THE MEASUREMENT OF BUNCH INTENSITY USING THE LHC BPM SYSTEM

J.L. Gonzalez*, E. Calvo, D. Cocq, R. Jones, CERN, Geneva, Switzerland

Abstract

A convenient way of having beam bunch intensity information available all around the LHC ring is to use the beam position monitor (BPM) system. The principle is to add the BPM signals, process them and make the result compatible with the time-modulation method used for transmitting the position over a fibre-optic link. In this way the same acquisition system can make both position and intensity data available. This paper describes the technique developed and presents the first intensity measurements performed on the CERN-SPS and LHC.

INTRODUCTION

The LHC beam position system is comprised of more than 1070 beam position monitors, the majority of which are electrostatic button electrode pick-ups. Each BPM provides both position and intensity information. The acquisition electronics is split into two parts, an analogue front-end, which sits in the tunnel, and an integrator/digitiser/processor VME module located on the surface [1]. Transmission from tunnel to surface is carried out using a time-encoded signal over a single mode fibre-optic link. A digital multiplexer, located in the position to time normaliser board [2], allows for either position or intensity selection, eliminating the need for a separate optical transmission system and digital acquisition boards for the intensity measurement. A WorldFIP fieldbus is used to control the tunnel stations.

THE LHC BPM SYSTEM

The LHC BPM system is foreseen to work with bunch intensities ranging from 1.5×10^{9} to 2×10^{11} protons, using two sensitivity settings (low or high). Figure 1 shows the basic layout of the system. Each normaliser module gets the high frequency beam signals of the horizontal or the vertical electrodes and filters them using a pair of matched, 70 MHz, low-pass filters in order to significantly reduce any bunch length dependence due to the shortening of the bunch during acceleration. The filter is followed by a passive combiner, which makes the analogue sum of these signals available for further processing in the beam intensity board. Intensity information can actually be transmitted either directly using the optical output of the intensity module or via the normalisers, since the signal produced is compatible with the time-modulation method used for encoding the beam position.

Intensity Measurement Principle

Figure 2 depicts the intensity measurement principle. An analogue input multiplexer selects for which of the two counter-rotating beams the intensity will be measured. The input signal is the combination of the horizontal and vertical sum signals from the two associated normalisers. Detecting the zero crossing of the BPM signal triggers both the laser "*Start*" pulse and the constant current discharge source after a predefined delay.

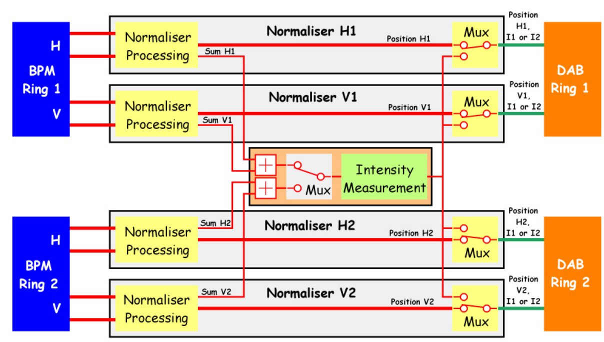

Figure 1: LHC position and intensity measurement system layout.

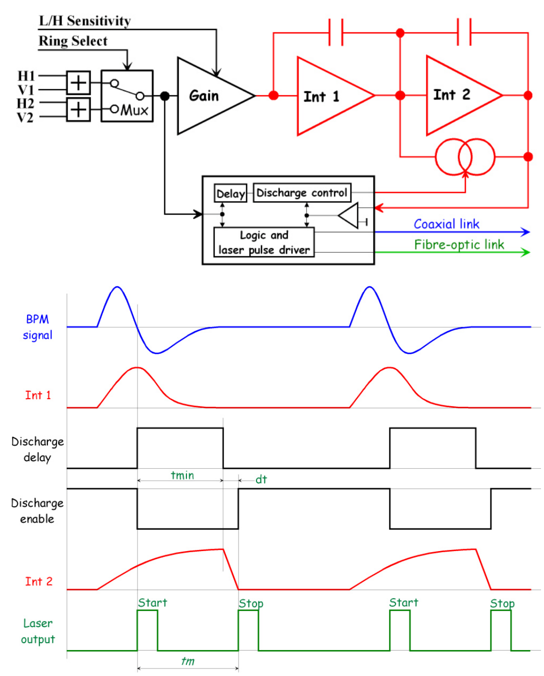

Figure 2: Intensity measurement principle and related waveforms.

The sensitivity control input adapts the gain to the beam dynamic range. The resulting signal is then integrated twice and a fast comparator produces the laser "*Stop*" pulse when the output voltage of the second integrator reaches zero, due to the constant current discharge. The *Start* and *Stop* pulses have a duration of 1ns and the

* jose.luis.gonzalez@cern.ch

intensity information is encoded in the time t_m between the two pulses, which can vary from 8.5ns to 11.5ns.

Laboratory Measurements and Simulations

700 Intensity modules have been installed throughout the LHC ring. Each of them has been tested and calibrated on a dedicated test bench, using a PC-driven "intensity beam simulator" to emulate the sum-outputs of a pair of normalisers. The measured linearity is better than ±4%. In order to verify that the accuracy is within the 10% specified for the system, further measurements in both frequency and time-domain were carried out on the whole analogue front-end, including the LHC button pick-up, the flange, actual cabling and the normaliser.

A unit Gaussian pulse excitation signal (909ps full width at half maximum) was used for time-domain network analyzer measurements. Such pulse response analysis had already previously been used to correct PSpice® simulation models to fit acquired data [3].

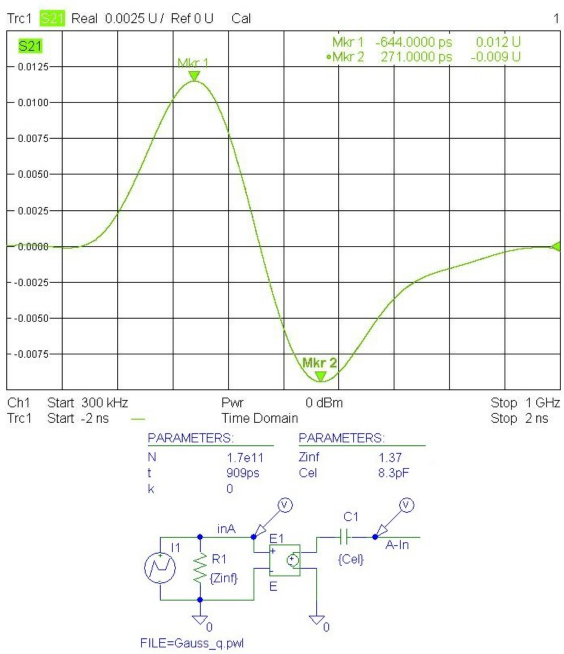

Figure 3: Measured pulse response of the LHC button pick-up and the electronic PSpice® simulation model.

The differentiated pick-up response and the simulation model are presented in Figure 3. A set of parameters are used to identify both the button electrical characteristics and the input-pulse charge content and duration.

Since the pick-up introduces around 40dB attenuation, any subsequent measurements were noisy. The normaliser and the associated wiring were therefore measured separately from the pick-up. Figure 4 shows the sum response to the same unit Gaussian pulse and the hardware equivalent PSpice model that fits the acquisitions.

The normaliser sum signal is produced by a passive combiner that adds the signals of two identical branches composed of input couplers, constant-resistance low-pass filters and matching attenuators. External wiring is simulated using another filter and the resulting losses are included in the input attenuator. Model parameters have been adjusted to obtain the same pulse response as the reference measurement.

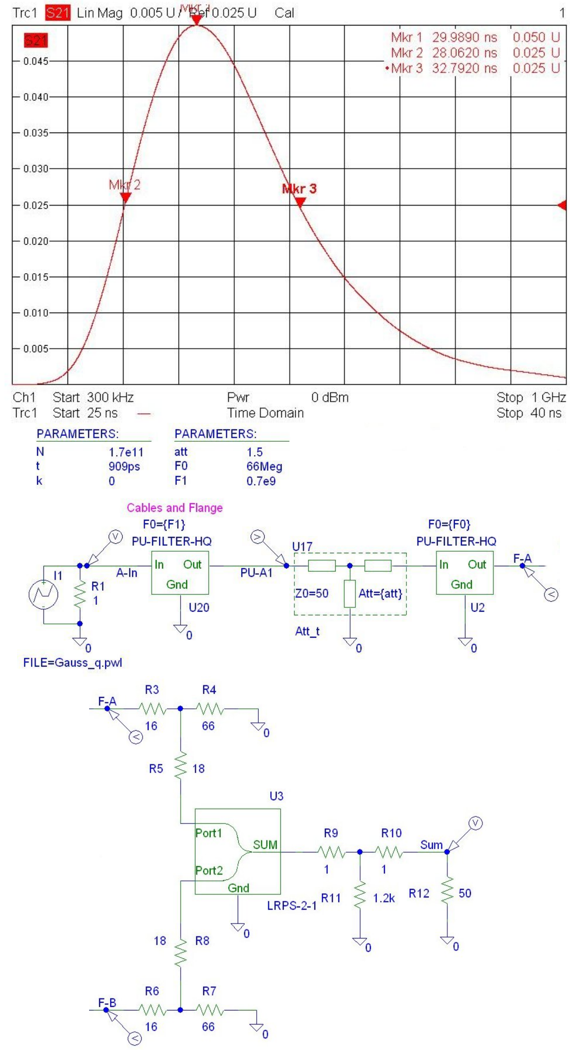

Figure 4: Network analyzer time-domain measurement of the normaliser sum-output and partial schematic of the equivalent simulation model.

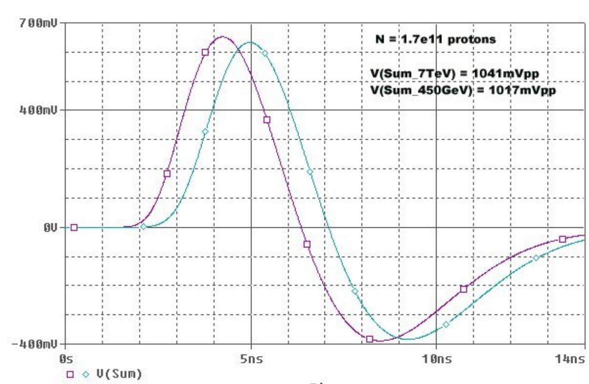

Figure 5: Simulated normaliser sum signal responses to the LHC bunch at 450 GeV and 7 TeV.

The results of full system simulation, from button to normaliser sum-output are presented in Figure 5. Notice that the sum signal variation, due to bunch length effects in going from beam injection to collision, is only $24mV_{pp}$ (about 2%), while the bunch length σ changes from 375ps to 252ps. The sum signal can therefore be considered as linearly proportional to the bunch intensity and its transfer function versus the number N of bunch protons is:

$$Sum_{\mathrm{mV}_{\mathrm{pp}}} = 6.06\times10^{-9}\, N$$

This is used to scale the internal calibrator of the normaliser and that of the test bench beam simulator to give bunch intensities.

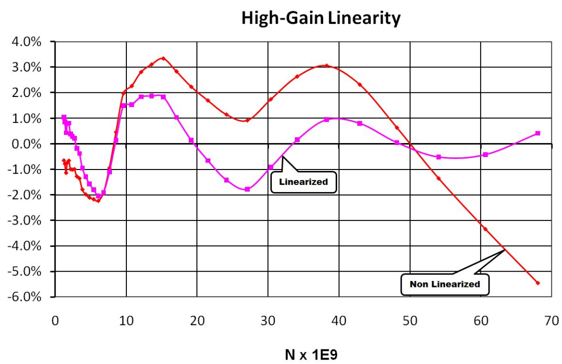

Figure 6: Linearization graph from the test bench.

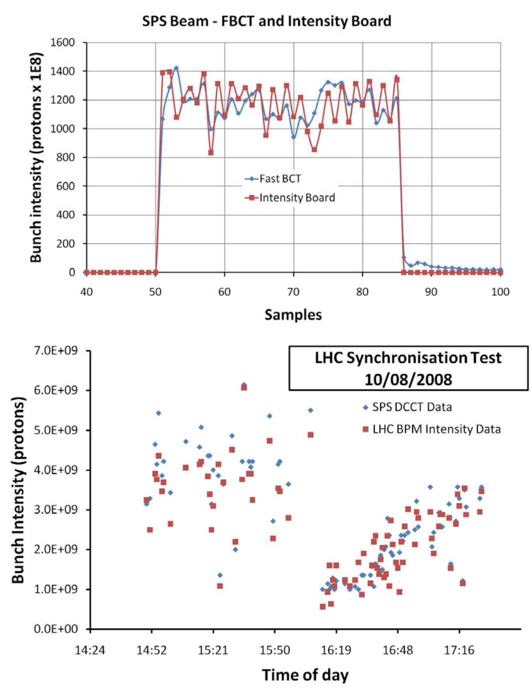

Figure 7: SPS (top) and LHC (bottom) measurements.

The 48dB range of the "intensity beam-simulator" extends from 1.2×10^{9} to 3×10^{11} protons per bunch. The intensity module covers it using two sensitivity ranges of 35dB each, with an overlapping region. The high sensitivity mode guarantees a linearity around ±2%, as illustrated with the example in Figure 6, while that of the low sensitivity is close to ±4%.

FIRST BEAM MEASUREMENTS

The first beam acquisitions showed a systematic offset of the intensity reading [4]. This was found to come mainly from the final cabling layout and small neglected electronics effects and led to the time-domain analysis previously discussed. Figure 7 presents actual proton beam measurements on both the CERN-SPS and from first beam in the LHC. The SPS trace shows the bunch by bunch intensity profile of a 72 bunch LHC type batch, taken on a single turn. It can be seen that the intensity module and the fast beam transformer are in reasonable agreement to within the accuracy possible due to the bandwidth limitations of the transformer. The LHC plot shows a comparison of the SPS DCCT data and a BPM intensity module at the end of the first LHC sector for single, very low intensity, pilot bunch injection over a few hours. Even working close to its detection threshold the intensity module can be seen to give a reliable measurement of the bunch intensity injected in the LHC.

CONCLUSION

An intensity module has been designed and built to provide bunch intensity measurements from each beam position monitor located in the LHC. As this was added at an advanced stage in the beam position project, the intensity module had to encode the intensity information using the same pulse modulation technique as the beam position system. Despite this tight constraint the BPM intensity card has shown to perform remarkably well, with a linearity of around 2% and an accuracy better than the 10% requested for the system.

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