Real-Time Control, Acquisition and Data Treatment for Beam Current Transformers in a Transfer Line

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Abstract

Particle beams are transferred from the 1 GeV Booster to the 26 GeV Proton Synchrotron and to an experimental area, ISOLDE. The characteristics of the beams and their destination change on a 1.2 s cycle basis. There are six beam current transformers to measure the beam intensities, i.e. the number of particles passing through the transfer lines. On each pulse of the Booster, a real-time system, called BTTR (Beam Transfer Transformers), acquires the transformer values, selects the range, executes a calibration, and treats the data. Part of the treatment is the subtraction of the base-value, which includes systematic perturbations, acquired in the absence of beam. The system also handles asynchronous tasks, such as acquisition of base-value, readout of calibration factors and other diagnostic actions. The concept of the BTTR and its design are presented, as well as some practical results.

I. INTRODUCTION

The locations of the six beam current transformers are given in Figure 1. The particle beam is ejected from the Proton Synchrotron Booster (PSB) towards either the Proton Synchrotron (PS) or towards the Isotope Separator On Line Device (ISOLDE).

Each of the 4 PSB rings holds 5 bunches of particles equally distributed over the machine circumference. At the ejection energy of 1 GeV the time between bunches is 120 ns. After sequential ejection of rings 3, 4, 2 and 1, the combined beam lasts 2280 ns and contains 20 bunches at 120 ns intervals (Figure 2). By introducing a delay \( \Delta T \) of 0.6 \( \mu \)s to 100 \( \mu \)s between the pulses to the 4 ejection kickers, one obtains a "staggered" beam: the 5 bunches from ring 3 are followed later by the 5 bunches from ring 4, then after \( \Delta T \) by ring 2 and 1. Its total length stays within the excitation time of the beam line elements (about 1 ms). The time structure of a staggered beam provides considerable advantage over a non-staggered beam for experiments at the ISOLDE facility [1, 2] when liquid targets (molten metal) are used.

The data acquisition system (see Appendix) for the six beam transformers in the transfer lines had to be redesigned to meet the requirements for both staggered and non-staggered beams [3]. The beam characteristics and destination change every 1.2 s to one of 24 configurations or Program-Line-Sequencer slots ("PLS-Users") in Pulse-to-Pulse Modulation (PPM) [4, 5]. When a beam has passed, a series of calibration pulses generates data which are used for calibration of the signal chain for the three sensitivity ranges. The sensitivity range which provides highest signal-to-noise ratio without saturation has to be chosen and base-values have to be subtracted to correct for systematic errors, mainly noise stemming from the ejection kickers.

To maintain and diagnose the system, which normally has to run without interruptions, asynchronous message handling permits the setting or readout of calibration factors and base-values. Further diagnostic functions permit e.g. the read-out of the ADC-RAM for a given PLS-User or the measurement of thread-execution times.

The first stage of the system became operational in June 1997 with static calibration of the signal chain. In the 2nd stage the signal chain from the transformers to the ADC output will be automatically calibrated after every pulse, for this additional calibration pulses C1, C2 and C3 have to be generated in the beam transformers to derive the calibration factors after each beam passes.

Figure 1: Transformer locations in the transfer lines between PSB, PS and ISOLDE: BT, BTP, BTM, Y112, Y213 and Y325.

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2 at the moment ring 1 cannot be delayed for technical reasons
II. SYSTEM LAYOUT

The signal from the transformers, e.g. from BT (Figure 2), is fed into three separate amplifiers with sensitivities 1, 2 and 3, and can be seen by the appropriate integrator when its gate is open (Figure 3). By synchronizing the gates of the gated integrators (equipped with S/H) with the ejection of the corresponding rings, the signals from the transformers after the beam recombination can be correlated to the different rings. Therefore, to observe staggered beams as well as non-staggered beams, it is sufficient to synchronize the gates of the integrators with the ejection kickers.

All S/H values are converted when the beam has passed. The conversion is triggered by an external pulse train (PT) consisting of 32 triggers for 32 ADC-channels, and consecutively stacked in the RAM of the ADC.

III. TIMING REQUIREMENTS

To calibrate the signal chain from the beam transformers up to and including the conversion inside the ADC, a series of 3 calibration pulses C1, C2 and C3, adjusted to stay just below saturation of the sensitivities 1, 2 and 3 of the amplifiers, are sent to the beam transformers in intervals of 20 ms after the beam has passed. A time window of about 300 μs is allowed between the first bunch of the beam (or the rising edge of C1, C2, C3) and the Pulse Train, which is long enough for non-staggered and staggered beams. The calibration pulses last about 2.5 μs, so that after the integrators have stabilized there is almost 20 ms time to trigger the conversion for all 32 channels of the ADC with a Pulse Train (PT). Table 1 also shows the memory contents (+ADC) and their consecutive addresses (&ADC). The last PT triggers the conversion in absence of any signal to record an offset.

About 81 ms after the kickers have fired, the last conversion is finished and all 160 values representing the beam, calibration and offset data for this PLS-User are available in the ADC-RAM. At about 205 ms the measurement thread (MEAS) of a multitasking program is activated by an interrupt which is derived from the PLS.

The MEAS thread reads out the ADC-RAM, resets and rearms the ADC to be ready for new PT-triggers and at its end activates the calculation thread CALC (Figure 4).

Table 1.

<table>
<thead>
<tr>
<th>time [ms]</th>
<th>V_BT</th>
<th>PT</th>
<th>+RAM</th>
<th>&amp;RAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>beam</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.3</td>
<td>-</td>
<td>32</td>
<td>beam</td>
<td>0.31</td>
</tr>
<tr>
<td>20</td>
<td>C1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>20.3</td>
<td>-</td>
<td>32</td>
<td>C1</td>
<td>32..63</td>
</tr>
<tr>
<td>40</td>
<td>C2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>40.3</td>
<td>-</td>
<td>32</td>
<td>C2</td>
<td>64..95</td>
</tr>
<tr>
<td>60</td>
<td>C3</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>60.3</td>
<td>-</td>
<td>32</td>
<td>C3</td>
<td>96..127</td>
</tr>
<tr>
<td>80</td>
<td>C0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>80.3</td>
<td>-</td>
<td>32</td>
<td>C0</td>
<td>128..159</td>
</tr>
</tbody>
</table>

Signaling between the threads and generating the additional busy-signals takes almost 2 ms. Execution times for both threads without any further diagnosis enabled are each about 4
ms, so that when CALC is finished, the results can be published to the network about 215 ms after the kickers have fired. The remaining 985 ms before the next beam arrives in PPM are available for networking and database interfaces.

Figure 4: execution times of thread MEAS (trace 1) and CALC (trace 2).

IV. DATA TREATMENT

The calibration factors \( c_{f_i}(ch) \) for each ADC-channel ch are derived from the ADC-RAM contents for calibration pulses C1(ch), C2(ch), C3(ch) and C0(ch) for each transformer (see Table 1 and Figure 3). First the factors for the present beam i are calculated in units of [charge/converted bits]:

\[
c_{f_i}(ch) = \frac{C^T(ch)}{C_{1,2,3}(ch) - C0(ch)}
\]

with:

\( C^T(ch) \) the charge of a calibration pulse C1, C2 or C3 sent to a transformer T and corresponding to the channel ch of the ADC

\( C_{1,2,3}(ch) \) C1(ch), C2(ch) or C3(ch), according to the amplifier's sensitivity for this channel ch.

Then these calibration factors are averaged over a history of pulses to improve the precision:

\[
\overline{c_{f_i}}(ch) = w \_i \cdot c_{f_i}(ch) + (1 - w \_i) \cdot \overline{c_{f_{i-1}}}(ch)
\]

with:

\( w \_i \) a weight factor in the interval \( [0, 1] \)

\( \overline{c_{f_i}}(ch) \) averaged \( c_{f_i}(ch) \) for pulse i

\( \overline{c_{f_{i-1}}}(ch) \) averaged calibration factor for channel ch and the pulse previous to i.

The \( \overline{c_{f_i}}(ch) \) are kept in memory and are updated each pulse. The beam-readings are then calibrated:

\[
I_{cal}^T = (I^T - C0(ch)) \overline{c_{f_i}}(ch)
\]

with:

\( I_{cal}^T \) calibrated beam current for transformer T

\( I^T \) value after conversion in the ADC-RAM for transformer T

The base-values to correct systematic errors which cannot be eliminated by the offset are recorded without beam for pulse i and only for transformers BT and BTP. The most important error is noise on the cables, introduced by the ejection kickers, for the high-sensitivity transformers BT and BTP. The base-values are averaged similar to (2):

\[
n_i^{BT}(pls) = w \_i \cdot n_i^{BT}(pls) + (1 - w \_i) \cdot n_{i-1}^{BT}(pls)
\]

with:

\( w \_i \) base-value weight factor in the interval \( [0, 1] \)

\( n_i^{BT}(pls) \) recorded base-value for BT, PLS-User pls and pulse i

\( n_i^{BT}(pls) \) averaged base-value for BT, PLS-User pls and pulse i

\( n_{i-1}^{BT}(pls) \) averaged base-value for BT, PLS-User pls and pulse previous to i

The \( n_i^{BT}(pls) \) for transformer BT and \( n_i^{BTP}(pls) \) for transformer BTP are kept as well in memory for every PLS-User pls, and they can be updated when operation conditions change.

V. DIAGNOSIS

By using an asynchronous message mechanism, additional diagnosis and maintenance functions can be executed independently of the PLS whenever required. These diagnosis can be exploited using an X-interface as shown in Figure 5. The functions are:

Freeze calibration: the \( \overline{c_{f_i}}(ch) \) from (1) and (2) are not updated after every pulse any more, the last valid values are used instead.

Reset calibration: the \( \overline{c_{f_i}}(ch) \) are reset to their default values.

Dump calibration: the whole table of \( \overline{c_{f_i}}(ch) \) is read out for diagnostic purposes.

Set one calibration factor: set a calibration factor for a given channel to a specific value. This allows external manipulation of the \( \overline{c_{f_i}}(ch) \) for diagnostic and maintenance purposes.

Dump ADC-RAM: the entire ADC-RAM contents (immediately after the conversion) are read out.

Dump base-values: the \( n_i^{BT}(pls) \) and \( n_i^{BTP}(pls) \) from (4) are read out for all 24 PLS-Users.
Reset base-values: the \( n_{BT}^{inp} \) (pls) and \( n_{BTP}^{inp} \) (pls) are set to their default values for one selected PLS-User.

Record base-values: the \( n_{BT}^{inp} \) (pls) and \( n_{BTP}^{inp} \) (pls) are recorded for one selected PLS-User in absence of any beam, but with all pulsed elements of the machine normally working.

VI. RESULTS

The critical timing requirements to synchronize the gates with the bunches of the beam are met by the hardware, therefore the conditions for thread execution time are loosened up for the benefit of flexibility, diagnostic possibilities and reliability. Beam intensities in up to 24 different configurations, including staggered beams, can be measured in PPM.

The systematic errors generated by noise from the ejection kickers can be registered and corrected, thus improving system sensitivity and precision to measure low intensity ion-beams.

![Figure 5: X-interface of an application program showing beam transformer currents (left), PLS-User selection (upper right), PLS trigger control (lower left), diagnosis control (center left) and an online help facility (right).](image)

The automatic calibration of the signal chain requires additional calibration pulses in the transformers. The first stage of the system operates successfully since June 1997.

VII. REFERENCES


VIII. APPENDIX

VME System Specification:

CPU m68030, RAM 8MByte, ADC Pentland MPV908, I/O Micronix ICV196. PLS CERN TG8 decoder, Gated Integrators CERN, Pulse Train Generator CERN, OS LynxOS 2.2.0.