

A 40MHZ BUNCH BY BUNCH INTENSITY MEASUREMENT FOR THE CERN SPS AND LHC.

H. Jakob, L. Jensen, R. Jones[#], J.J. Savioz, CERN, Geneva, Switzerland

Abstract

A new acquisition system has been developed to allow the measurement of the individual intensity of each bunch in a 40MHz bunch train. Such a system will be used for the measurement of LHC type beams after extraction from the CERN-PS right through to the dump lines of the CERN-LHC. The method is based on integrating the analogue signal supplied by a Fast Beam Current Transformer at a frequency of 40MHz. This has been made possible with the use of a fast integration ASIC developed by the University of Clermont-Ferrand, France, for the LHC-b pre-shower detector. The output of the integrator is digitised using a 12-bit ADC and fed into a Digital Acquisition Board (DAB) that was originally developed by TRIUMF, Canada, for use in the LHC orbit system. A full system set-up was commissioned during 2002 in the CERN-SPS, and following its success will now be extended in 2003 to cover the PS to SPS transfer lines and the new TT40 LHC extraction channel.

INTRODUCTION

In order to be able to evaluate the quality of the LHC beam before its extraction from the CERN-SPS it was necessary to develop a beam intensity measurement capable of distinguishing between the individual LHC bunches spaced by 25ns. This system was also foreseen for beam optimisation, allowing the operators to see the intensity structure of the beam throughout the SPS cycle, providing information on where in the batch losses are occurring and at what time. Since the same system was to be installed in the PS to SPS transfer lines it was important that the same electronics was capable of measuring standard, 200MHz structure SPS fixed target beams. To this end a new beam current transformer (BCT) system has been developed and installed in the SPS and its transfer lines. This is comprised of a commercial fast BCT, a specially adapted housing, a calibration unit, an integrator card containing a fast 40MHz integrator ASIC and a digital acquisition readout. There are currently 4 such systems installed in the SPS, one at each end of the PS to SPS transfer lines, one in the SPS ring itself, and one in the TT40 extraction channel towards the LHC and CNGS. A further 4 systems will be installed over the coming years: 3 completing the layout for the LHC transfer lines and one in front of the CNGS target station.

THE SPS FAST BCT SYSTEM

The Fast Beam Current Transformer

The new fast beam current measurement in the SPS makes use of commercially available Bergoz low-droop,

passive, fast beam current transformer (FBCT) as the detection device. The 40 winding core used has a frequency response up to ~400MHz and a droop of less than 0.1% per microsecond. This low droop is important if difficult baseline correction is to be avoided during the passage of the beam. The FBCT is installed in a specially designed housing aimed at maintaining a clean signal response (see Fig. 1). An 80nm titanium coating is applied to the vacuum side of the ceramic gap, giving a series resistance of ~20Ω and effectively damping any cavity resonances.

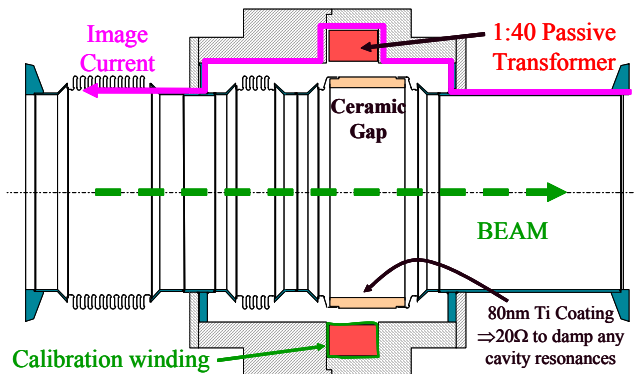


Figure 1. Schematic of the SPS Fast BCT

A calibration winding has been added to the transformer core to allow the injection of a 5μs, 128mA calibration pulse generated on demand by a switchable current source. This provides the absolute calibration for the system and corresponds to 2×10^{10} charges in 25ns.

Fig.2 shows the typical response of the FBCT to LHC type beam. Each of the 4 batches visible contain 72 bunches separated by 25ns.

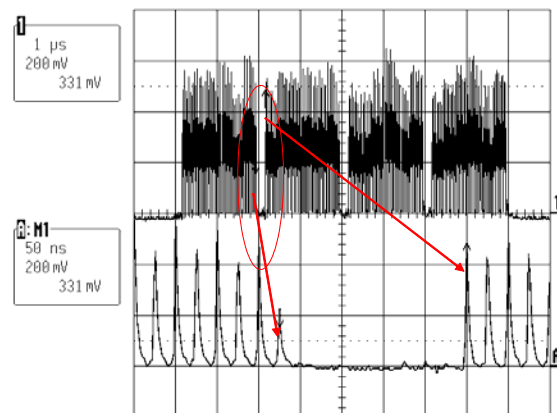


Figure 2. SPS Fast BCT response to LHC type beam.

[#]Rhodri.Jones@cern.ch

The 40MHz Integration Card

The output of the FBCT is fed into a 40MHz integration card which performs both the integration and the AD conversion. The card is based around a 40MHz integration ASIC developed by the Laboratoire de Physique Corpusculaire, Université Blaise Pascal, Clermont-Ferrand for use in the LHC-b preshower detector [1]. The ASIC has 8 individual channels capable of integrating at up to 40MHz. Each channel consists of 2 separate integrators followed by track & hold circuitry working at 20MHz. While one integrator integrates, the other discharges, with the track and hold outputs multiplexed to give an effective integration frequency of 40MHz (see Fig 3).

A 50Ω input of $\pm 3nV$ s, equivalent to $\pm 120mV$ for 25ns, gives $\pm 1V$ at the output. In practice only one channel is used for the FBCT application, with the output digitised by a 40MHz, 12-bit ADC. In order to be able to take into account the DC offset introduced into the system by a circulating beam the ADC is configured to be bipolar. This means that a single measurement effectively uses only 11 bits. The FBCT input signal is attenuated to give a full scale ADC output corresponding to 2×10^{11} charges in 25ns, allowing it to handle the ultimate LHC bunch intensity of 1.7×10^{11} charges.

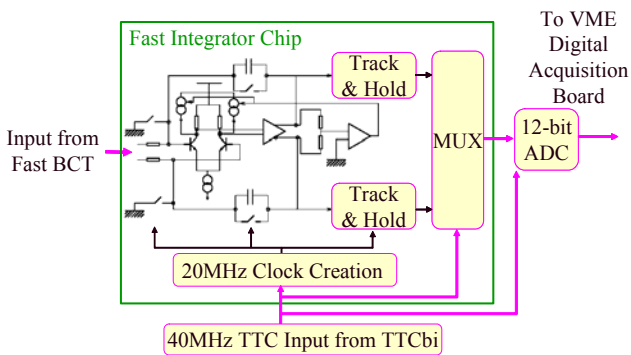


Figure 3. Schematic of the FBCT 40MHz integrator mezzanine card

Fig. 4 shows the measured response of the 2 individual integrators within a selected channel to a DC input voltage. As can be seen the individual integrators are highly linear but have slightly different gains. The reason for this difference is twofold: the simple gain difference between integrators and a difference in the effective integration time of the two integrators. The latter is clearly visible if the DC results are compared to the response to a pulsed signal ($\ll 25ns$) of the same effective charge per 25ns period. The simple gain difference of the two integrators can be calculated directly from the difference in the pulsed response (in this case negligible), while the effective integration time can be inferred from the difference between the DC and pulsed values. Each integrator typically integrates for between 20ns and 23ns of each 25ns clock period.

The integration and ADC clocks are derived from the SPS 40MHz bunch synchronous timing, distributed using the Timing, Trigger and Control (TTC) system developed for the LHC [2]. A reset of the integrators is performed on each turn clock to ensure that the same integrator is always used for a given 25ns acquisition window.

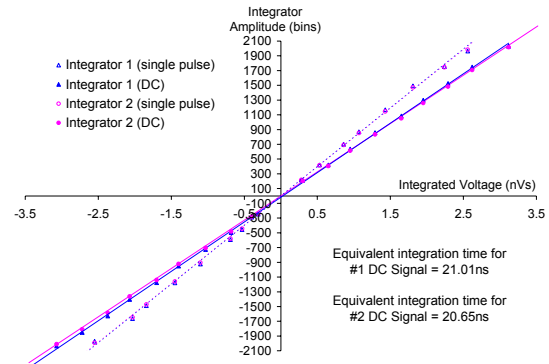


Figure 3. Comparison of the DC and pulsed response of both integrators for a single channel

Data Treatment and Display

The 40MHz integration card has been developed as a mezzanine card to the Digital Acquisition Board (DAB), a VME board developed by TRIUMF, Canada for the LHC orbit and trajectory acquisition system [3]. A single DAB is capable of handling two 12-bit 40MHz input streams, and is quickly becoming the standard data treatment board for all 40MHz LHC related beam instrumentation applications.

For the FBCT application, the DAB is used in its so-called "capture" mode, a single shot acquisition of a user specified number of bunches and turns. For the transfer line FBCTs an acquisition is performed at every injection, while for the SPS ring FBCT, data is acquired at 100ms intervals throughout the SPS cycle. On completion of an acquisition the DAB generates an interrupt for the local controller, a PowerPC running Lynx-OS. This PowerPC is responsible for reading the acquired data and applying the calibration procedure.

The calibration procedure differs depending on whether the FBCT measures DC or pulsed beams. Here DC is taken to mean any beam for which the 25ns integration effectively filters the bunch to bunch response, e.g. for standard SPS 200MHz fixed target beams. In both pulsed and DC cases the turn preceding the injection, or for the circulating beam the beam dump gap, is used to calculate the average offset for each integrator. This can then be subtracted from the data of interest.

In DC mode integrator number 2 is simply gain corrected with respect to integrator number 1 using the values measured in the laboratory. The final value for each integrator is then converted to charges per 25ns by comparing the result with that obtained for a calibration pulse equivalent to 2×10^{10} charges in 25ns.

In pulsed mode, i.e. for bunches spaced by 25ns or more, the value obtained for each integrator is first adjusted using the known individual integration times to obtain the equivalent DC value. The calibration then proceeds as described for the DC case.

A graphical user interface allows the operator to select the bunches of interest and to compare the evolution of these bunches throughout the SPS cycle.

SPS RESULTS IN 2002 & 2003

Use of the FBCT for Beam Optimisation

The first tests of the new fast BCT system were performed in 2002 using the monitor located in the SPS ring. All acquisitions were taken using LHC type beam, with up to 4 batches of 72 bunches separated by 25ns. Fig. 4 shows an example of the type of information available from such a system. In this case there was a poor RF capture of the first batch after injection. The uncaptured beam can clearly be seen to drift away from the batch, slowly dispersing itself around the SPS ring.

Other studies which will benefit from this system are the investigation of instabilities such as the electron cloud phenomenon in the SPS, where losses tend to occur towards the tail of each batch. The system is also intended to be used as part of the beam quality interlock for all beams destined for the LHC.

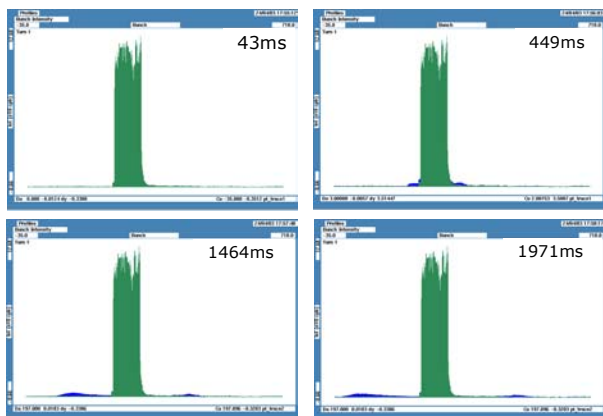


Figure 4. Evolution of one LHC batch in the SPS for 2276ms after injection with poor RF capture.

Use of the FBCT with 200MHz Beams

In order to investigate the suitability of the new FBCT system for the measurement of standard SPS 200MHz fixed target beams, and to qualify the calibration procedure, the data from the SPS ring monitor was compared to the DCCT data throughout the SPS cycle. In this case only the total batch intensity was required from the FBCT, since no bunch to bunch information was available, each integration being the sum of some 5 bunches. The result from such a comparison is shown in Fig. 5. The DCCT data is an average taken over 1ms, while that for the FBCT is based on a single-shot, single turn measurement. The band around the DCCT measurement has been added to indicate a $\pm 2\%$ window.

The agreement in the absolute calibration value obtained from the two different systems is very good, especially considering that no averaging was performed on the FBCT data. This therefore validates both the use for the system with 200MHz beams and the calibration procedure.

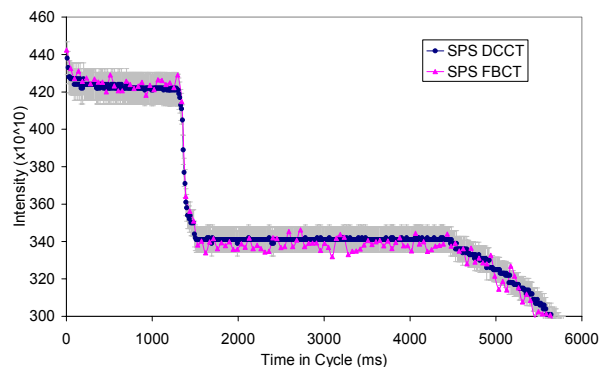


Figure 5. Comparison of the DCCT and FBCT intensity values for a 200MHz fixed target beam throughout its cycle in the SPS.

CONCLUSIONS AND OUTLOOK

The new fast BCT systems for the SPS and its transfer lines have been commissioned successfully. The initial results show that the absolute calibration is accurate to better than 2% for 200MHz fixed target beams. It remains to be seen what accuracy can be achieved for the bunch to bunch measurements, which unlike the 200MHz beam, will suffer from any transient signals generated by previous bunches.

One of the main uses of this system in the future will be as part of the beam quality interlock for the LHC. For LHC luminosity runs it has been specified that the bunch to bunch intensity variations of the injected batches should be less than 10%. It will be the fast BCT's job to measure this bunch distribution just before extraction and lift the extraction veto only if this is the case.

In the future all the SPS, LHC and CNGS transfer line fast BCTs will use the same fast BCT acquisition system measuring both 40MHz LHC beams and 200MHz fixed target beams. The LHC fast BCTs themselves will also probably be based on the same acquisition system, although the transformers will differ due to the much reduced vacuum chamber dimensions.

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