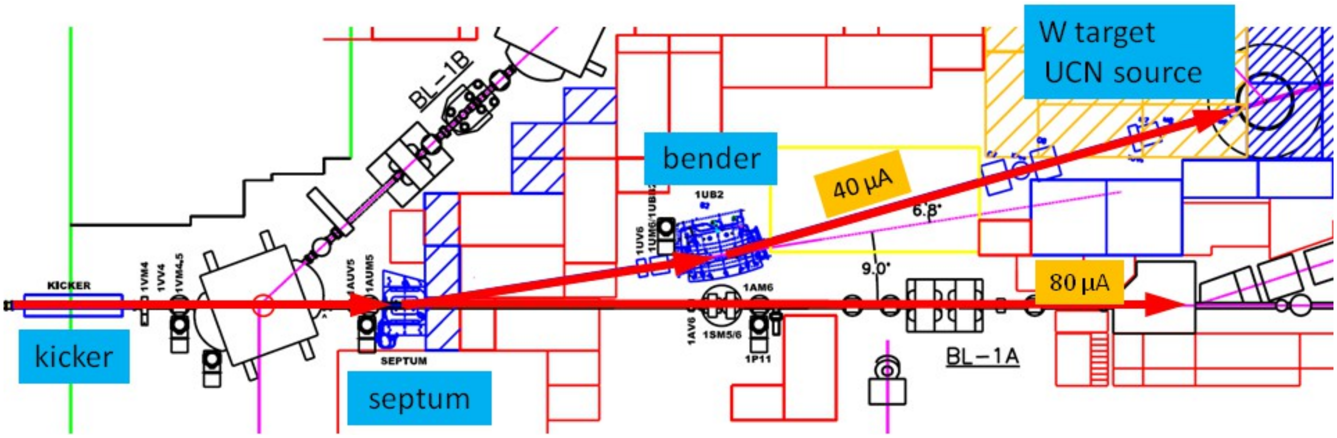
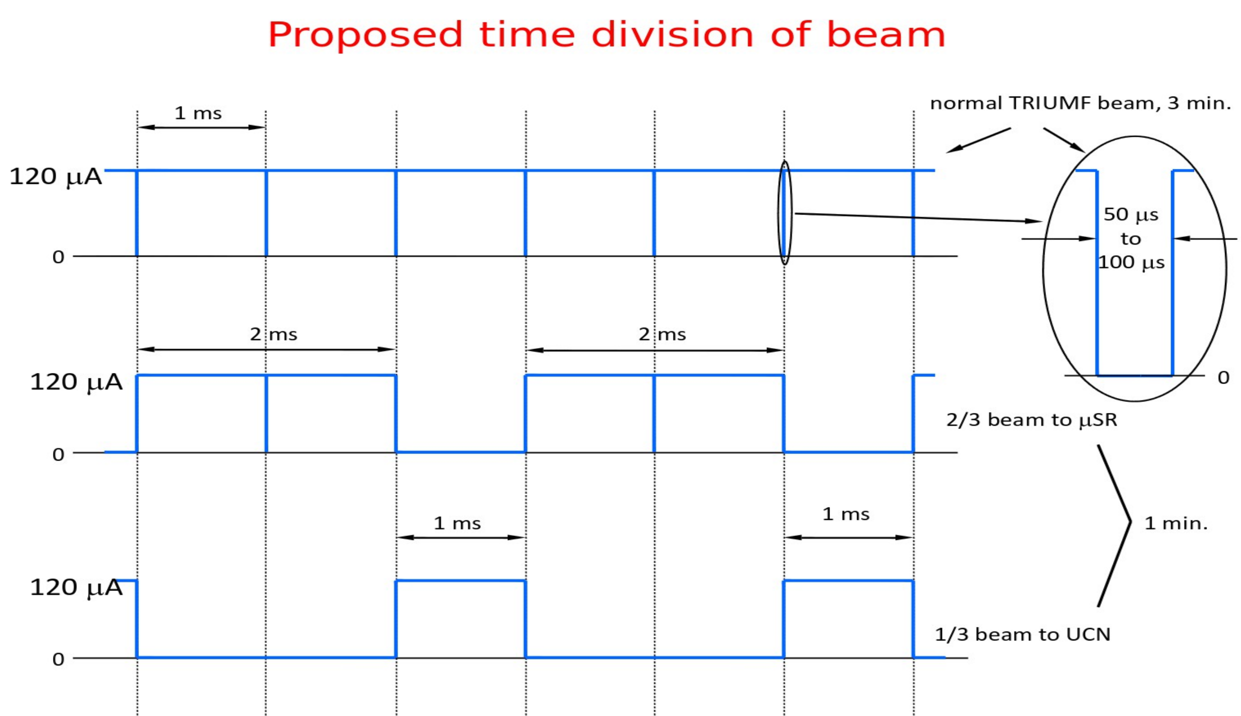
UCN Kicker Diagnostics and Control

Introduction

During operation of the Ultracold Neutron Facility, beam will be shared between the existing meson hall users (beamline 1A) and the new UCN line (beamline 1U). The UCN line is designed to take up to one-third of the total current, for example 40 µA to UCN and 80 µA to the meson hall, as shown here:



The beam from the cyclotron is delivered in 1 ms "buckets" separated by shorter periods were the beam is blanked by the ion source pulser. During UCN operation the blanking interval will be required to be 50 µs or longer (normally in the range 50µs to 100 µs). Beam sharing will be done by deflecting a certain fraction of the beam buckets to UCN. For the 2:1 split shown below, 1 bucket is deflected to UCN, 2 buckets allowed to pass undeflected, and so on.



To deflect a beam bucket to UCN, the kicker magnet ramps up during the 50 μs blanking interval, deflects the bucket to the UCN line, then ramps down again in the 50 μs following the beam bucket.

The Kicker Diagnostics and control must deliver a signal synchronized with the arrival of the beam at the kicker. Since the beam takes approximately 330 μs to travel from the ion source to extraction, and the time can vary by some tens of μs depending on the machine tune, it is necessary to have a suitable beam current monitor near the kicker. This is provided by the 1VM4 capacitive beam monitor located just downstream of the kicker (see "UCN Kicker Time Pickoff" below). The kicker control system must use the 1VM4 signal to confirm that the kicker trigger is locked to the real beam at the kicker magnet.

It is also important to measure the amount of beam present during the blanking notch. During this time, the beam sweeps from the straight-through port of the septum magnet to the magnetic field section that deflects the beam to UCN (see picture in appendix). If any beam is present during the sweep, it will hit the steel of the septum. The slower the beam sweeps, the more will be spilled on the septum. Assuming the slowest of 50 μs for the full sweep, the beam will cross the septum steel and beam pipe wall during the time from 18 μs to 32 μs after firing the kicker. In this interval the beam current should be below 430 nA to limit the spill onto septum to 1 nA averaged over the UCN cycle. If the beam monitor indicates notch contamination exceeding this limit, we can blank the kicker trigger and not kick until the contamination is once again under the limit. For good signal to noise ratio, the 430 nA limit based on long term beam spills could be be measured with several seconds of averaging. Spills large enough to cause a radiation trip of the cyclotron will be detected by the nearby TRIUMF beam spill monitors.

Finally, it should be noted that these fast kicker cycles (ramping up to spill one bucket onto UCN target, ramping down to send two buckets to beamline 1A) is superimposed onto a slower UCN cycle, where we want to put beam onto the UCN target for 1 minute (to produce UCNs) and then have a 3 minute period to do measurements of the UCNs. This 1-minute ON, 3-minute OFF cycle would then be continuously repeated. It is also expected that the different, more complicated UCN cycles will be needed (details in following section).

Context for proposed kicker control system

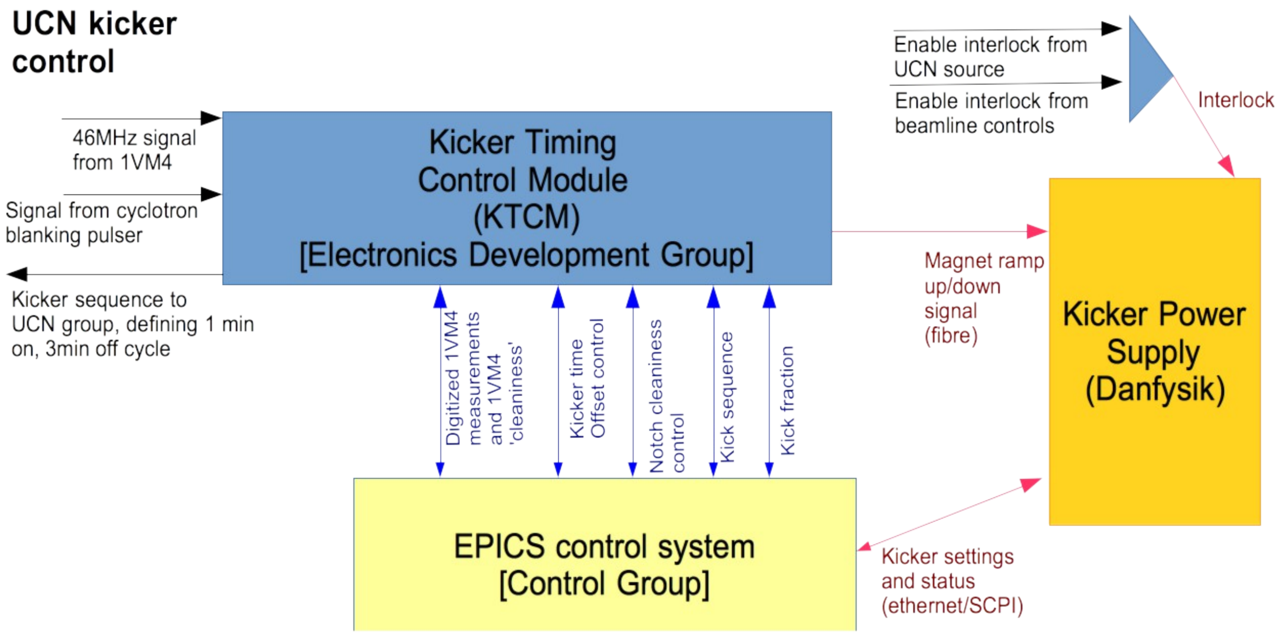
Before discussing the kicker control system, we note that there are several major unresolved questions about the kicker and the UCN beamline that will affect the kicker control design:

1. **Who controls the 1U beamline and the kicker magnet?**
   For this proposal we assume that the main cyclotron operations group will control the 1U beamline and kicker operation, but that the UCN group will often provide input regarding the kicker operation (such as over the kicker mode or changing the 1min-beam-on/3min-beam-off UCN cycles).
2. **Is the kicker timing alignment a 1U machine protection issue? Is so, how do we address it?**
   Yes. As explained above, the kicker timing alignment (ie, getting the kick timed correctly within 50us blanking interval) is a machine protection issue, since we don't want to spilling beam onto the septum magnet and the rest of the beamline. The necessary machine protection to stop this happening will be provided by a beamline monitor on the septum magnet.

3. **Is the total amount of beam going to UCN target a 1U/UCN machine protection issue? If yes how do we address it? Ie suppose there was a problem with the kicker control that caused 40uA to be sent to UCN target, when only 1uA was desired?**
   Yes, this situation would be a machine protection issue for both the UCN target and the UCN source, because of the increased heat load. The best way to ensure that we don't exceed the allowed beam intensity to 1U is to have a beamline interlock based on two of the non-intercepting beam intensity monitors on 1U beamline [should list these monitors]. This would ensure that we separate the element that decides the fraction of the beam to 1U (the kicker control) from the element that provides the safety interlock (the beam intensity monitors). Presumably the kicker control will also have interlocks from the UCN cooling system and temperature sensors, so could also protect the UCN source that way, but the beam intensity monitors should react faster.
   If such a higher-than-expected-beam-power situation persisted then it might be a radiation safety issue, if the UCN shielding was only set for 1uA of current. But presumably that would be a much longer timescale than the UCN machine protection issue. [maybe shouldn't note this...]
4. **Does the kicker control system need to address the 1U machine protection issue raised in points 2 and 3?**
   From our point of view the answer is no. The 1U machine protection should be handled be independent beam line monitors described above. The kicker control system will provide diagnostic feedback related to these machine protection issues, like the measurement of the kicker timing; but the kicker control system will not directly implement any machine protection.
5. **What actions should be taken in the case of problems with the kicker magnet?**
   In our opinion, we imagine the following actions in case of kicker problems
   - *If the septum beamline monitor indicated bad kick alignment or the 1U intensity monitors indicated too much beam current, then we could trigger the kicker interlock so that the kicker stopped kicking any beam. This would have the advantage of protecting the 1U beamline while maintaining beam to 1A and ISAC.*
   - *On the other hand, there will be other kicker problems that should result in a cyclotron trip. For instance, if the kicker somehow gets stuck in a state where all the beam is being sent to 1U, then that should probably trip the cyclotron.*
6. **What does the general operations control of UCN beamline look like?**
   We will want to be operating the UCN beamline in a variety of different modes. For instance
   - *For initial commissioning we would want to have the kicker permanently on and running at low beam current for first tests of UCN target and UCN source. In this mode there would be no beam to beamline 1A.*
   - *During UCN source development we would want to run in a mode where we occasionally asked for 1uA of kicked beam for 1 minute, then looked at the results for a while, then request another 1 minute ON. In this mode the beam to 1A would be normally 120uA, with occasional minutes of 119uA.*
   - *Eventually we would move to the long term mode of getting a repeating cycle 10-40uA of beam for 1 minute ON and 3 minute OFF. But we would still need flexibility in the details of this cycle. In this mode the beam to 1A would be normally 120uA, with periodic minutes of 80-110uA.*

   We would request that the UCN beamline control be designed in a way to facilitate these different modes. These different modes may also have implications for 1A users.

Overview of kicker control system
Given the context described above, one possible organization of the kicker control system is shown below



The two main components of the control system would be

I) Kicker Timing Control Module (KTCM): this custom designed electronics module would handle the following:

- digitizing the signal from the 1VM4 capacitive beam monitor
- creating a kick signal
- making a decision about whether the kick signal is well aligned with the notch and notch background is sufficiently low.
- Creating the short and long timescale sequence of kicks
- Actually ramping the magnet.

We assume that the hardware and firmware for this module would be provided by the electronics development group.

II) EPICS control system: this system would provide the EPICs control of the KTCM as well as various control settings for the kicker magnet itself.
We assume that this component would be handled by the controls group.

We will describe these modules more below, after describing 1VM4 signal.

UCN Kicker Time Pickoff
The TRIUMF beam has a microstructure of bursts a few nanoseconds wide separated by 43 nanoseconds (RF frequency 23 MHz). The time monitor is a capacitive pickoff, 1VM4, located just downstream of the kicker. The pickoff is sensitive to the 23 MHz microstructure. The raw signal is fed

to a broadband preamp followed by a tuned second stage operating at the second harmonic, 46 MHz. The output of the tuned stage is a 46 MHz sine wave whose envelope follows the beam current. The bandwidth of the second stage can be adjusted to trade settling time against noise (low noise = long settling time). It is now set to settle (several 1/e time constants) in 1 μs. At this time constant, the electronic noise is 0.15 μA. The monitor and front-end electronics are already in place.

The electronics handles beam currents of 0 μA – 120 μA. The input is triax cable from the capacitive pickoff and the output is normal Coax. Leonid Kurchaninov has the details. We have to use the signal from the time pickoff to deliver a kicker signal synchronized with the arrival of the beam at the kicker, and to prevent kicking if the contamination in the beam-off-notch is too high.

Kicker Timing Control Module (KTCM)
The first task of this module is to digitize the signal from the tuned 1VM4 signal. We would start by demodulating the 46MHz signal down to a signal with 1us variations. We would then digitize the signal with a sampling of 0.2-1.0 MHz. The digitized signal should clearly show the 50us notchs in which we want to kick the magnet.

The next step for the module would be to define the time at which the magnet kick should start. This time could either be determined by the analysis of the digitized 1VM4 signals or by adding a fixed offset to the time from the cyclotron notch generation signal. In either case the operator would need the ability to change the time offset of the kick signal. Once set, it might be best if the time of kick signal was continually shifted (using some sort of phase locked loop) to adjust to changes in cyclotron operation.

The module would then analyze the digitized 1VM4 signal in order to determine how much beam background was present in the magnet ramping period. In order to get good signal to noise the module might need to average a number of notchs before measuring the beam background. The operator will need to specify a limit for the beam background. For diagnostic purposes we would also want to have a way of reading out and examining the digitized 1VM4 signals.

Finally, this module would define the actual short term and longer term sequence for kicker magnet; ie define the short term kick of a fraction of the beam buckets and the 1min beam-on/ 3 min beam-off cycle for normal operation. As mentioned earlier, there would need to be a large number of different modes and configurability in defining the longer term sequence.

Possible architecture for KTCM: this module could be a custom electronics card, with an ADC for digitizing the 1VM4 signal and an FPGA for processing the digital waveforms, determining a kick time and the notch cleaniness and producting the kick sequence.

Challenges for KTCM: it may be hard to accurately measure the blanking notches if the cyclotron is running at low beam power.

EPICS control system:
The EPICS control system would provide control of the kicker control system to the cyclotron operations group. Important parts of this control would include:

I. Configuring the KTCM: setting the notch cleaniness threshold, kick timing offset, kick fraction and kick sequence. The EPICS control should provide some basic validation of the kick sequence, to ensure that the operator was not requesting a higher 1U beam current than allowed.

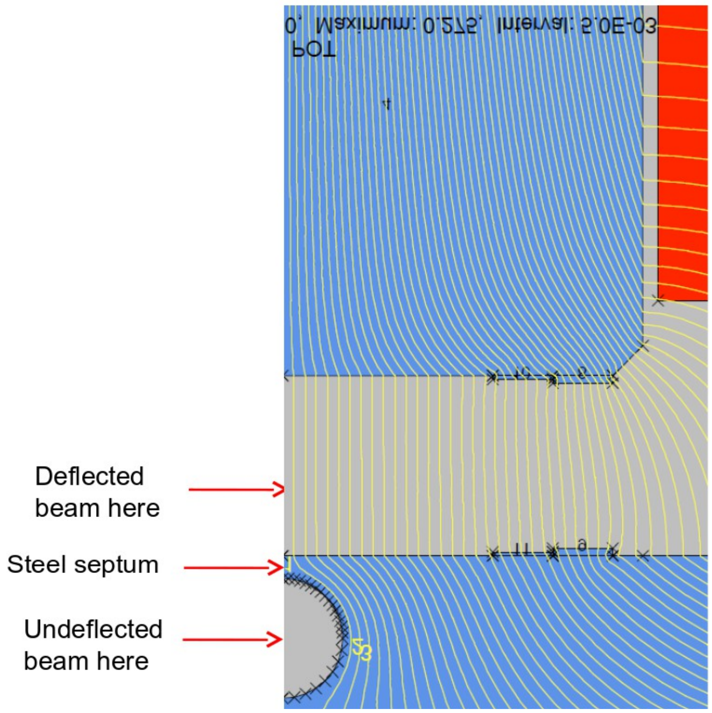
II. Reading out the digitzed 1VM4 signal and various KTCM status bits.
III. Configuring the settings and monitoring the status of the Danfysik kicker power supply.
IV. Reading/controlling PLCs that monitor the various kicker interlocks. These interlocks would include
   1. The Enable interlock from UCN Source will have to also include an "UCN Area enable" (area armed, gates locked, certain magnets ON, and Beam-blocker OUT).
   2. The Enable interlock from beamline controls will have to include a BL1A enable (i.e. a "BL1A ON/BL1B OFF" condition, because the dipole magnet 1BVB2 sits between the kicker and septum magnets, and is ON when BL1B is running). The prescaler or BL1U:BL1A current ratio is also folded into this signal, we presume.

Appendix

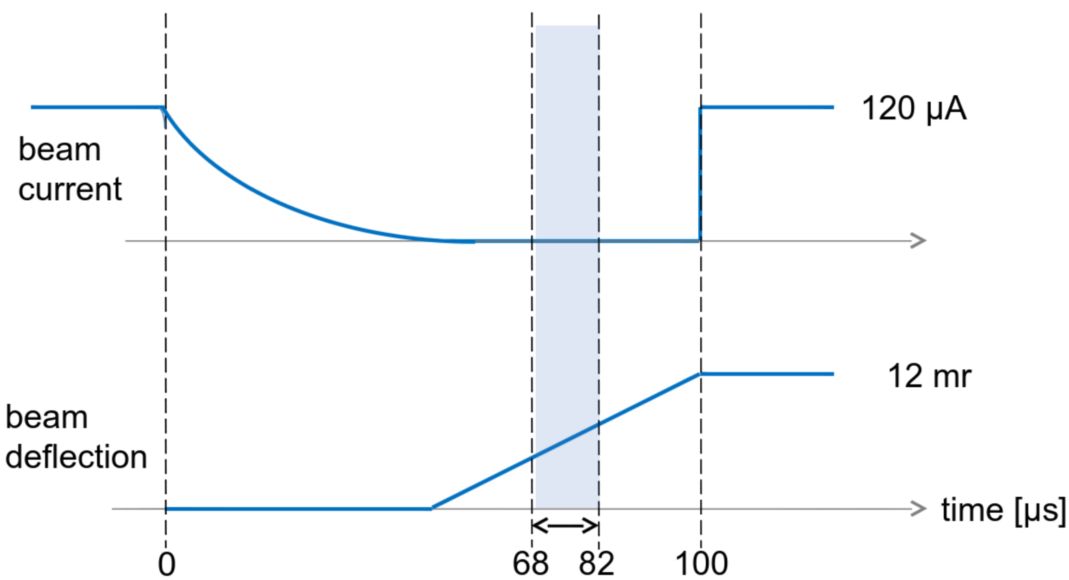
TRIUMF UCN Septum Magnet

Beam current must be less than 430 nA when it sweeps over the beam pipe wall and septum

Keeps time averaged beam spill to <1 nA



Beam current and deflection at 90% duty cycle



If the beam does not cut off cleanly at the start of the pulser notch, the kicker sweep could be delayed. 90% duty cycle would give us the option of up to 50 μs delay.