EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CERN — A&B DIVISION

AB-Note-2003-019 OP

Prototyping Real-Time Control in the SPS

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Abstract

Real-time control of beam related parameters will be required in the LHC. In order to gain experience of the issues involved in implementing distributed real-time control over large distances, a prototype local orbit feedback system is being developed in the SPS. This will use 6 pickups, each equipped with the full LHC acquisition electronics chain and linked to a real-time communication and feedback system.
This reports summarises the .rst tests performed with this system in October 2002, where the data from four pickups was successfully acquired and displayed at 10 Hz in the control room.

Geneva, Switzerland
February, 2003

AB-Note-2003-019 (OP)

February 18, 2003

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Keywords: REAL-TIME, CONTROL, LHC, SPS

Run no.	Date
SPS LHC Cycle	21st Oct 2002

Summary

Real-time control of beam related parameters will be required in the LHC. In order to gain experience of the issues involved in implementing distributed real-time control over large distances, a prototype local orbit feedback system is being developed in the SPS. This will use 6 pickups, each equipped with the full LHC acquisition electronics chain and linked to a real-time communication and feedback system.

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1 Introduction

Real-time control will be required in the LHC [1, 2, 3] to stabilize among other things: the global orbit, the local orbit at various positions in the rings and the tune. Feed forward will also be necessary from the so-called multipole factory. These needs have been anticipated when considering the design of the LHC control system. In order to explore the challenges of real-time control, it has been decided to test a local orbit closed loop feedback system in the SPS. This is to be based on the RT acquisition from 6 new pickups installed near point 5 of the SPS equipped with the full chain of LHC acquisition electronics. Local orbit measurements are performed every 100ms, with the results transmitted to the control room, where they are displayed in real-time (10 Hz). The eventual aim is to close the loop using a second RT connection to the MuGeFs controlling the orbit correctors.

This set-up provides a realistic test of the LHC beam position acquisition system and allows the development and testing of the supporting control system architecture. The final aim being to prototype both the LHC real-time acquisition from top-to-bottom and the LHC feedback loop control, in particular for local orbit feedback.

The LHC style pickups were installed during the 2001/2002 SPS shutdown, with the acquisition electronics added and tested throughout 2002. The complete RT acquisition was finally tested during an MD in October 2002. This paper summarizes the system design and the results from that MD.

2 System architecture

The size of the LHC and the distributed nature of both the acquisition systems and actuators require the handling of multiple input/multiple output on a global scale. In order to generalize the situation and facilitate data management of control settings for related systems it has been decided to collect acquisition results and distribute corrections using a global framework. To this end all essential aspects of the prototype LHC orbit acquisition system in the SPS resembles the final implementation foreseen for the LHC and its transfer lines. The system architecture is shown in Figure 1. In addition the position data is transmitted to a central real- time processor from which it can be re-distributed to the various clients (in this case the real-time display and feedback).

- The six pick-ups installed are similar to those that will be used in the TI2 and TI8 SPS to LHC transfer lines and are based on recuperated LEP button electrodes. These are located at quadrupoles 515,517,518,519,521 and 522. All the pick-ups are capable of measuring both the horizontal and vertical planes. Coaxial cables connect the electrodes to the analogue front-end electronics housed at the bottom of the BB5 shaft.

- The analogue acquisition electronics used are prototypes of the Wide Band Time Normaliser (WBTN) foreseen for the LHC and LTI BPM systems [4]. A front-end card is responsible for processing the data from each measurement plane and converting the position for each bunch into a time between the rising edges of two pulses. These pulses are then transmitted via a single mode fibre- optic link to the integrator and digitization cards located in an existing rack in BA5. Twelve of the front-end cards sitting in 3 separate chassis will be required to treat the full horizontal and vertical data from the six pick-ups. During the 2002 run only four were available and were used to treat the horizontal data from pick-ups 515,517,519 and 521. The front-end cards are controlled via a WorldFIP fieldbus, which is used mainly to set the calibration mode or change the sensitivity setting. The WorldFIP commands are created in a PMC mezzanine card (CC142) located on the host PowerPC in BA5 and are received and decoded using a CERN developed front-end control card.

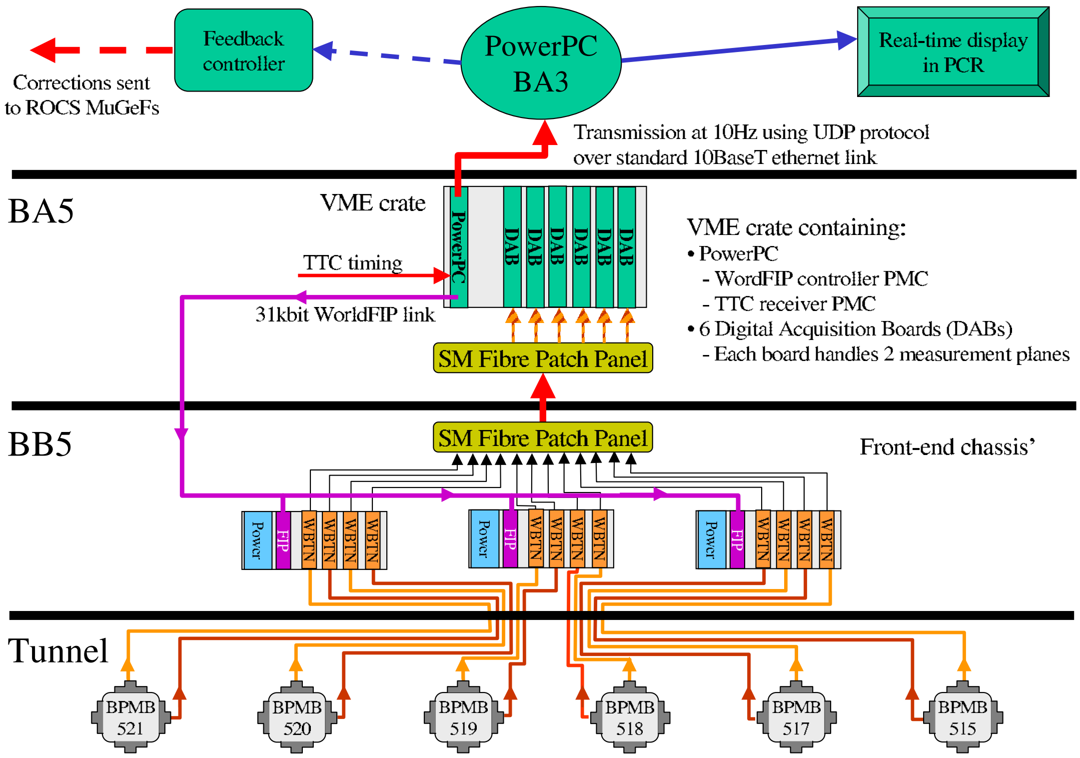

Figure 1: Architecture of the prototype LHC orbit acquisition system that is used in the SPS.

- The digital treatment of the incoming data is performed by a VME Digital Acquisition Board (DAB) developed by TRIUMF (Vancouver, Canada) as part of the Canadian contribution to the LHC. Two integrator-and-digitization mezzanine cards treat the incoming optical data and provide each DAB with 40MHZ 10-bit position data for two measurement planes. A single high performance FPGA sitting on the DAB is then responsible for processing this data. The DAB is capable of three parallel modes of operation:
  - An *Orbit mode* continuously providing 5ms (255 SPS turns) of accumulated position data every 100ms (10Hz).
  - A *Capture mode* for acquiring selected bunches over large numbers of turns as requested by an operator.
  - A *Post-Mortem mode* for storing recent orbit acquisitions in a rolling buffer for post- mortem analysis.

  The orbit mode is triggered every 100 ms via the beam synchronous timing

(BST) using the TTC system and a TTC PMC receiver located on the host VME PowerPC. This also provides the 40 MHz and turn clocks required to synchronize the DAB with the beam. On completion of an orbit acquisition the DAB sends a VME interrupt to the PowerPC, and provides it with the sum of the positions, the valid bunch count and the error count for the completed acquisition. The DAB also stores a histogram of the position data that can be used to further validate the measurement. The PowerPC is responsible for producing a position from this data by applying calibration factors and the fifth order polynomial required for the correction of pick-up non-linearity.

- The final position data is pushed via UDP over the standard SPS network (10baseT) to a second PowerPC located in BA3 using a pre-defined C structure. The simple UDP transmission routine is used linked to the low-level server, which handles priorities, scheduling and the like. A program on the receiving machine is responsible for unpacking the data, writing it to a file, and pushing it to a fixed display in the PCR. Statistics are taken on the transmission reliability and acquisition timings.

Daytime	Cycle No.	Beam structure	Bunch intensity
8:30	1	1 batch	$1.1 \cdot 10^{11}$ p
10:30	250	single bunch	$1.1 \cdot 10^{11}$ p
13:20	640	single bunch	$6 \cdot 10^{10}$ p
13:50	710	single bunch	$3 \cdot 10^{10}$ p
14:20	770	single bunch	$5 \cdot 10^{9}$ p
16:15	1050	1 batch	$1.1 \cdot 10^{11}$ p
16:40	1120	2 batches	$1.1 \cdot 10^{11}$ p
19:00	1440	4 batches	$1.1 \cdot 10^{11}$ p

Table 1: Approximate time schedule of the MD period on 20th October 2002. 1 batch consists of 72 bunches. The cycle no. indicated in the second column is identical the numbering used for Figure 5.

3 Machine Setup

Most of the data was collected during the last SPS MD period on the 20th and 21st of October 2002. Cross-calibration data for the new BPMs with respect to the standard SPS MOPOS system was recorded on the 20th of October between 11:30 and 13:00. On the 21st of October data was recorded continuously on every cycle between 08:00 and midnight. With the exception of a short period, most of

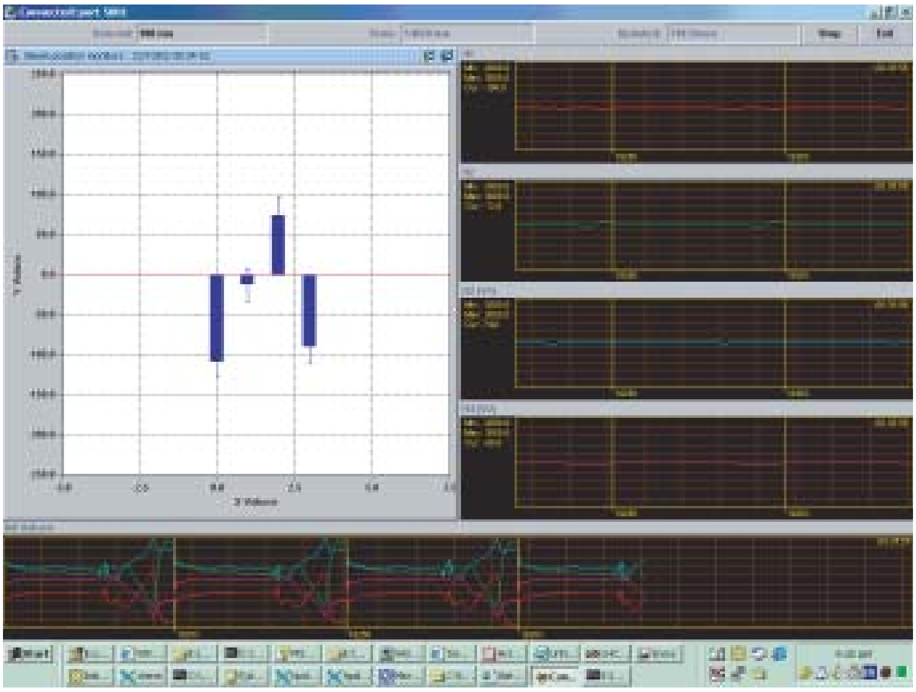

Figure 2: Real-time display as seen in the control room.

the data was taken passively while the foreseen MD program progressed. For this test only 4 horizontal planes were equipped with the acquisition electronics. The chosen pickups were located in positions 515, 517, 519 and 521 corresponding to vertically focussing quadrupoles. The horizontal betatron function at these positions is ~ 20 m, while the horizontal dispersion is rather small, at around 0.5 m.

In addition to recording the data to file, an online display updating at 10 Hz showed the real-time development of the horizontal orbit (see figure 2).

During the entire MD the SPS was running with super-cycle No. 540, the standard LHC beam cycle with a total length of 21.8 seconds. Beam was injected at 26 GeV/c onto a 10.8 second long injection flat bottom. The beam was accelerated to 450 GeV/c in ~ 8 seconds. The extraction flat top started 18.3 s after the first injection and lasted for ~ 1 s before the beam was dumped.

LHC beam with a bunch spacing of 25 ns was used during the entire MD. Beam structure varied between a single bunch and the nominal maximum of 4 batches of 72 bunches. The intensities varied between 5×10^9 and 1.1×10^{11} protons per bunch, as indicated in Table 1.

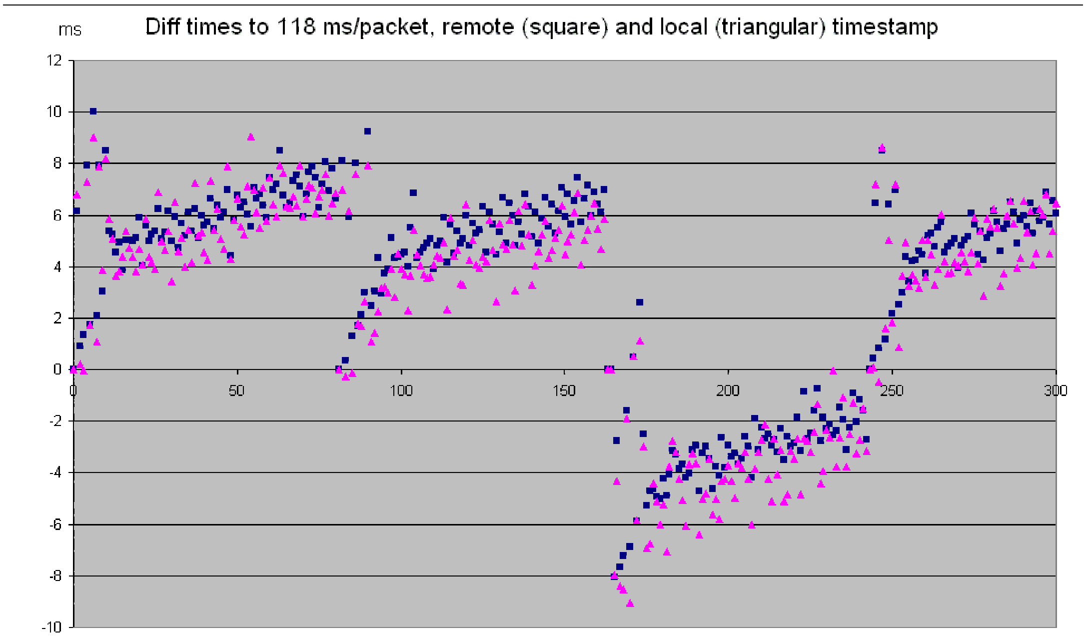

Figure 3: Variation in transmission times

4 Network and data transmission

The standard SPS network was used and in spite of the fact it is only 10baset and subject to bursts of traffic it performed reasonably well. The displaying of 10 Hz data from bpl50s via qlsba3 to the SPS control room (Windows, Java) worked well.

4.1 Transmission jitter

Although not measured during the MD, earlier tests showed that the network jitter was small compared to the latency of the sending process waking up, see figure 3.

With a trigger like the GPS+LEMO (or similar) the wake-up latency is expected to be significantly reduced (< 1 ms). Network parameters will be measured in a more realistic environment with multiple connections etc., however based on the above the network can be expected to be good enough.

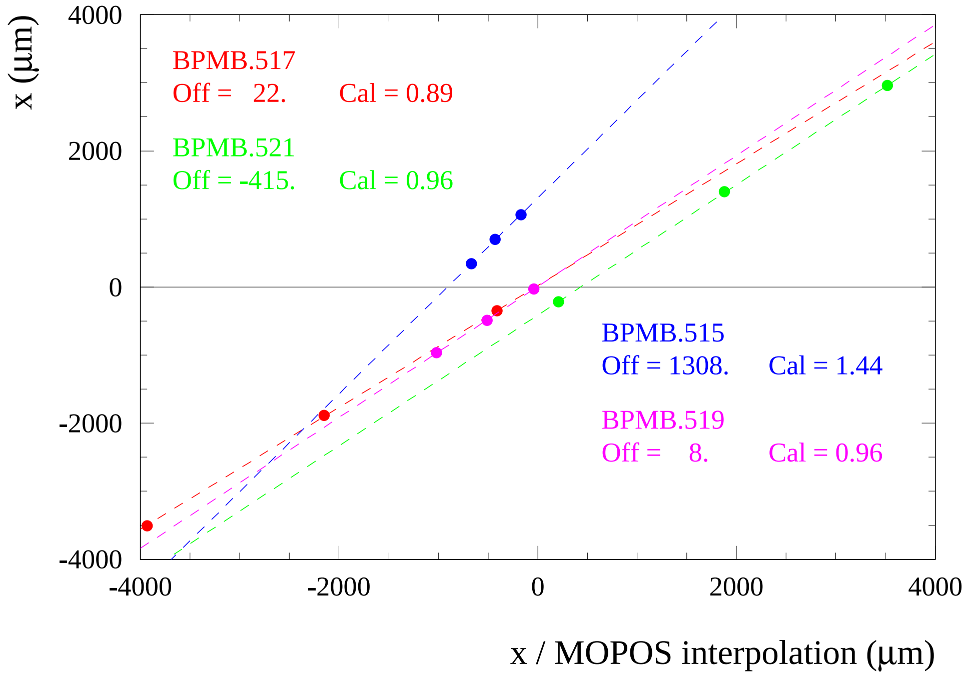

Figure 4: Calibration of new BPMs against existing SPS BPMs. The position determined with the new BPMs (vertical scale) is compared to the position interpolated from two nearby machine BPMs with $x = Off + Cal \cdot x_{interp}$. The accuracy of the calibration factors is around 5%.

5 Beam Position Monitors

5.1 Beam Position Monitor Cross-Calibration

A cross-calibration of the new BPMs was performed with respect to interpolated positions obtained from the normal machine BPMs. The accuracy of the cross-calibration is estimated to be $\sim 5\%$. Results are shown in figure 4. Monitor BPMB.517 (blue color, same color code in all plots) has rather strange calibration factors and offsets, which have yet to be fully understood. The calibration factors used for the new BPMs were global estimated factors and had not been measured for the individual electronic chains involved, as will be the case for the LHC.

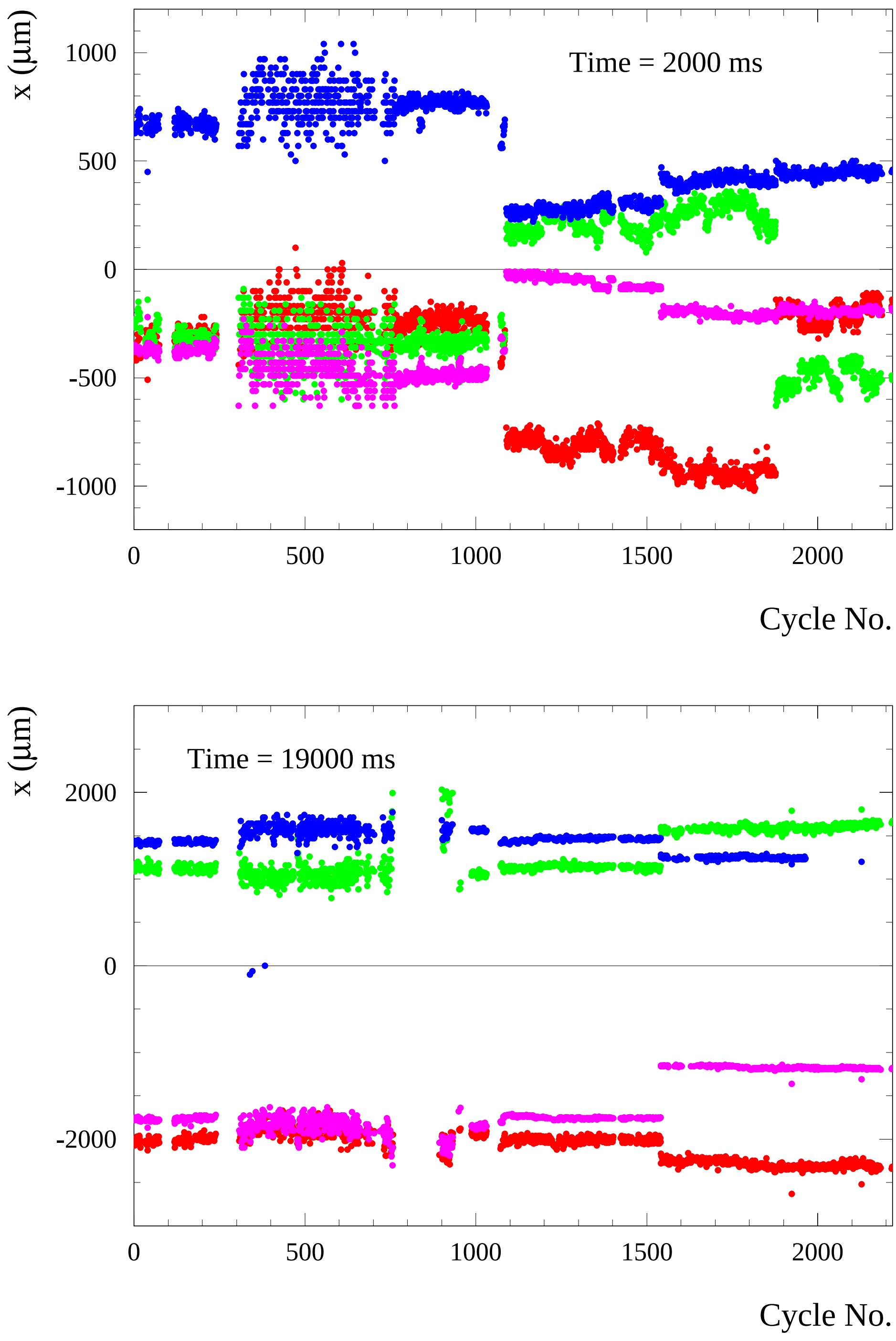

Figure 5: Variation of the beam position at 2000 ms and at 19000 ms in the SPS cycle over the MD period. The increased 'noise' on the beam position between cycles 300 and 750 is due to the mode of the BPM electronics that was switched to a single turn, single bunch measurement, while during the remaining period, the position was averaged over 250 turns.

6 Analysis of orbit measurements

6.1 Long term stability

The stability of the position at 2000 and 19000 ms of the standard SPS cycle for LHC beam between 08:00 and 24:00 on October 21st is shown in figure 5. One can see that the overall stability is good. Variations (mainly 'jumps') due to steering by the operation crews are clearly visible. The stability of the measurement is $\sim$ 20 μm when the position measurement is averaged over 250 turns. This number is a combination of the machine, the beam and the electronic stability. In single turn mode, the rms spread of the measurements increases to $\sim$ 80 μm, see Figure 5 for cycle numbers 300 to 750.

The stability of the position at 19000 ms, which corresponds approximately to the time of extraction in either LSS4 (to TI8 and LHC ring 2) or LSS6 (to TI2 and LHC ring 1), is excellent. Again jumps due to operator interventions are clearly visible.

The stability of the position over the first 250 cycles is shown in figure 6 as a function of the time in the cycle. No operator steering was performed during this period, which therefore exhibits the 'natural' stability of the SPS orbit. The beam position varies significantly during the cycle, but the RMS position spread at injection and during the extraction flat top (given by the error bars on the plot) is typically 20-30 microns over 250 $\times$ 22 s = $\sim$ 5000 s. The fact that the RMS position spread during the ramp (where the position changes most rapidly) increases is an artefact of the analysis, since the acquisitions on consecutive cycles were not necessarily taken at the same time. This is linked to the fact that the SPS BST, used to trigger the acquisitions was not linked to the elementary cycle but was free-running giving triggers every 100 ms. The overall stability is in line with what has been seen before, namely that the SPS orbit is very stable, in particular at high energy. Typical RMS drifts over few months are in the range of 1 mm rms.

7 Conclusion

The foreseen maximum acquisition rate for LHC orbit measurements for both global and local control is 10 Hz. It is encouraging that this has proved possible, with acceptable jitter, using only the standard SPS 10baseT network. Further tests simulating multiple acquisition crates will explore the effects of loading the network.

The development has also been very useful in testing the full LHC BPM acquisition chain including the use of the TTC system for beam synchronous timing and the WorldFIP field bus for controlling the front-end settings.

The next step is to close the loop and attempt orbit stabilisation by pushing

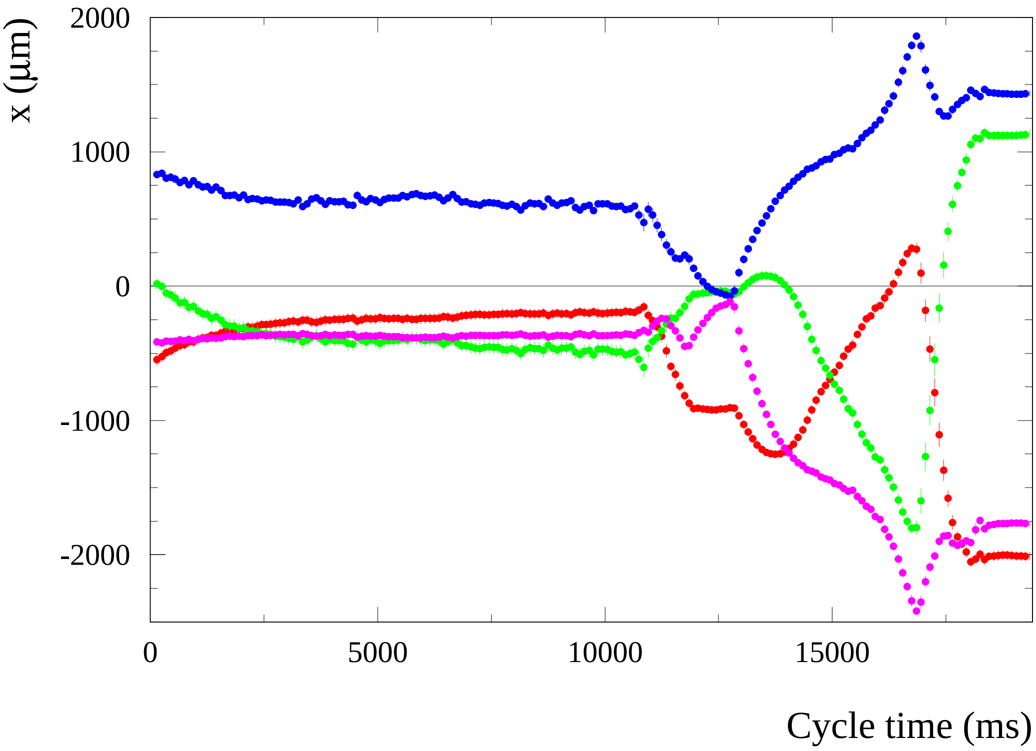

Figure 6: Beam position over the first 250 cycles (see also Figure 5) as function of the time in the cycle. The error bars correspond to the rms position spread of the entire period.

corrections to the ROCS MuGeFs controlling the local orbit correctors in the region of the pickups. It is planned to start these tests with beam during the first half of 2003.

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