# COMPACT RECONFIGURABLE BEAM CURRENT SAFETY SYSTEM FOR UCN

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*Abstract*

At PSI, a new and intense Ultra-Cold Neutron (UCN) source based on spallation was commissioned in December 2010 and will start production in 2011. The 590 MeV, 1.3 MW proton beam will be switched towards the new spallation target for about 8 s every 800 s.

A beam current monitoring system has been developed as part of a machine safety system for the UCN source operation. This monitoring system is based on a compact reconfigurable I/O (cRIO) field-programmable gate array (FPGA) system from National Instruments Corporation. This paper presents the general characteristics of such a system and its actual implementation.

## INTRODUCTION

A new beam safety system specifically for UCN operation [1] has been tested last year and is now in operation. A description of the whole machine safety system can be found in [2].

Additionally, there was a need to monitor the beam current on the UCN beam line so that beam intensity and pulse length were in accordance with the intended beam operation. A hardware monitoring system was already in operation but was not flexible enough to cover the different modes of beam operation.

After the ring cyclotron, the proton beam can be either split or kicked towards the UCN target (see Fig.1). In addition, a small beam dump before the UCN can be used to check the beam quality before directing it to the UCN target itself. Maximum allowed beam intensity and pulse length are dependent on the particular beam operation, the main limitations being the maximum allowed heat load on the beam dump and the maximum average radiation level for the UCN beam line. In particular, it is imperative that the pulse duration for beam dump operation is limited to 10 ms at full beam intensity. Otherwise, the heat load may damage the dump. For these reasons, a flexible system was developed to meet the various beam operation monitoring requirements.

## DESIGN OF THE BEAM CURRENT SAFETY SYSTEM

### *Required Performance*

The system has to generate an interlock signal for the following conditions:

- beam current larger than 0.02 mA for the split mode;
- integrated beam current larger than 0.022 mA.sec for the kick mode towards the beam dump (i.e. 2.2mA pulse of 10ms duration);
- integrated beam current larger than 17.6 mA.sec (i.e. 2.2mA pulse of 8 sec duration, duty cycle: 1%) for the kick mode towards the UCN target;

The reaction time for the monitoring system should be less than 1 ms.

In addition, the system should have enough reserve for future requirements. If necessary, new signals may have to be recorded or generated.

### *Adopted Solution*

cRIO systems from National Instruments were chosen as generic solution. They are reconfigurable control and acquisition systems designed for embedded applications with high performance and reliability. The hardware architecture of cRIO systems has a reconfigurable FPGA / controller chassis with a 4 or 8 slot backplane. The FPGA interfaces the hot-swappable I/O modules with built-in signal conditioning for direct connection to sensors and actuators. Various ADC and digital input/output (DIO) modules can be used. These systems easily satisfy the response time requirement and have plenty of reserve for possible future requirement.

Such technology presents also an advantage that it can be implemented efficiently as an independent local controller without network connection.

### *System Architecture*

Applications may be developed at 3 different levels: on the FPGA, within the VxWorks based real-time system or on a standard host PC. The FPGA program typically performs I/O tasks, hardware-based timing and triggering, low-level signal processing and control. The real-time controller program performs tasks such as processing data, control and data logging. On the host PC are usually tasks performed such as data logging and database access, user-machine interface and supervisory control.

### *Programming Language*

LabVIEW is the programming language for these cRIO systems. It can be used to program the application at the PC host level, at the real-time or at the FPGA level. LabVIEW is well suited for FPGA programming because it clearly represents parallelism and data flow. It is possible to implement measurements and control hardware without low-level hardware description language or board-level design. LabVIEW and VxWorks support EPICS and can then be easily integrated in the machine control system of an accelerator.

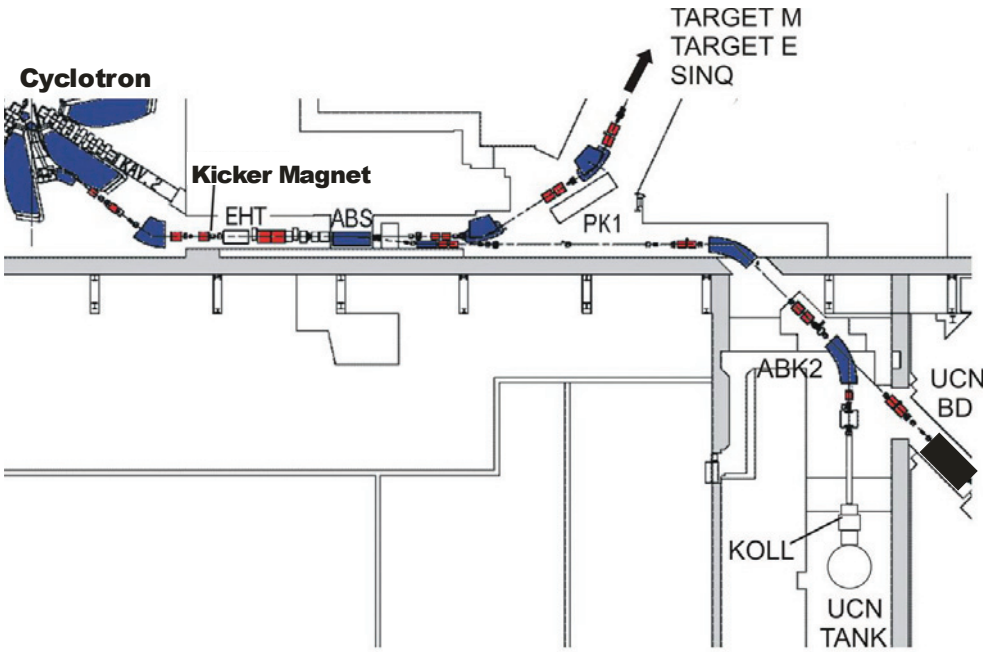


Figure 1: Overview of the UCN beam line. The 590 MeV, 1.3 MW proton beam delivered by the ring cyclotron on the left is diverted to the UCN beam line by means of a kicker magnet. The beam is then either directed to a beam dump (UCN BD) or to the UCN target using the ABK2 magnet.

## IMPLEMENTATION

### *Hardware*

For our application, we are currently using either a cRIO-9073 (266 MHz) or a cRIO-9074 (400 MHz), both with 2 M gates, a 10/100BASE-T Ethernet port and a RS232 serial port.

Modules used for the input and output signals are a NI-9215 4 channel 16-bit 100 kHz ADC module and a NI-9403 digital input output (DIO) module. In addition, a custom module was built to handle the specific digital interlock signals (a 10mA complementary logic: OK, not OK and ground signal).

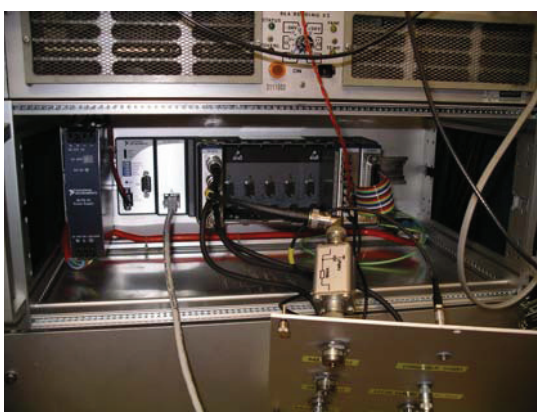

Figure 2: Photo of the opened system. The 8-slot CRIO system is visible as well as the ADC and DIO modules.

### *Input Signals*

Input digital signals used for this system are: i) the operation mode (Splitter or UCN Kick mode), ii) the UCN target selection (beam dump or UCN target), determined by ABK2 magnet current; iii) the Kicker signal indicative of the actual kicking of the beam. With these signals it is possible to deduce the actual operation mode at any time. It also allows the detection of impossible situations such as a kick while in splitting mode.

Figure 3 shows a typical time sequence for UCN operation. The operation mode is first changed from Splitter to UCN Kick mode. The selected target may the beam dump or the UCN target. Usually two 5 to 10 ms short beam pulses are kicked to check the beam optics. There are followed by a full beam intensity (up to 8 sec) pulse on the UCN target.

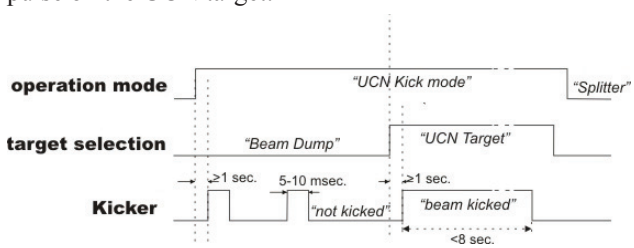


Figure 3:Typical time sequence for UCN kicks.

The beam current signal is provided by the standard beam current monitor electronics (MESTRA). A low pass 1kHz RC filter is used to avoid false alarms during the Splitter operation mode, the input signal being only 80 mV for a 20uA beam current and noisy.

### *Firmware*

The processing of the beam current signal, type of operation (split or kicked), the type of target (beam dump or UCN) and the limit checks have been fully implemented in the FPGA (Fig.4). After the necessary initialization, a continuous loop running at 40 MHz performs all the processing tasks. First the actual operation mode is deduced from the input signals. Then, the current beam is integrated by a simple summation though a current corresponding to the actual beam current limit for split operation mode $I_{\lim Splitter}$ is also subtracted: $S(t_i) = S(t_{i-1}) + I_{beam}(t_{i-1}) - I_{\lim Splitter}$. That way, the signal integration does not need to be synchronized with the beam kicking and it mirrors the heat load dissipation effects. Depending on the operation mode and on the comparison results with the different operation mode limits the interlock output signal may be activated. The interlock output signal is directly connected to the accelerator interlock system.

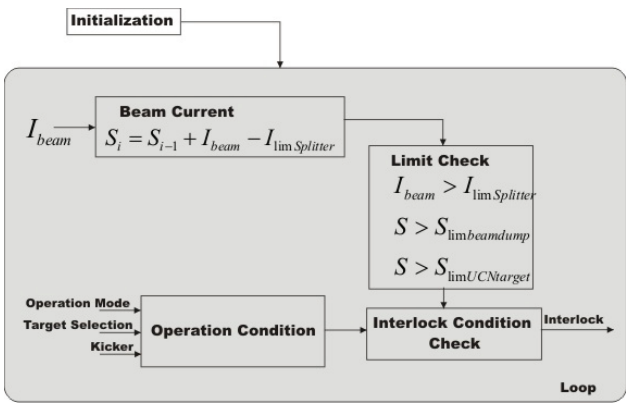


Figure 4: FPGA program structure.

The LV FPGA program is compiled within LabVIEW and the so created bitstream file containing the gate array configuration information is stored on the local non volatile flash memory. It loads instantaneously when the cRIO system is powered up. The implementation of the whole monitoring application on the FPGA makes the system highly reliable.

At the level of the real-time system, shared variables are defined that allow communication and exchange of data with a host PC or with the control system of the machine via EPICS.

### *Deployment*

A first version of the system was successfully tested last year. During the 2011 shutdown period, the final system has been installed, ready for UCN operation.

## SUMMARY

A new current monitoring system was developed to cover the safety needs of beam operation with the new UCN. An FPGA module and real-time system based on LabVIEW and cRIO systems from National Instruments has been built and used for this purpose. It satisfies the machine safety requirements for reliability and is flexible enough to allow further extensions and will be integrated in EPICS.

## REFERENCES

[1] B. Lauss, Commissioning of the new High-Intensity Ultracold Neutron Source at the Paul Scherrer Institut, Proceedings of the International Nuclear Physics Conference - INPC-2010, July 4 - 9, 2010, Vancouver, Canada.

[2] B. Blarer et al. ”The Beam Safety System of the PSI UCN source” DIPAC 2011.