Upgrade of the LHC Bunch by Bunch Intensity Measurement Acquisition System

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ABSTRACT
The fast beam intensity measurement systems for the LHC currently use an analogue signal processing chain to provide the charge information for individual bunches. This limits the possibility to use higher level correction algorithms to remove systematic measurement errors coming from the beam current transformer and the associated analogue electronics chain. In addition, the current measurement system requires individual settings for different types of beams, implying the need for continuous tuning during LHC operation. Using modern technology, the analogue measurement chain can be replaced by an entirely digital acquisition system, even in a case of the short, pulsed signals produced by the LHC beams. This paper discusses the implementation of the new digital acquisition system and the calculations required to reconstruct the individual LHC bunch intensities, along with the presentation of results from actual beam measurements.

MEASUREMENT METHOD EXPLAINED

1. Head Amplifier
2. ADC/FMC module
3. What sampling frequency and ENOB is needed to keep integration error under 1%?
4. VME carrier board: one FMC high pin count slot
   • 6 SFP slots, 2 of them dedicated to CERN timing and Ethernet
   • DAC/counter, equipped with Arria V GX
   • Custom: Arria V GT having 10Gbps transceivers

In combination with FMC-3000 from Innovative Integration a sampling system was constructed:
• FMC-3000 allows up to 1.25 GSPS sampling, however:
• VFC-HD with Arria V GX can only go up to 650 MSPS
• Successful tests carried with Arria V GT version and custom deserialiser to run at 1 GSPS

VFC-HD IS AN OPEN HARDWARE: www.ohwr.org/projects/vfc-hd

5. FMC-3000 is a two-channel 14-bit DC-coupled with ENOB of 9.5 bits, however, 10.5 bits is required for single shot measurements. For circulating beams averaging is used to reduce these requirements.

Track the clock frequency changes in the LHC during the acceleration cycle

Comparison of baseline correction methods

Bunch by bunch correction

Using a peak-finding algorithm, a measurement of one LHC lead-ion fill showed, that a total phase shift of 1.5 ns has to be accommodated.

This corresponds to a displacement of the bunch boundary by 1 ADC sample.

LHC proton beam in the SPS, a total phase shift of up to 12.5 ns was observed.

Noise performance of different intensity measurement methods

The noise performance is comparable to the old analogue system.

DCCT measurements shown using 16-bit and 24-bit acquisition systems, 24-bit system outperforms other measurements when significant beam circulates (1 x 10^11 charges), but does not provide bunch by bunch measurements.

Comparison of three beam intensity measurement methods for the LHC

• DC current transformers (DCCT), analogue system (VFC) and the digital system (FMC)
• Agree at start of acceleration where there is no unbunched beam in the machine.
• Higher ratio at injection: slow rise-time of the DCCT measurement.
• Beam de-bunching causes increasing deviation from the DCCT measurement.

Comparison of baseline correction methods

Bunch by bunch correction

Abort gap correction

Zero suppression uses a suitable threshold to filter the bunch integrals. Applied on raw or averaged integrals.

The calculated bunch and turn integrals are averaged over 224 LHC turns (~20 ms) to improve the rejection of the 50 Hz component in the signal spectra.

in the de-serialised data a bunch boundary is identified, internal 40 MHz clock is generated, its phase is adjusted on fly using digital delay.

Innovative Integration a sampling system

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