Project of a Beam Position Monitor for the ESRF Storage Ring

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Abstract

The realisation of the ESRF design objectives demands new standards of precision & reproductibility for the closed orbit correction which by consequence require a BPM system with functionality and performances of superior quality to that sofar realised :

- absolute accuracy : < 150 μm
- resolution : < 10 μm
- beam intensity range : 0.1 to 200 mA
- simultaneous measurements at all 224 stations.

The absolute accuracy should be attained directly, i.e. not relying on a reiterative process of verifications, calibrations and corrections with the beam after installation. To garantuee this particular difficult performance characteristic, all sources of error have been analysed : Qpole magnetic axis measurement, BPM block mechanical position, BPM block electrical offset and offset of electronics signal treatment.

The choice of the concept (RF time multiplexing of the 4 electrode signals) to keep these errors to a minimum and the methods used to further eliminate them will be described. The complete electronics treatment chain and the performances obtained in laboratory will be presented.

1. SPECIFICATIONS

The Storage Ring (SR) contains 224 BPM stations (7 per cell) (figure 1). This BPM system has two functions :

- to measure the beam position during the first turns
- to measure the closed orbit when the beam is stored.

First turn mode specifications

* Beam characteristics : (e- or e+)	1 to 5mA during 1μs bunch frequency :352.2MHz injection rate : 1 Hz or 10 Hz
* Accuracy (rms) :	1mm + 10%
* Resolution (rms) :	0.5mm
* Range :	horizontal plane (X) : ±25mm vertical plane (Z) : ±10mm
* number of turns to be measured :	1 to 8

Closed Orbit Mode specifications

* Beam characteristics	bunch length 20 ps rms
Multi bunch beam	1 to 200 mA bunch frequency 352.2MHz
Single bunch beam	0.1 to 10 mA bunch frequency 355 KHz
* Accuracy (rms):	0.15mm + 10%
* Resolution (rms)	10μm
* Drift	50μm for 1 day
* Range	X and Z : ± 5mm
* Acquisition duration	min 1 ms

2. SENSOR

2.1 Description

The principle of detecting the electrostatic field induced by the beam on 4 button electrodes was prefered for its simplicicty. The mechanical design is presented in figure 2. The position of the electrodes was chosen so as to have the same sensitivity in both planes (see § 2.2.2).

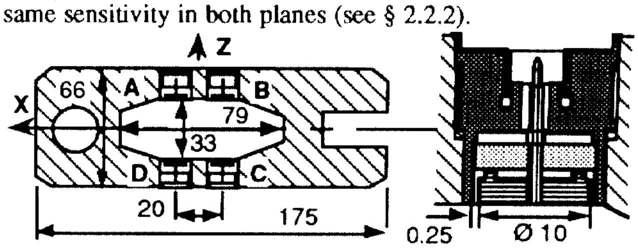

Figure 2. BPM Block and one of its electrodes

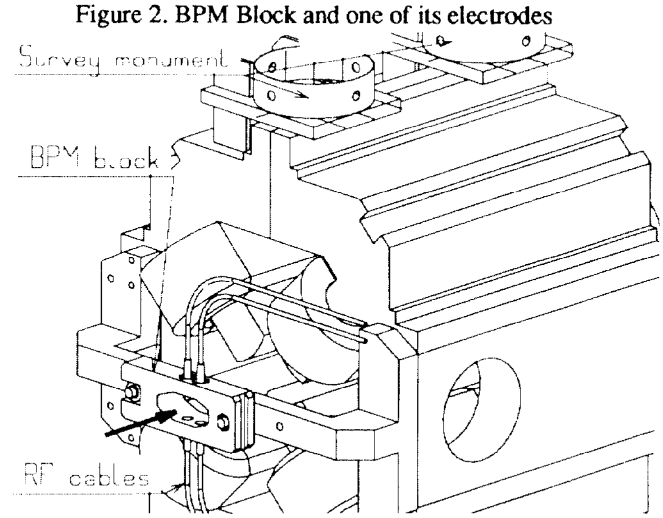

Figure 3. Quadrupole with BPM Block

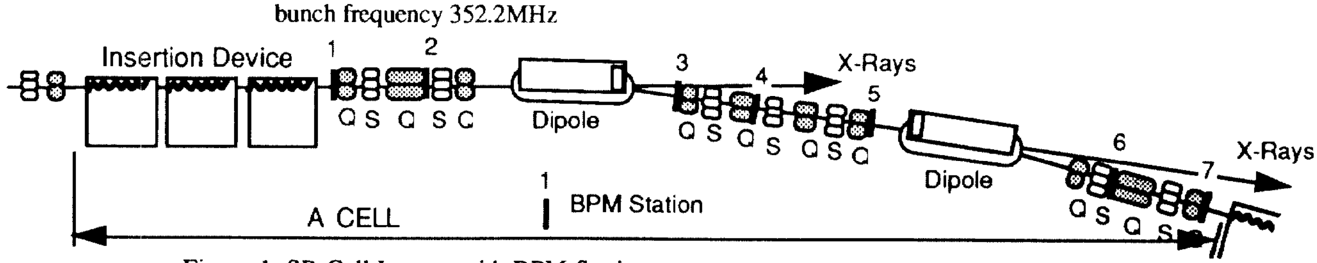

Figure 1. SR Cell Layout with BPM Stations

In order to provide the highest reliability, a button has been designed in collaboration with METACERAM [1]. It is directly welded on the stainless steel block. The capacitance button-ground was chosen at 3 pF to obtain a cut-off frequency of 1 GHz with a 50Ω load. This capacitance does not influence the button sensitivity at 352.2 MHz.

The blocks are directly fixed on the quadrupoles as shown in figure 3. They can move during the vessel bakeout. The coaxial cables can withstand the bakeout temperature.

2.2.1 Errors on the BPM block position

a - Magnetic center error (∂M)

The magnetic center of each quadrapole is measured and then defined through two survey monuments : they define a magnetic axis which passes through the magnetic center at a 450mm vertical shift. This measurement is done with an accuracy ∂M of 30μm rms

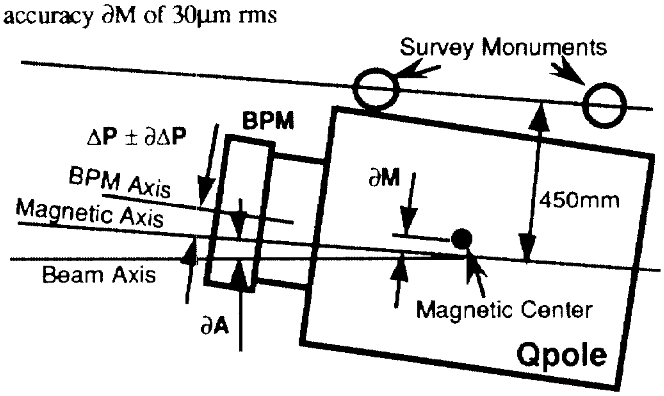

Figure 4. Errors on the BPM Block Position

b - BPM block position error (∂ΔP)

The BPM block is mechanically fixed on the yoke of the quadrapole and its position is determined by the precision of this yoke. This causes a shift ΔP between the BPM center and the magnetic axis. A special tool was used to measure the distance survey axis-BPM block for each BPM, the rms ΔP error was found to be ≈400μm. This measurement ΔP is used in the control software to correct the BPM result. The rms accuracy ∂ΔP of this ΔP measurement is estimated at 100 μm (x) and 50 μm (z).

c - Alignment error (∂A)

Although the magnetic axis is aligned on the theoretical beam axis, these two axes cannot be exactly parallel. This induces an error on the BPM block position relative to the beam axis which passes through the magnetic center. This error ∂A is estimated at 50 μrms.

2.2.2 Errors on the BPM block calibration

There are two types of errors :

a - An error due to the difference in sensitivity of the electrodes which induce a shift ΔB at the electrical center relative to the mechanical center of the block. The four electrodes of each BPM block have been measured with a special bench consisting of an antenna precisely centered (± 20μm) on the blocks axis. A precise RF voltmeter with a very symmetric multiplexer measured the difference in sensitivity of each of the four electrodes and the results are used in the control software to correct the measurement. This error ΔB was found to be about 100 μm rms, the accuracy ∂ΔB of this correction is estimated at 30 μm rms.

The relative electrode sensitivities are not expected to drift as verifications done on some blocks after having been welded on the vessel then subjected to baking-out conditions showed no significant change. Moreover, during beam operation a possible clair electrode failure can be detected by the control software which obtains the four electrode signal values.

b - An error due to the approximation of the relation between the 4 relative electrode signal strengths and the beam position. This relation has been approximated by simulating the BPM block geometry and the beam on a WINGZ worksheet (about 2000 cells of 1 x 1mm with 1000 iterations for each beam position). The so-obtained mapping of the BPM block was confirmed by laboratory measurements using a movable antenna in a BPM block.

The simple formulas (A, B, C and D are the respective electrode signals) :

$$\mathbf{X} = \mathbf{K_X}.\mathbf{P_h} \quad \text{with } P_h = \frac{(A+D)-(B+C)}{A+B+C+D} \text{ and } K_x = 15.7\text{mm}$$

and

$$\mathbf{Z} = \mathbf{K_Z}.\mathbf{P_v} \quad \text{with } P_v = \frac{(A+B)-(C+D)}{A+B+C+D} \text{ and } K_z = 15\text{mm}$$

will be used to determine the beam position in a window X=±5 mm and Z=±5 mm with an error smaller than 10%.

During the first turn tuning the beam can reach ± 20 mm in the horizontal plane in particular in the injection bump. The following formulas :

$$X = 9.5\ \mathrm{TAN}\left(0.8\left|\frac{A-C}{A+C} + \frac{D-B}{D+B}\right|\right) \text{ and } Z = K_Z P_v$$

gives sufficient precision up to X=±25mm and Z=±5mm.

2.2.3.Electrical Sensitivity

A simple computation gives the shape of the signals picked up from an electrode loaded by 50Ω. The peak value can reach 600V with a 10mA single-bunch beam and 6V with a 100mA multi-bunch beam. The electrodes yield signals with a frequency spectrum up to 10 GHz in which the 352.2 MHz component has a rms value of 0.6 mV/mA.

3. ELECTRONICS SIGNAL TREATMENT

3.3.1 Concept of RF Multiplexing and heterodyne detection

The electronics of the BPM system consists (per BPM station) essentially of a RF Multiplexer and a heterodyne detector at 352.2 MHz (the RF acceleration frequency) with a bandwidth of either 2 Mhz (First Turn(s) mode) or 3 KHz (Closed Orbit mode). In Closed orbit mode the four signals of a BPM station are being scanned in a time window of 1 mS by this multiplexer and treated by one single chain of electronics. These electronics, which perform amplifying filtering, detection and DC de-multiplexing operations on these four signals, can be relatively straight forward as any change or drift of its characteristics (like gain, bandwidth or offset) affect the four signals in the same manner. As the beam position coordinates are being calculated on the relative strength of the four electrode signals any variation in their absolute values (due to drift of the treatment electronics after the RF multiplexing point) does not affect the result of the beam postion measurement.

The narrow-band heterodyne detection at 352.2 MHz permits the system to function completely independant of bunch configuration. The only parameter which needs control in the analog electronics is its Gain which is has a range corresponding to range of beam intensity and which is being set by the control software.

While the application of this concept greatly simplifies the realisation of the electronics after the RF multiplexing point it implies that the precision of the measurement depends on the characteristics of the RF multiplexer, in particular its symmetry and the drift of this symmetry. This RF multiplexer consists of an array of PIN diodes configured as a SP4T switch (four inputs, one output) It is preceded by a four channel attenuator/filter unit (3 dB, 35 MHz B.W. at 350 MHz) which serves to avoid multiple reflections and any damage or saturation to the PIN diodes by the high peak voltages obtained from the electrodes. This unit is connected to the electrodes by four short (80 cm) cables. The required precision of the BPM system determines the maximum difference in insertion loss between these four channels which in our case comes to 0.05 dB (also referred to as symmetry of the multiplexer). This value can not be achieved easily in series production so instead the symmetry of each RF multiplexer unit was measured and is compensated for in the control software in the same way as with the other measured sources of errors (mechanic). The four RF cables and the attenuator/filter unit were included in this symmetry measurement.

Prior to the adoption of this concept it was assured through many long period measurement cycles under different temperature conditions that the symmetry of the RF multiplexer unit does not drift. The PIN diodes showed an excellent long term reproducibilty while the cables and attenuator/filter unit (being passive) do not cause any drift. The absence of any drift permits the system to completely omit calibration loops.

3.3.2. First Turn(s) mode operation

In contrast to the Closed Orbit mode when a stable beam is present during at least one mS in which the scanning of the electronics is done, the First Turn beam position measurement has to be performed on a passage of a 1 µS beam (possesing already the 352.2 MHz bunch structure). This implies the following differences : The RF multiplexer does not scan but selects one input, thus one electrode signal, which is now measured by the signal treatment electronics with a bandwidth of 2 MHz The detected 1 µs pulse is digitized by a special ADC card. For the next injection (freq. =1 or 10 Hz) the RF multiplexer selects another electrode the signal of which is being detected and digitized in the same way. In this way it takes four injections to measure the four electrode signals, any fluctuations in intensity between these different injections are being compensated by intensity measurements taken on each injection.

The revoltion time being 2.8 µs some simple additional logic permits the ADC card to be triggered on one of the first eigth output pulses from the detection electronics thus measuring, say, the third turn after injection.

3.3.3. The digital interface, network and computer control

The 224 BPM stations cover a circumference of 844 meters and are grouped into 32 cells of 7 BPMs each. Each cell has its own technical gallery where all the analog, digital and interface electronics for these 7 BPMs are housed in three Eurocard racks. Each cell has its own G64 bus, these 32 cells are linked through a Field Busnetwork which is controlled by a Field Bus master which is in the VME environment.

All the control software operations are executed here by one single CPU in this VME crate which runs under OS9.

3 3.4 Performances of the electronics

(a) Precision : The non-symmetry of the four RF cables, the filter/attenuator unit and the RF Multiplexer having been measured and compensated for and the drift of this symmetry being found neglegible (in long term lab. tests) the error contribution of the electronics is estimated at less than 30 µm rms. Even for a far-of-center beam (thus relative difference in the four electrode signals in the order of a factor of 5 or 10) the linearity of the simple detector in the treatment electronics is fully sufficient.

(b) Resolution : In Closed Orbit mode this depends on two parameters : the beam intensity and the time window of the electrode scanning (programmable between 1 and 256 ms, bandwidth respectively 3 kHz and 10 Hz). The rms resolution was measured to be less than 10 µm for beam intensities >1mA and the fastest time window of 1ms. This resolution decreases proportionally with increasing beam intensity and 'square root' proportionally with increasing time window.

In First Turn mode (2MHz bandwidth) the rms resolution is better than 250µm for injected beam intensities >1mA.

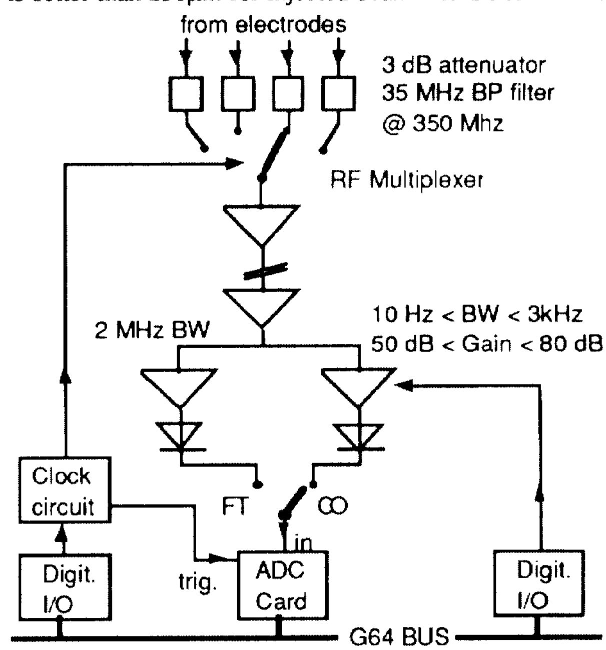

Figure 5 . Schematic BPM Electronics Block-Diagram

4. GLOBAL ACCURACY

Taking in account the different causes of errors described above, we can estimate the expected absolute accuracy of the BPM system at (rms) : ∂X = 125µm and ∂Z = 100µm .

5. REFERENCES

[1] METACERAM, 94800 VILLEJUIF, FRANCE
[2] R.Biscardi and J.W.Bittner, "Switched Detector for Beam Position Monitor", Proc. IEEE of PAC, 1989
[3] Workshop on BPM, ESRF, Grenoble, 8-9 Jan.1990