power supplies. There are thousands of such small power supplies that can cause issues, ranging from use in electronic signal generation for low level RF control to power supplies in proton beam instrumentation electronics. None-the-less, when equipment is working properly, the AC ripple issues can be avoided.

3. SEQUOIA Description

The SEQUOIA spectrometer is a fine resolution, direct geometry, thermal to epithermal Fermi chopper spectrometer. The neutron beam originates from the decoupled ambient temperature H_2O moderator and travels 20 m to the sample position. A Fermi chopper, located 18 m downstream of the moderator and 2 m upstream of the sample, monochromates the beam. Two Fermi chopper choices and an open beam position are provided on a translation table. Fermi chopper 2, with 2.03 mm slits and a channel curvature of 0.58 m was used for the data described in this contribution. The Fermi chopper slit package is 100 mm long. A narrow bandwidth T_0

chopper is located 9.8 m from the moderator. Its primary purpose is to block the highest energy neutrons generated when the proton pulse hits the target. It also serves as a bandwidth limiting chopper to control when neutrons are available to the Fermi chopper. Neutron guide is utilized to provide a high flux of neutrons on a sample that can be as large as 50 mm by 50 mm. A cylindrical detector array consisting of $\sim$ 110,000, 12 mm tall by 25.4 mm wide pixels is located 5.5 m downstream of the sample position. This detector array has a maximum scattering angle of 60° in the horizontal and 18° in the vertical. The minimum scattering angle is 2.5° in both the horizontal and vertical directions. Each neutron event is recorded and timed with a 100 ns clock from a set offset to when the injection signal is sent to the kicker magnet. [12]. The phase of a given chopper is measured by recording its Top Dead Center (TDC) signal into the event stream. The TDC signal is generated each time the chopper makes a full revolution. In the event stream, first two bytes of the event record are used to differentiate a TDC signal from a neutron event. This style of event recording can be used for any parameter that one wants on the same clock as the detectors and has also been used for strain on Vulcan[13]. Further details of the SEQUOIA instrument are given elsewhere. [3, 4]

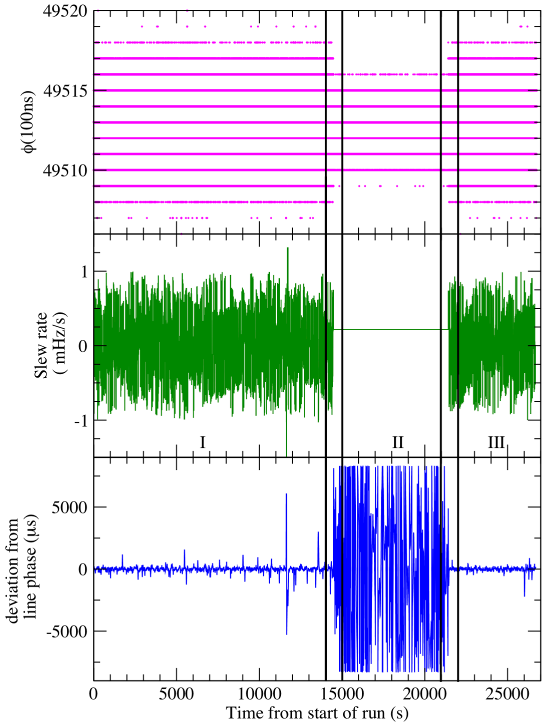

Figure 1. Fermi Chopper TDC signal and several accelerator parameters during the course of the run. The three regions indicated by the black vertical lines are the three regions analyzed separately.

4. Test run on SEQUOIA

For these specific tests the accelerator was operated for 2 hours at fixed frequency. Before and after the run the accelerator was operated at a maximum slew rate of 1 mHz/s. A 30 mm x 30 mm x 2 mm thick V plate was placed in the sample position on SEQUOIA. The sample was kept at room temperature. Fermi chopper number 2 was phased for 100 meV at a rotation speed of 600 Hz and a run was started. The run was started before the accelerator was changed to fixed frequency operation and was operated in this configuration through the fixed frequency operation and after the slew rate was restored to 1 mHz/s. The fact that neutron data is acquired as events, allows these three regions to be gathered into independent histograms after the acquisition is complete. The accelerator paramaters and the Fermi chopper TDC signals (ϕ) as a function of time from the beginning of the run (t) are shown in Figure 1. As the Fermi chopper rotates 10 times per source pulse, only the TDC pulses corresponding to timing for $E_i = 100\ meV$ are shown. The regions that are analyzed together are indicated by the Roman numerals on the plot and are summarized in Table 1. The equally spaced horizontal lines in the top most pane reveal the 100 ns clock used to record the Fermi chopper TDC signal. Furthermore the phase stability gets noticeably better in region II. Also in Region II the slew rate is obviously zero but the deviation from the line phase greatly increases. Specifically one notices that the deviation from line phase swings through a full cycle many times (identified as a time difference of -8333 μs to 8333 μs or the opposite).

Table 1. Statistics describing the performance of the choppers during the three different timing regions

Region	$t_{min}(s)$	$t_{max}(s)$	$\overline{\phi}(\mu s)$	$\phi_{FWHM}(ns)$	$(\phi_{i+1} - \phi_i)_{FWHM}(ns)$
I	0	14000	4951.28	346	330
II	15000	21000	4951.269	216	260
III	22000	26759	4951.27	344	260

The primary question is if there is any observed change in the data on the detectors. To look for such a change the data was converted to energy transfer and then separated by acquisition time into the three aforementioned regions. The events from each region were compiled into a histogram, and then all the detectors were summed for each histogram. The net result is shown in Figure 2. There is no noticeable difference in the signals. This result confirms the scientific design criteria of no sensitivity to a phase uncertainty of 1 μs. [14]

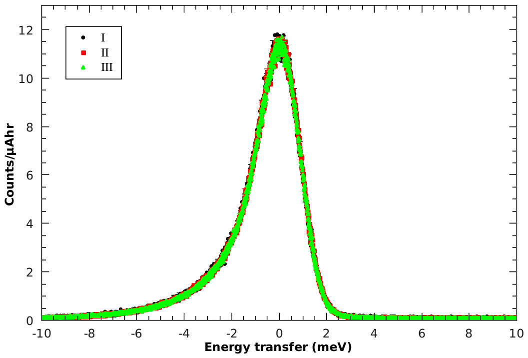

Figure 2. A view of the elastic line summed over all detector pixels for the three different regions

Nevertheless we wish to quantify the phase uncertainty differences shown in Figure 1 To this end, events in each region were collected in to a histogram and the normalized results are shown in Figure 3. The first thing to note is that better than 99.99% of the pulses are within 1 μs of each other which means there should be no difference in the measured signal. Statistics on these histograms are provided in Table 1. If one looks at the Full Width at Half Maximum of ϕ

(ϕ_{FWHM}) column, clearly in all three regions the performance is better than the 1 μs required for this chopper. However the timing criteria would only be met in the fixed frequency regime if we were using the tightest chopper with the 230 ns timing requirement. Nevertheless the 216 ns, for the fixed frequency width, still seems quite large. Another way to characterize the data is the difference between neighboring TDC events ($\phi_{i+1} - \phi_i$) for the same E_i. Such a method should be relatively insensitive to the variations of the line frequency. This data was again collected in histograms and is shown in normalized form in Figure 4. Note there is essentially no difference in the three distributions, and a quantification of the widths of these distributions in Table 1 shows no difference either. Furthermore in this characterization the limit for the tightest chopper is exceeded. This implies that the ultimate limit in phase control arises from a jitter other than the accelerator variation of ~ 200 ns. Tests of the chopper controllers, with an isolated stable frequency source, reveal that it is not internal to them. Finding the source of this jitter is underway. Irregardless the jitter in the TDC center signal does not control the resolution of the instrument for the most used fine resolution cases. To demonstrate this even further, we used the event based data to filter out all events except those that use the center time bin. Again the filtering does not increase the observed pulse width. Nevertheless, this technique can be used to improve the instrumental resolution with the finest resolution chopper until the source of the aforementioned jitter can be found.

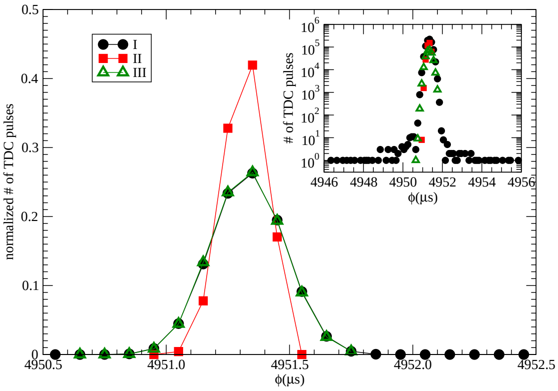

Figure 3. Distribution of chopper TDC signals during the three regions

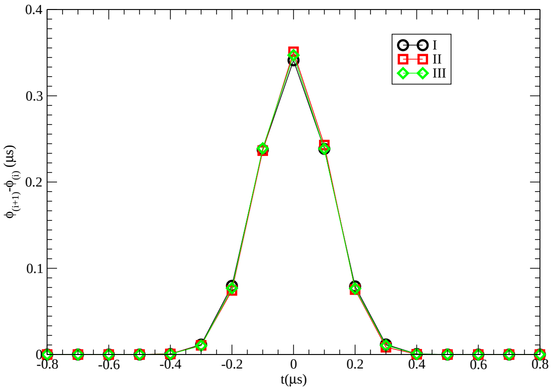

Figure 4. Distribution of the phase change from one pulse to the next.

5. Implications for other chopper types.

There are other types of choppers at the SNS, most of them are negligibly affected by the variation in line phase. However there is concern over two types of choppers: The horizontal axis T_0 chopper and the High Speed Double Disc chopper.

The horizontal axis T_0 chopper is applied widely across wide bandwidth instruments at the SNS. They are all located in places of significant radiation fields so prolonging the time between maintenance is of high priority. Quite often this maintenance is bearing replacement. So a program of tests, to see if bearing life can be extended by operating, at fixed frequency, has begun. To quantify the effects, an off the beamline T_0 chopper is instrumented and it is run with the fixed or varying phase input. In this case it was instrumented with thermometers in several locations to see if more energy is going into specific components as compared to others. Though this is a rough test it was straightforward to instrument so was a good place to start. Only the thermometer on the bearing between the motor and the rotor saw a significant temperature decrease during fixed frequency operation. Specifically a $0.5 \pm 0.15\ K$ temperature difference between varying frequency and fixed frequency operation was observed. As there are many different factors that would control the heat flow away from this bearing, detailed predication are difficult to make. This result suggests that this bearing is a possible place to more carefully investigate with regards to lifetime issues.

The other chopper of concern is the CNCS high speed double disc chopper. Recently the controller for this chopper was upgraded to provide a timing window of $\sim 1.2\ \mu s$, rather than the as delivered $\sim 1.6\ \mu s$, when the accelerator was operating at varying frequency. With the accelerator frequency fixed, the timing window could be narrowed to $\sim 250\ ns$ before the chopper phase was out of that window more than 90% of the time.

6. Conclusions

Advances in DC power supply technology and large mass filaments in the klystrons have allowed the SNS accelerator to run at a fixed frequency of $60\ Hz$, if all the accelerator components are working perfectly. A histogram of the TDC signal on SEQUOIA narrows during fixed frequency runs, but the instrument works fine either at the fixed or narrowed frequencies for all but the finest resolution chopper. Further work is underway to identify a non-accelerator based source of frequency variation. The CNCS chopper can be phased much more tightly with fixed frequency operation. Studies of other effects of fixed versus varying frequency operation are under way.

Acknowledgments

We acknowledge discussions with G. Ehlers on the benefits of fixed frequency operation to CNCS. Interactions with S. Hicks on the details of the SNS timing system were also very useful. The technical staff of the Research Accelerator Division of ORNL is thanked for enabling this study. This research at Oak Ridge National Laboratory's Spallation Neutron Source, was sponsored by the Scientific User Facilities Division, Office of Basic Energy Sciences, U. S. Department of Energy.

References

[1] Abernathy D 2008 *Notiziario Neutroni E Luce di Sincrotrone* **13**

[2] Ehlers G, Podlesnyak A A, Niedzela J L, Iverson E B and Sokol P E 2011 *Review of Scientific Instruments* **82** 085108

[3] Granroth G E, Vandergriff D H and Nagler S E 2006 *PHYSICA B-CONDENSED MATTER* **385-86** 1104

[4] Granroth G E, Kolesnikov A I, Sherline T E, Clancy J P, Ross K A, Ruff J P C, Gaulin B D and Nagler S E 2010 *Journal of Physics: Conference Series* **251** 012058

[5] Winn B and Hagen M In preparation

[6] Potts C, Brumwell F, Rauchas A, Stipp V and Volk G 1983 *Nuclear Science, IEEE Transactions on* **30** 2131

[7] Findlay D 2007 Isis - pulsed neutron and muon source *Particle Accelerator Conference, 2007. PAC. IEEE* 695

[8] 2003 Accelerator technical design report for high- intensity proton accelerator facility project, j- parc Tech. Rep. JAERI-Tech 2003-044, KEK Report 2002-13 JAERI KEK

[9] Schoenberg K 2007 The lansce accelerator: A powerful tool for science and applications *Particle Accelerator Conference, 2007. PAC. IEEE* 120

[10] McQueeney R J and Robinson R A 2003 *Neutron News* **14** 36

[11] Henderson S and*et. al.* submitted *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*

[12] Riedel R, Cooper R, Funk L and Clonts L 2011 *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*

[13] An K, Skorpenske H, Stoica A, Ma D, Wang X and Cakmak E 2011 *Metallurgical and Materials Transactions A* 1

[14] Granroth G and Abernathy D 2006 Science design study for fermi choppers for the arcs and sequoia instruments Report SING17-32-DA0001- R01 SNS