BEAM POSITION MONITORING SYSTEM FOR ELETTRA

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Abstract

In order to provide a good tool for the users, synchrotron radiation facilities have stringent requirements concerning the stability and the resolution of their beam position monitor system. The system chosen for ELETTRA has also to be fast in order to implement a real time closed orbit feedback, and it should be able to measure the successive positions of an injected beam which does not complete its first turn into the storage ring. The monitors, the electronics and its architecture are described. A resolution of a few microns, a stability during a whole shift in the ten micron range, concurrently with a measurement rate of 2400 orbits/s are the main performance features expected.

Introduction

ELETTRA is a third generation syncrotron radiation source being built[1] in Trieste (Italy). Stabilizing all photon beams is a very challenging task for such a low emittance machine. The most ambitious of the stabilizing systems, a real time closed orbit feedback[2], requires top performances from the beam position monitors (BPM) and their electronics.

With eight BPMs per achromat and twelve achromats, a total of 96 BPMs will equip the machine. A BPM is made of four button electrodes (figure 1a) delivering narrow pulses to its own electronic detector via four coaxial cables. The detector works at the ring radio frequency; it delivers four digital numbers proportional to the electrode signals, to a microprocessor which computes the x and y positions relating to an achromat. A VXIbus chassis for each achromat houses the sensitive electronics; it is compatible with the VMEbus standard adopted for ELETTRA[3]. All the electronics is housed in a free access area in order to assure the maintenance at any time.

Tasks of the BPM system

The BPM system fulfills several important tasks:

- Measure the closed orbit for correcting it later with steering magnets. The important performance is the absolute accuracy of the monitor survey with respect to the quadrupoles. An extensive computer simulation[4] of the correction scheme predicts residual closed orbits smaller than 0.25 mm r.m.s..

- Give closed orbit information at a high rate for the real time global feedback. The relevant characteristics are the stability of the monitor mechanical supports as well as the stability, resolution and speed of the electronics.

- Measure the beam trajectory after injection for steering it (multibunch only) onto its first turn around the ring to aid commissioning. The global accuracy is released to 1/4 mm for this task.

- Measure the closed orbit dependance upon various parameters for important accelerator physics measurement of lattice functions and beam dynamics.

Table 1 lists the relevant storage ring parameters and table 2 provides the BPM system specifications that will fulfill all of the above requirements.

Table 1. Machine characteristics at 1.5 GeV

RF system frequency	499.654 MHz
Number of bunches	1 - 432 bunches
Beam current , multibunch	400 mA
" , single bunch	8 mA
Bunch length	3.5 mm $\leq \sigma_s \leq$ 15 mm
Minimum bunch spacing	2 ns
Injected beam structure	≈ 75 bunches at 2 ns intervals
Injected beam charge	≥ 1.5 nC
Injection rate	10 Hz
Beam sizes, bending magnet	σ_x = 100 µm, σ_y = 60 µm
Beam sizes, insertion device	σ_x = 181 µm, σ_y = 32 µm

Table 2. BPM system specifications

Accuracy	
Resolution at high currents	≤ 5 µm (rms)
Stability, eight hours	≤ 10 µm (rms)
Absolute accuracy	≤ 150 µm (rms)
Speed	
First turn mode	≈ 1 trajectory / minute
Closed orbit mode	≥ 2 graphics / second
Position feedback	≥ 2400 orbit / second
Dynamic range	
Closed orbit and feedback	1 - 400 mA
First turn mode	0.2 - 2 mA

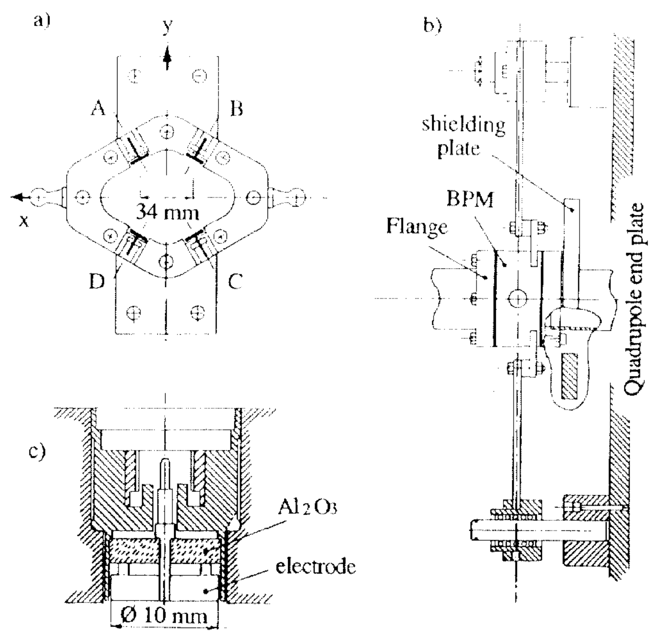

Figure 1: Mechanical design. a) Monitor; the top and bottom plates allow the attachment to the support; the two lateral balls define the mechanical center as the middle of the line joining the ball centers. b) Monitor and its support fixed on a nearby quadrupole. c) SMA vacuum feedthrough with button electrode.

Monitor Mechanical Design

The BPM itself is shown in figure 1a; its support (fig. 1b), attached to a nearby quadrupole, is very rigid in the transverse plane but moves freely in the longitudinal direction and has some flexibility in rotation for accommodating the vacuum chamber movements due to normal temperature variations. In this way the mechanical center should remain transversally stable, at least for a period of a few hours. A laboratory test of the support showed a 25 µm displacement with 20 kg applied horizontally and 4 µm for a 14 mrad rotation.

In order to compensate the offsets caused by unequal electrode sensitivities, each monitor will be calibrated in the laboratory with a central antenna simulating the beam. The calibration consists of averaging the two output signals measured successively on each electrode, one before and the other after a 180° rotation of the BPM around the antenna. The rotation has two important goals: it defines the BPM mechanical center as the middle point between two reference spheres (figure 1a), and it removes the antenna position uncertainty from the calibration error which should then reach the 20 µm range. Once the BPMs are installed in the ring, their mechanical centers will be surveyed accurately (≤ 50 µm) with a jig that measures the position of the two spheres with respect to the alignment references of the quadrupole. The position of the magnetic center with respect to the quadrupole references being known to better than 100 µm, the global accuracy including the electronics should reach 150 µm rms.

Each side of the BPM is attached to the vacuum chamber via a VAT seal; the inner perimeter of the flange and of the gasket matches perfectly that of the vacuum chamber which minimizes the impact of a large number (≈ 200) of these flanges on the total vacuum chamber impedance.

Monitor Electrical Features

A detector measures the four electrode signals V_A, V_B, V_C and V_D labelled as in figure 1, and a microprocessor computes the positions x and y after the following formulas:

$$x = \frac{1}{S_x}\frac{(V_A+V_D)-(V_B+V_C)}{V_A+V_B+V_C+V_D} \quad \text{and} \quad y = \frac{1}{S_y}\frac{(V_A+V_B)-(V_C+V_D)}{V_A+V_B+V_C+V_D} \qquad (1)$$

where S_x and S_y are respectively the horizontal and the vertical sensitivities. We used a spreadsheet program running on a personal computer (Excel on Macintosh) for computing the BPM table of potentials and we looked for an optimum electrode separation E_s yielding the same sensitivities on both axis; E_s = 34 mm leads to $S_x = S_y = 0.048$ mm^{-1}. By using the linear approximation of formulas (1), the error does not exceed 1% within a 8 mm diameter central area (figure 2).

Figure 1c shows a button electrode brazed on a bakeable vacuum feedthrough that is matched to 50 Ω for frequencies up to several GHz. This simple construction is available commercially (Ceramex-Metaceram model 1183.06.00).The button diameter is 10 mm; the limit in increasing this diameter is around two or three times the smallest bunch length σ_s in order to avoid any high frequency resonance to take place in the electrode and send clean signals to the electronics.

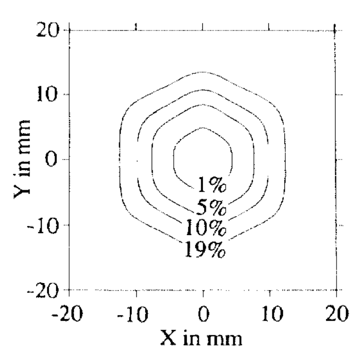

Figure 2: Computation of the BPM non linearity in the central area

The beam spectrum represented in figure 3, extends far into the high frequency domain (f_{rms} = 13.6 GHz). The electrode capacity with 1 pF, sets a frequency cut off much larger than the electronics working frequency F_1 = 500 MHz. In these conditions, the following formula gives a good approximation of the expected F_1 harmonic level:

$$V_{e\,rms} = \frac{\pi}{c\sqrt{2}} I_o F_1 R \frac{d^2}{D} \qquad (2)$$

c is the speed of light, I_o the beam DC current, R the cable impedance, d the electrode diameter, and D the diagonal distance between electrodes. According to this formula, a 400 mA beam stored into ELETTRA will yield 137 mV r.m.s (or - 4 dBm) on an electrode, at the 500 MHz harmonic .

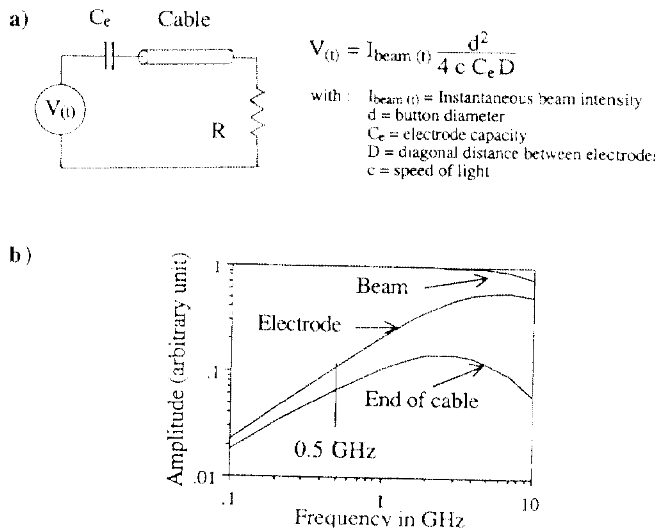

Figure 3: a) Equivalent circuit. b) Spectrum at the various points of the circuit; a 3.5 mm bunch length corresponds to multibunch operation at 1.5 GeV.

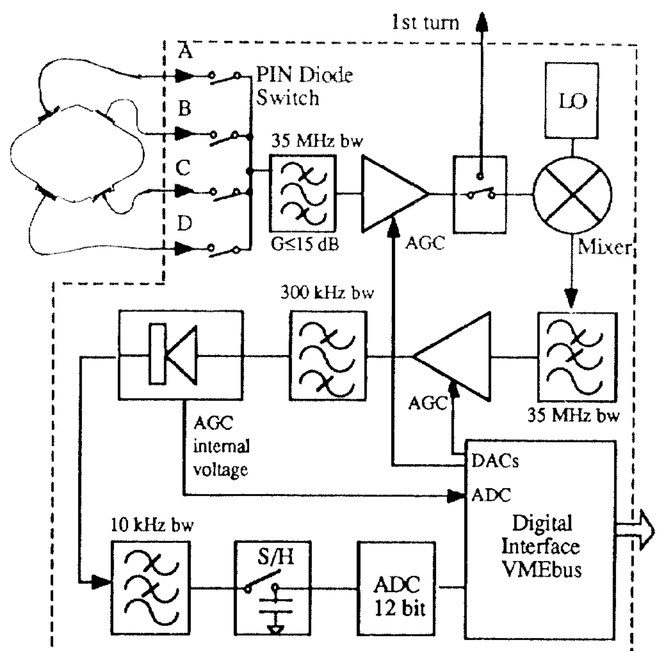

Figure 4: Block diagram of the position monitor electronics.

BPM Detector

The first laboratory tests conducted on a system that could measure both stored and injected beams, showed too large a beam current dependence for the feedback application. The present system therefore uses different detectors for those two functions.

The 20 m of RG214 doubled shielded coaxial cable introduces a 4 dB attenuation that brings the maximum level down to - 8 dBm at the detector inputs for a centered beam.Two main features of the BPM detector shown in figure 4, have already given good results on previous machines [5, 6, 7]. One is the PIN diode relay that multiplexes the 4 electrodes onto the same electronics; the second is an automatic gain control (AGC) that maintains the same working point of the detector circuit.

The PIN diode relay has a good linearity, even for the single bunch mode which yields the highest peak voltages; a test on a prototype with a single pulse at low repetition rate, 100 V high and 1 ns wide did not show appreciable non linearities (measurement uncertainty ≤ 1%). After the four electrodes, the relay scans a fifth position with all switches open for measuring the detector pedestal and subtracting it from the electrode measurements. A first bandpass filter avoids saturating the 500 MHz low noise preamplifier; then a mixer brings the frequency down to 10.7 MHz and after amplification the signal is filtered with a standard ceramic filter. A coaxial electromechanical relay mounted after the amplifier can direct the signal to an output labelled "1st turn" that goes to a special detector dedicated to the measurement of an injected beam that does not complete its first turn around the machine. In that operating mode, all BPMs are multiplexed to the same detector. In addition, the four electrode signals induced by four different Linac pulses will be normalized to the charge of the corresponding pulse.

The integrated circuit (IC) TDA2148, commonly used as a television audio decoder, is a synchronous detector using part of its input signal once amplified and limited, as a synchronous reference. This IC has its own AGC internal loop stabilizing its mean output voltage. In an early design, the global AGC scheme was including that loop by superimposing a voltage on the gain control point; however, an other method shown in figure 4 gives better results: the IC internal loop does not receive any forced control; the AGC voltage, representative of the internal gain, is read in order to bring it to a predefined value by driving the gain of the two other AGC stages. As a consequence the IC internal gain is stabilized and its input signal also. The noise bandwidth of the whole chain is set by a 10 kHz low pass filter. Figure 5 shows the resolution obtained with a test circuit whose gain was controlled manually. The 1 or 2 μm resolution obtained at high current will probably increase with an actual beam. The beam current dependence is a critical characteristic of a BPM detector. That performance must be measured with an off center beam to take into account the non linearity of the electronics preceding the detector IC. Figure 6 shows the good results obtained with the test circuit using only the formulas (1) corrected with the detector pedestal.

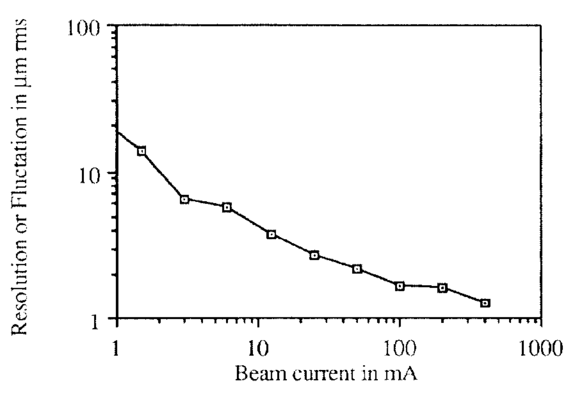

Figure 5: Resolution (r.m.s. measurement fluctuation) of the x or y positions as measured on the test detector with a simulated beam. The thermal noise has a dominant effect at low currents whereas the 12 bit ADC sets the resolution limit at high currents at about 2 μm.

Additional experiments on the test circuit showed variations smaller than 3 μm before and after a 12 h power interruption. A eight-hour stability test and a 10°C temperature rise gave similar results.

The closed orbit measurements do not need a high speed but good global accuracy, and so the sampling operation must wait for the complete stabilization of the detected signal (≈ 150 μs) once the multiplexer has addressed a new electrode. The real time closed orbit feedback requires the highest possible speed without any absolute accuracy requirement, so the sampler does not have to wait for the detected signals to reach their final value. Although the highest speed introduces an error due to the crosstalk from one electrode to the next, it still allows any change in the position to be read which is the main requirement. Scanning electrode or pedestal values for 50 μs each takes 250 μs; taking the VME communication time and the computing period into account should not add more than 160 μs; thus the global time for obtaining the x and y values amounts to 410 μs which is the part of the total delay budget allocated to the closed orbit acquisition. The BPM system will therefore read about 2400 orbit/s.

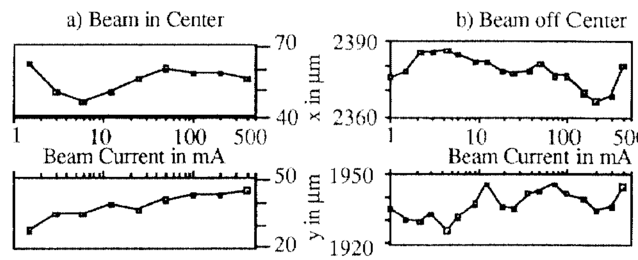

Figure 6: Beam current dependence of the position measured with the test detector. The drift versus the beam current does not exceed a 20 μm peak-to-peak amplitude over the 1 to 400 mA range though the simulated beam offset is large: ≈ 2 mm in each direction; however, that drift disappears below noise level for centered beams. The beam has been simulated with a 500 MHz sine wave generator feeding a 4-way power splitter followed by four appropriate attenuators.

Conclusion

A simple design of the BPMs and their supports has been presented; it should give at relatively low cost the good absolute accuracy required by the standard closed orbit correction and also the high stability required by the position feedback. The test of an experimental electronics circuit in the laboratory showed good characteristics concerning the resolution, the stability and the current dependence. The stability performance of that circuit is based upon the association of a PIN diode switch with a detector working always at the same point. Some complementary tests on an actual machine will investigate the reproducibility of the measurements with various bunch structures and check the results obtained in the laboratory.

Acknowledgements

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