THE SPS INDIVIDUAL BUNCH MEASUREMENT SYSTEM

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Abstract

The Individual Bunch Measurement System (IBMS) allows the intensity of each bunch in an LHC batch to be the measured both in the PS to SPS transfer lines and in the SPS ring itself. The method is based on measuring the peak and valley of the analogue signal supplied by a Fast Beam Current Transformer at a frequency of 40MHz. A 12 bit acquisition system is required to obtain a 1% resolution for the intensity range of 5×10^9 to 1.7×10^{11} protons per bunch, corresponding to the pilot and ultimate LHC bunch intensities. The acquisition selection and external trigger adjustment system is driven by the 200MHz RF, which is distributed using a single-mode fibre-optic link. A local oscilloscope, controlled via a GPIB interface, allows the remote adjustment of the timing signals. The low-level software consists of a real-time task and a communication server run on a VME Power PC, which is accessed using a graphical user interface. This paper describes the system as a whole and presents some recent uses and results from the SPS run in 2000.

1. INTRODUCTION

Since 1999 the PS pre-injector complex has been able to produce proton beams for LHC [1]. The LHC batch, consisting of 72 bunches spaced by 25ns is generated in the PS at 26 GeV/c and transferred to the SPS. Following three or four of such injections, the SPS is ramped in energy to 450 GeV/c, after which injection to the LHC will take place (see Fig. 1).

The Individual Bunch Measurement System (IBMS) was designed for a continuous monitoring of the intensity of each bunch of each LHC batch. The total range of intensities involved is summarised in Table 1.

Beam Type	Intensity per bunch ($\times10^{11}$ppb)	Max Nb of Bunches	Total Current (mA)
Pilot	0.03	1	0.05
Set-up	0.03	72	3.6
Commissioning	0.17	288	34
Nominal	1.05	288	209
Ultimate	1.7	288	340

Table 1: Bunch intensity for LHC type beams.

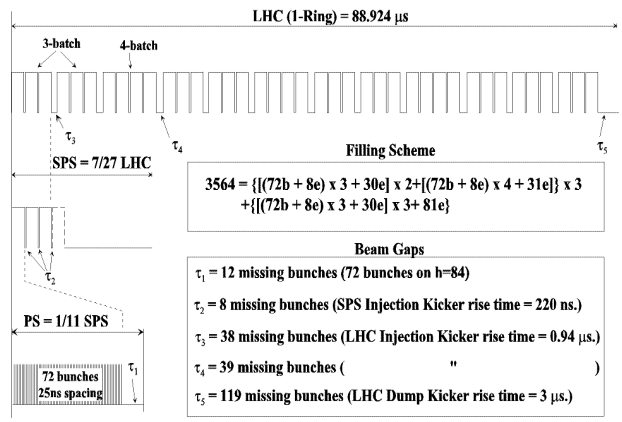

Figure 1: Bunch disposition in the LHC, SPS and PS.

The system is able to measure all bunches for all injected batches in the PS to SPS transfer lines, and a selected number of turns in the SPS ring, or up to 16 selected bunches for all turns in the SPS.

2. INSTALLATION

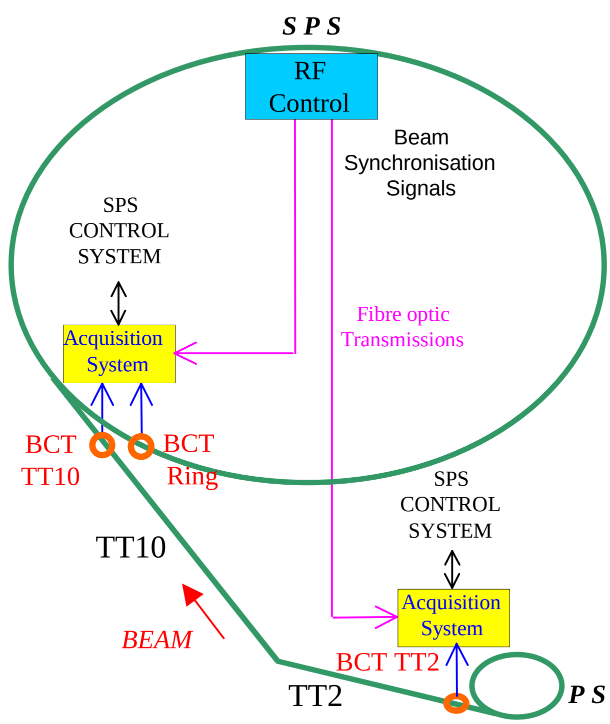

Figure 2: Layout of the installation.

The layout of the current installation is shown in Fig. 2. Three existing Fast Beam Current Transformers (FBCTs) were used: one at the beginning of the TT2 transfer line, one at the end of the TT10 transfer line, and one after a complete revolution in the SPS. The acquisition systems were installed in the nearest surface building to minimise the cable lengths required.

3. ANALOGUE FBCT SIGNALS

The first measurements for the IBMS project where performed on a prototype transformer integrated into an existing CERN-SPS DCCT housing. An LHC batch with 72 bunches spaced by 25ns shows an important droop of 5%/µs which needs to be much lower for precise measurements (Fig. 3(a)). The ringing between the bunches of the same batch is essentially due to the resonance of the big cavity formed by the wall-current bypass and the outer side of the vacuum chamber (Fig. 3(b)). The signal therefore needed to be filtered before sampling.

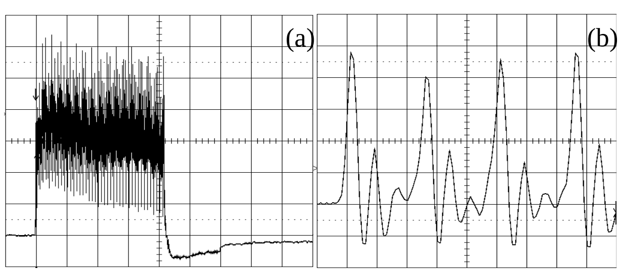

Figure 3: a) 72 bunches showing 5%/us droop.
b) zoom showing ringing between bunches.

A new housing, Fig. 4(a), has now been designed, with a much smaller cavity between the vacuum chamber and the wall-current bypass. By integrating a low droop transformer into such a housing, a good bunch to bunch signal can be obtained even without filtering (Fig. 4(b)). Such a system will be installed in the CERN-SPS for tests in 2001.

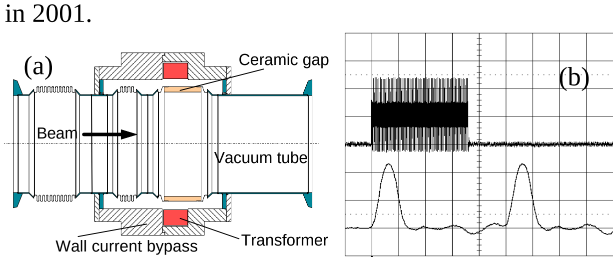

Figure 4: a) new FBCT housing.
b) resulting signals with new housing.

4. THE ACQUISITION SYSTEM

A 60 MHz low-pass filter is used treat the noisy signal (see Fig. 3(b)) coming from the FBCT to maintain the zero level between two consecutive bunches. A 50Ω splitter and a 12.5ns delay then provide the two phase shifted signals, for the synchronisation of the simultaneous sampling. Two 12-bit ADCs using an external 40MHz clock convert the data to digital format, and write into a 4096 location FIFO. A PowerPC running under Lynx/OS is then used to transfer the FIFO contents each time it is half-full. The read-out from the FIFO has to be faster than or equal to the rate of the incoming data. This limit is in fact reached when collecting 16 bunches on a turn-by-turn basis. If more bunches are to be collected, the time between acquisitions has to be increased. For example, in order to collect the data from all 72 bunches, the acquisition can only be performed every 7 turns. The exact delay between the revolution frequency and the sampling time is controlled via an adjustable phase shift of the 200MHz RF acceleration frequency providing the external clock.

5. GRAPHICAL USER INTERFACE

Two user applications (GUI's) have been built in order to visualise remotely acquired data in different fashions. A third GUI is necessary to set up the delays required for the synchronisation of the top and valley acquisitions (see Fig. 5).

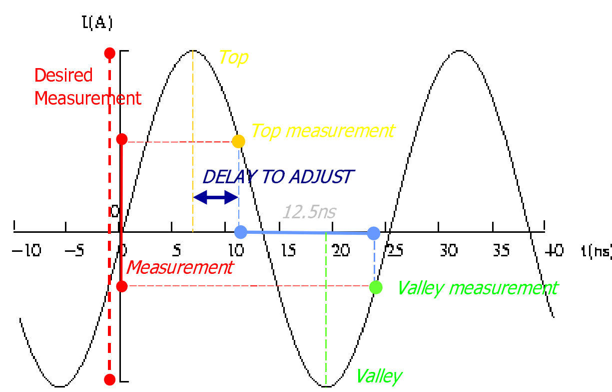

Figure 5: Delay adjustment requirements.

The first of the user applications, allows the visualisation of data from a single system for a configuration where bunches, number of turns and acquisition time can be selected. The same data can be viewed in different ways: measurement of all bunches and turns acquired as shown; measurement of up to eight selected bunches (out of the acquired bunches) for all turns; raw data (top, valley and measurement) for all bunches on a given turn (see Fig. 6).

The second application provides information from all three systems installed at the same time. Measurements are gathered for the same injection in the transfer lines and at any of the first four turns in the SPS ring. This user application therefore automatically configures the acquisition parameters to obtain a one batch measurement from all the systems. Cross-calibration of the systems has not yet been performed, hence only the shape of the acquisition curve could be used to find out if there were losses at injection.

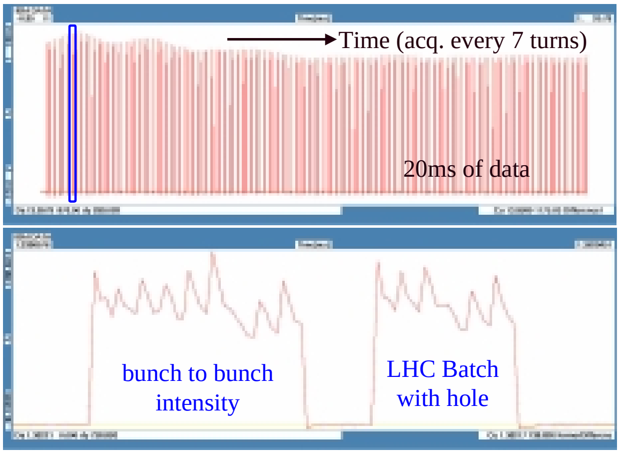

Figure 6: Example of a typical acquisition, in this case with a missing PS booster injection.

6. RESULTS

The capability of the system permits the measurement of single bunch intensities for a few thousand consecutive turns in the case where only a few bunches from the batch have been selected, or the whole cycle for the complete batch if the acquisition frequency remains low enough. This bunch-by-bunch capability has been extensively used during SPS operation in 2000, to study the injection of LHC type beams, and their stability while circulating. Fig. 7 shows an acquisition where the total batch intensity is seen to decrease during the cycle. Looking in more detail at specific bunches within the batch shows that the loss is concentrated at the tail of the batch. This type of instability was linked to the electron cloud effect [2], where secondary electrons are accelerated by successive bunches, hit the vacuum chamber and produce even more secondaries, leading to a cloud build-up along the batch.

There are, however, also some problems with the current system using the peak and valley approach. It is very sensitive to any bunch length variations, as can be seen at the start of the graphs in Figs. 6&7, where the intensity is seen to oscillate due to bunch length variations linked to longitudinal mismatch at injection. It is also sensitive to any phase differences between the beam and RF frequency. This arises during acceleration, where the time taken for the RF signals to reach the acquisition crate remains fixed, but the beam time-of-flight changes. Such errors can be corrected by modifying the delay parameter according to the momentum increase during the acquisition if the ramp function is known. Such a solution will be adopted for the IBMS system in 2001.

Figure 7: IBMS acquisition for a complete SPS cycle, showing beam loss at the tail of the batch.

7. CONCLUSIONS

The IBMS has proved very useful for a first evaluation of the LHC beam in the transfer lines and the SPS. However, the current system is not optimised, and several changes will be made during the coming years. Notably, the FBCTs currently used will be replace by three identical, low-droop FBCTs, all housed in a purpose built assembly. The top and valley acquisition system which is very sensitive to the timing adjustment and bunch length will be replace by a new system based on a fast integration and digitalisation of the signal from each bunch. In addition a Digital Acquisition Board (DAB), designed for the LHC beam position monitor system [3], will replace the current digital storage system based on a FIFO.

8. REFERENCES

[1] The Large Hadron Collider Project http://lhc.web.cern.ch/lhc/

[2] G. Arduini et al. “Electron Cloud : Observations with LHC-Type Beams in the SPS”, Pres. at: 7th European Particle Accelerator Conference, Vienna, Austria, CERN-LHC-Project-Report-434, 2000.

[3] D. Cocq et al., “First beam tests for the prototype LHC orbit and trajectory system in the CERN-SPS”, in these proceedings, DIPAC 2001, Grenoble, 2001.