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THE SECOND GENERATION AND OPTIMIZED BEAM ORBIT MEASUREMENT (BOM) SYSTEM OF LEP : HARDWARE AND PERFORMANCE DESCRIPTION

J. Borer, D. Cocq, A. Manarin, G. Vismara

Abstract

The BOM System with its 504 Beam Position Monitors and 40 Processing Electronics Stations, distributed along the 27 km of the LEP tunnel, has been optimized for all beam conditions and modes of operation. The description of the Beam Position Monitors (or PU) behavior in the tunnel is given. The guiding approaches for obtaining both main aspects of the critical BOM performances were: a) high reliability, since most of the electronics is not accessible during operation, and b) resolution, precision and stability of the signal processing equipment for the management of the LEP optics, polarization and energy calibration. The finalized analog signal processing chains, both Wide-Band and Narrow-Band, are described. Since local memories allow for the recording of data at each bunch passage during more than 1000 revolutions, it can be followed by a powerful digital signal processing allowing for many modes of beam observation. Examples are presented of beam and machine behavior studies. The BOM System has been a key instrument for the success of LEP operation.

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THE SECOND GENERATION AND OPTIMIZED BEAM ORBIT MEASUREMENT (BOM) SYSTEM OF LEP: HARDWARE AND PERFORMANCE DESCRIPTION

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1. INTRODUCTION

The LEP Beam Orbit Measurement system has been described in many conference papers [1,2]. With its 504 Beam Position Monitors of the capacitive button electrode type, distributed along the 27 km of LEP tunnel, it is the largest among such beam measuring equipments. It was also the first to include local fast buffer memory to store in real time up to 1000 revolutions of all bunches data. It has opened the door to many data processes allowing for very precise local knowledge of the machine optics.

The BOM system is composed of two different processing electronics: the Narrow-Band, less costly, for most of the machine and the Wide-Band for PUs nearby the IPs, where time resolution is a critical problem.

The originally designed processing equipment did present some sources of systematic measurement errors and lack of stability and reliability.

The main performance limitations were:

- horizontal orbit offset (NB) on e^- = -0.5 to -0.9 mm,
- horizontal orbit difference (NB) (e^+-e^-) = -0.5 mm,
- scaling factor (for NB e^+ = 0.86, e^- = 0.95),
- position dependence on beam intensity,
- linearity (2% on the full scale).

Both the performance limiting electronics and data transmission and processing hardware have since been replaced. The software has also been redesigned [3].

New interpolation and calibration technics have been implemented to further improve the measurement resolution.

2 BEAM POSITION MONITORS (PU)

The original beam position monitors design, made of an Al bloc (Stainless Steel in the straight sections) and of four stainless steel button-electrodes, has not presented any problem even in the much feared corrosion domain. The interchangeability concept of the electrodes has been very useful for repair and for the numerous machine changes.

3. NARROW-BAND PROCESSOR ELECTRONICS

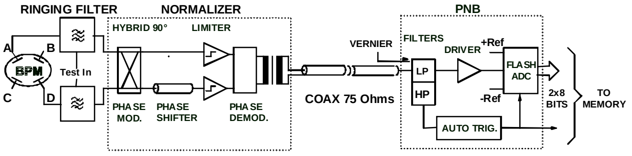

Fig. 1 - Narrow Band processor block diagram

3.1 Ringing-filter

The original design of the 70 MHz Gaussian type double resonator, showed a lot of spurious resonances in the GHz region. As a consequence the wide frequency spectrum of the induced signal is exciting all these parasitic modes and the phase of the output signal is distorted. The calibration signal, which has a frequency spectrum one order of magnitude smaller, results in a stable output phase. The behavior difference between beam and calibration signals resulted in an offset of the absolute and relative $(e^+ - e^-)$ position measurement.

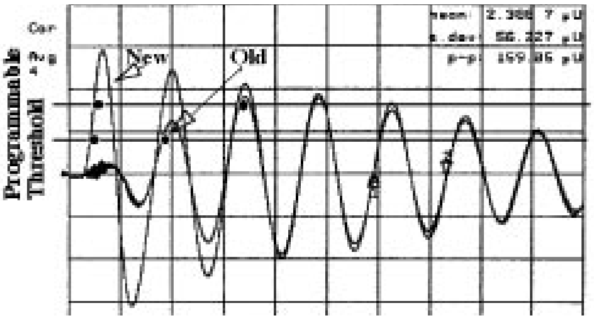

Fig. 2 - Old and new ringing filter time response

For the new design [4] a single resonator filter, which include the electrode capacity, has been chosen for:

- its simplicity, which means easier fabrication,
- its stable phase,
- no trigger uncertainty, since the first oscillation is the largest one (Fig. 2).

The price to be paid is a longer damping time (600 ns for 60 dB attenuation). The spurious resonances are suppressed by a built-in low pass filter.

The calibration and beam signal responses are now identical.

3.2 Normalizer

The beam intensity position dependence, from the threshold level up to 20 dB overdrive, and the non-linearity problems for large transverse oscillations were due to the normalizer.

The new realization is based on two identical and totally independent normalizing channels.

The *phase shifter* delay line (a 50 Ω micro-strip of 3.57 ns) is now located between the 90° hybrid and the dual limiter.

The *dual limiter and phase demodulator* is a thick film hybrid module. The completely symmetric switching (50% duty cycle), guaranties a stable measurement, even at the lowest threshold limit [Fig. 3]. The adjustable threshold control allows for a stable output signal duration (400 ns) independent of the beam intensity [4]. A reset circuit has been added to insure defined output level between bunch signals.

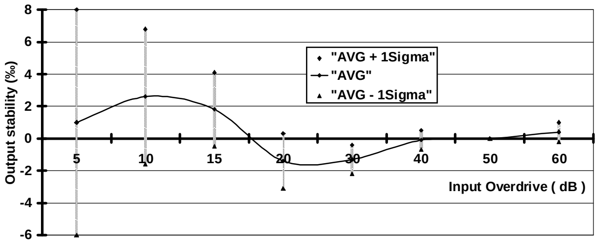

Fig. 3 - Normalizer stability vs. input signal overdrive

The "phase to amplitude" demodulation is obtained with an ultra-fast ECL Lite EXOR, which presents an excellent linearity as shown in Fig. 4.

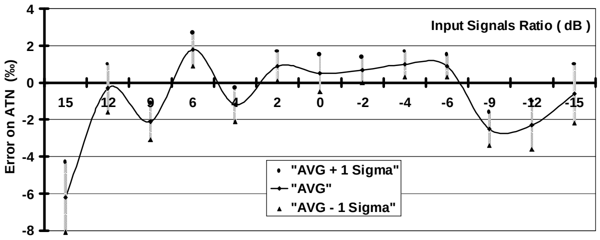

Fig. 4 - Normalizer linearity vs. input signals ratio

The 140 MHz signal is then filtered by a low-pass circuit, amplified by a 75 Ω video buffer driver, ground insulated by a transformer and sent via two long coaxial cables to the digitizing card.

3.3 Processor NB with FADC

The heart of the PNB module is the A/D conversion. Due to the AC coupling of the processing chain, two measurements, spaced by 100 ns, are necessary for each pulse: the pedestal and the height. This condition requires the use of a Flash ADC, but with a limited resolution of 8 bit for cost reason.

The problems associated with the original PNBs were related to poor integral linearity (2% of the full scale) and differential linearity errors caused by cross-talk with the digital output signals, in the most critical region corresponding to centered beam signals around bin 127.

A video FADC was used in the original design. Its characteristics are optimized for a continuous clock, which is not the case for this application. The consequences were large linearity error (±2 bin) which could only be partially software compensated (±.5 bin) and first few turns measurements inaccuracy (i.e. at injection) (Fig. 5).

The new design is based on Motorola 8 bit ECL FADC, with Grey encoding. Its excellent integral and differential linearity (0.25 bin) associated with an encoding rate from DC to 20 MHz, have solved all above mentioned problems (Fig. 5).

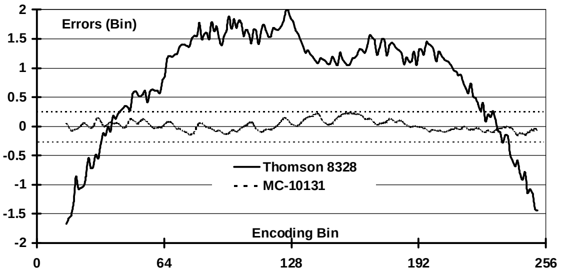

Fig. 5 - FADC linearity errors

The auto trigger logic and veto sub-module has also been redesigned for the new LEP mode of operation called Bunch Train.

3.4 Vernier generator

The use of an 8 bit FADC allows for a beam position resolution ≅140 µm in the vertical plane. The orbit measurements require still better resolution. An interpolating technics called *Vernier generator* has been implemented. A ramp signal shifts the FADC input pedestal by 1/8 of bin at each revolution period.

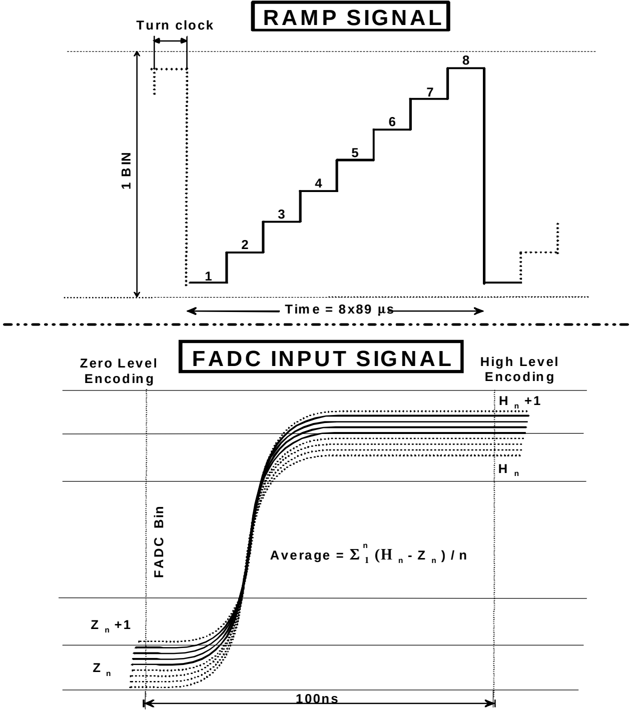

Fig. 6 - Functional diagram of the Vernier interpolation

The signal under measurement is then shifted through the bins and the measured difference changes when either the pedestal or the height level change of bin. The average value has a resolution equivalent to 3 extra bits. **This technique has increased the beam position resolution, down to 16 µm for the vertical and 11 µm for the horizontal plane.** In addition the differential linearity errors are smoothened when several bins are covered, (1 up to 8).

4. WIDE-BAND SYSTEM ELECTRONICS

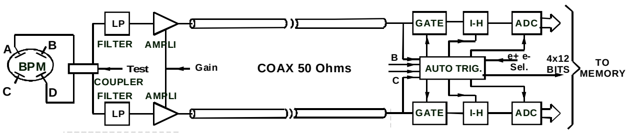

Fig. 7 - Wide Band processor block diagram

4.1 Controllable Gain Front End Amplifiers

The original version did suffer from degrading contact resistance of the front end attenuator relays. They were replaced by Hewlett Packard attenuators with three cells of 10, 20 and 40 dB. It allows a dynamic range from -30 to +40 dB. The attenuation is now very reproducible and stable. The associated new wide-band amplifier has a bandwidth of 250 MHz. Its maximum output level is 8 Vpp on 50 Ω with a non linearity < 0.2 dB. Its typical noise figure is 3.5 dB.

4.2 Detectors

The very bad quality resistors of the original modules did imply their replacement. The opportunity was used to optimize the circuit and to introduce SMD technology. An analog gate (35 ns) allows for the bunch signal selection and adaptation of e^+ and e^- polarity. It is made of a diode bridge mixer and driver and is followed by Integrate-and-Hold circuit. The latter one is based on a current source charging up a capacitor through a diode. An amplifier matches its output to the following ADC.

The new circuit [5] has a much reduced influence of the memory capacitor discharging circuit and hence the importance of the charging-up rise time. The circuit linearity range has been increased from 18 to 24 dB (absolute linearity error <5% and relative between two channels <1%) and is much easier to calibrate. The circuit sensitivity to external LF noise has been improved by factor 6. An overall noise reduction of about 25% has been measured with the new detector.

4.3 ADC Modules

For savings reasons the original system did use ADC (HAS 1202) recuperated from the ISR machine. These converters of hybrid technology started to degrade after 4 years of operation. New cards have been installed which contain monolithic ADC of type AD 7572 (12 bits) with reduced power consumption: 100 mW instead of 2 W.

4.4 Calibration

Since gain changes are required by the beam intensity variation, the WB electronics was suffering from some position jumps during such changes. This was due to a fixed threshold value applied to all detectors for the position calculation. A new dual point calibration method has been introduced to determine the individual value of these thresholds and the averaging of measurements over 20 ms has much reduced the 50 Hz noise influence. The present position jumps due to gain changes are <100µm.

5. BEAM TESTS WITH MOVABLE PU BENCH

The best solution to check the BOM performances and to tests equipements is to mechanically displace the PUs with respect to the beam. Two PUs, equipped with different signal processing chains, are placed on a straight section of the LEP vacuum chamber.

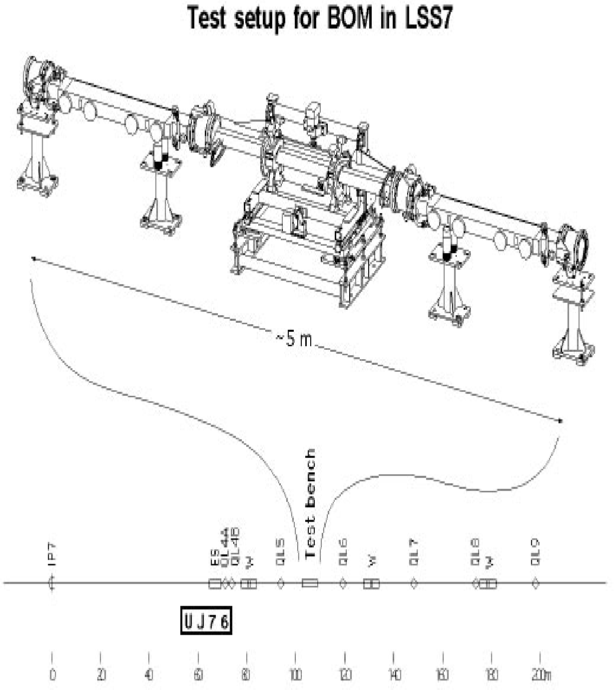

Fig. 8 - Layout of the PUs test bench

They are supported by a motorized X and Y movable bench, capable of ± 15 mm displacement on both transverse axis, with an accuracy < 10 µm. The system is associated to two reference PUs, placed on both side, for beam fluctuations compensation. During dedicated MD and stable physics runs, linearity, scaling factors, X-Y cross-coupling and comparative measurements were performed. Signal treatment and acquisition process are identical to the BOM but a dedicated software allows for automatic scanning. Most of the BOM performances characterization have been done with this test bench.

6. BOM PERFORMANCES

The new electronics has been installed in several stages between 92/93 and 94/95 shut-downs. All the following measurements refers to a standard 224 turns (20 ms) acquisition time with vernier generator across 4 bins.

The measurements of the BOM resolution and long term stability have been performed with the "central beam" simulation test mode: NB and WB systems present respectively a resolution of **11 and 9 µm rms (**Fig. 9). They have shown an average position measurement fluctuation of respectively **17 and 24 µm rms** for 40 measurements spread over a period of 12 hours.

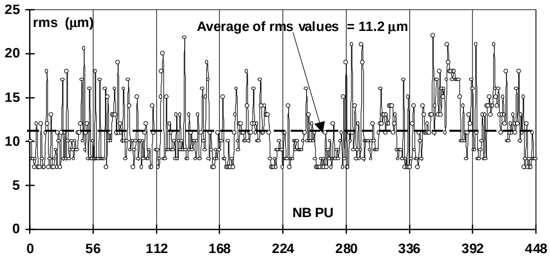

Fig. 9 - Horizontal position fluctuation vs. time

The following parameters have been measured for both e$^+$ and e$^-$ beams with the mobile PU test bench, in a range of ±10 mm:

Scaling Factors: In the vertical plane its value is 1±0.005, while in the horizontal plane it is 1.004 ±0.002 for e$^-$and e$^+$. The discrepancies between both NB and WB systems never exceed 1%.

Linearity: The measurement error has been limited by the mechanical error which is of the same order of magnitude. In both planes it is <20 µm rms.

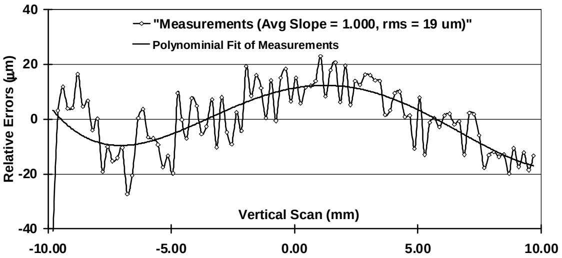

Fig. 10 - NB vertical linearity errors

X/Y coupling: The effect is negligible and below the measurable limits of -46 dB.

Dispersion Measurements: A useful global check, for most NB PUs situated in the arcs, can be obtained with a dispersion measurement. This is done by subtracting two orbits measured with different rf frequencies. The horizontal displacement should be proportional to:

$$dx = -D_X \frac{dp}{p} = -D_X \frac{df}{\alpha f}$$

For a df = 10 Hz, the LEP optics gives a dx = -91.4 µm, with Dx = 0.597 , $\alpha = 0.1856 * 10^{-3}$ and f = 352.21 MHz.

An example is given in Fig. 11 where one sees that most of the observed oscillations are due to the machine imperfections and measurements errors account for less than 10 µm.

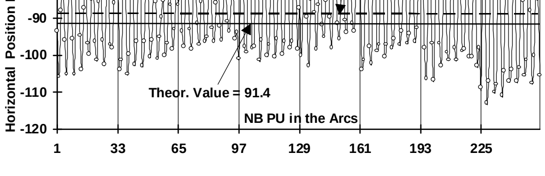

Fig. 11 - Dispersion measurements in the arcs

7. CONCLUSIONS

The BOM System is now a mature instrument. Orbit correction allows to reduce the V-distortion down to 0.4 mm rms, which is very important for luminosity and polarization. The WB PUs measurements allow to survey beam positions at the IPs with a resolution of 1 µm . The BOM stability makes it feasible to record and compensate alignment error between PUs and adjacent quadrupoles as measured with K modulation [6]. The analysis of 1000 turns acquisition is a very powerful tool to unveil the lattice parameters of the real machine, like the exact phase advance between Ips [7,8] or the exact beta values needed to compute emittance from measured beam sizes [9]. The BOM system will have to cope now with the challenge of the bunch trains [10].

8. ACKNOWLEDGMENTS

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