OPTIMIZATION OF THE DETECTOR GEOMETRY AND DATA PROCESSING ALGORITHMS FOR FAIR CR BPMs

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Abstract

A beam diagnostic is an important part of all FAIR accelerators and storage rings. A small flux of antiprotons in the collector ring CR (10^8 particles in a store ring) as well as dominated at first turns p-meson component of a beam require careful design for all elements of the beam position monitoring system. To increase a BPM resolution and sensitivity we propose a compact multi-electrode design of the position detector, matched low-noise electronics in connection with dedicated enhanced digital data processing algorithms. Here we present a comprehensive set of aspects of a preliminary design of the BPM system for FAIR CR.

SYSTEM OVERVIEW

The antiproton and rare isotopes collector ring (CR) is a specific component of FAIR. It is designed for conditioning of crude assemblies of particles with large initial transversal emittance and wide energy spectra. The estimated beam intensity for antiprotons is 10^8 particles in the ring. For rare isotopes only the highest intensity is specified as 10^{10} stripped ions in the ring. Geometrical constrains of the beam position monitor chamber are

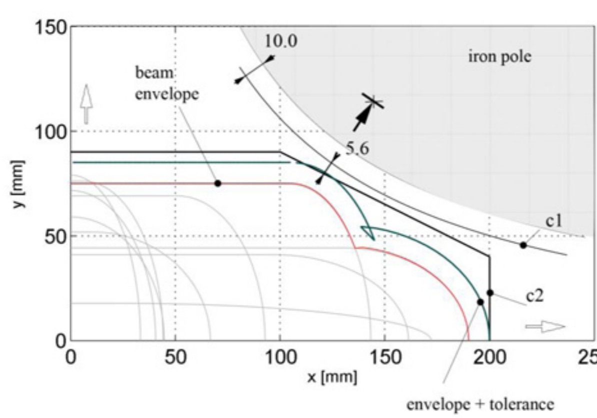

Figure 1. Geometrical constrains for the BPM chamber and electrodes design. c1 – the inner surface of the vacuum chamber, c2 – electrodes.

shown on 0. This figure shows the possible beam profiles and their envelope. Due to the limited space BPM chambers must be installed inside of quadrupole magnet so the chamber's outline must follow the inner shape of the yoke.

NUMERICAL MODEL OF THE BPM CHAMBER

A detailed investigation of the BPM antenna has been performed by numerical simulation. An electrostatic and low frequency AC approaches had been chosen according to operating frequencies and characteristic length of the system. A general 3D CAD model used for simulation of the BPM chamber is shown on 0. In this model electrodes are presented as a conducting surfaces connected to the circuit with defined impedance. A high-Z preamplifier, impedance transformer and direct 50-ohm cable connection were investigated.

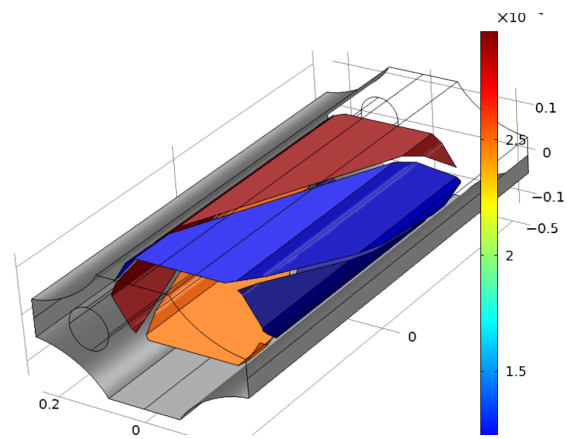

Figure 2. A 3D simulation model of the BPM chamber.

The beam of charged particles was simulated by space charge distribution. Generally the distribution is uniform in longitudinal direction and limited by volume of the circular or elliptical cylinder as it is shown on 0. Practically the charge density used in simulation was given by formula

$$Q = A(1-r)^2;\ r^2 = \left(\frac{x}{a}\right)^2 + \left(\frac{y}{b}\right)^2;$$

where a and b are semi axes of the cylinder crossection, A is a normalisation coefficient.

THE TOPOLOGY OF ELECTRODES

The signal strength and therefore signal to noise ratio important for low current measurements directly depend on effective length of pick-up electrodes. 0 on bottom schematically shows a classical design with separate electrodes for vertical and horizontal measurements. Such two modules are placed in space allotted for the BPM. The length of each section is about 40% of full dedicated length taking into account the gap required for decoupling of the vertical and horizontal sections. To obtain a higher sensitivity for CR BPM we consider a combined topology of the BPM. Because of digital signal processing it is possible to use more comprehensive algorithms for beam position detection. Particularly it allows dynamic 'reconfiguration' system consisting of four or even more

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electrodes like in the system shown on top of 0. There pairs of double length electrodes 1-2 and 3-4 are used for position detection in horizontal direction, and in same time the combination 1-3 and 2-4 gives a vertical position of the beam.

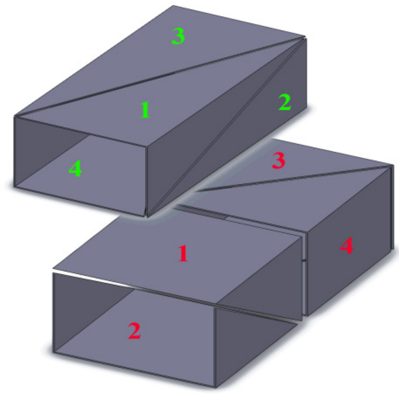

Figure 3. Combined (on top) and classical(bottom) configuration of electrodes.

GOALS AND PARAMETERS OF SIMULATION

Important functional properties of the BPM are position sensitivity, sensitivity to beam current, conversion linearity, beam shape tolerance, direction decoupling, accepted signal frequency bandwidth.

Various models of different level of abstraction using corresponding constrains were used to get an optimal result for beam position monitor system. Fig. 4 shows tools and models interconnection during entire BPM system design and optimization. Most comprehensive and time and computation power consuming 3D simulation is used for accurate simulation of electromagnetic parameters of the BPM elements. 3D model is only suitable model for quantitative analysis of the system linearity sensitivity and estimation of coupling between horizontal and vertical measurements. Results of simulation are used then for estimation of parameters of equivalent schematic. A proper schematic model is effective for analog chain design – selection of the amplification model, amplifier design, noise analysis. PSpice models of electrodes coupled to proper loads are used also for behavioural simulation of the system.

SIGNALS AND MODES OF OPERATION

Beam position monitoring distinguishes four stages – injection, debunching, stochastic cooling, extraction. For debunching stage Collector Ring has two fixed revolution frequencies for antiprotons and rare isotopes. This means that for bunched beam the frequency domain and narrow-band operation are well suited for the beam position monitoring.

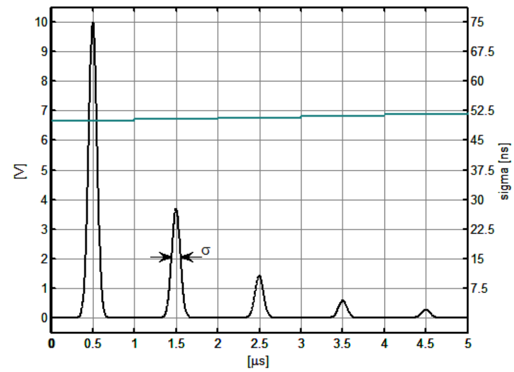

Figure 5. The signal at the beginning of antiproton cycle.

During injection the BPM system could be an important part of first-turn non-destructive diagnostics. The signal in this case is a short pulses fast decaying (see Fig.5.) due to pi-meson decay in the case of antiproton cycle. Because of the spectra of short pulse the BPM system must support a wideband operation which is achieved by using fast ADCs and data buffers of sufficient size.

The main goal of CR is a conditioning of the charged particle beam. Most of the time in the ring the beam is non-bunched and the revolution frequency signal strength is pretty low. Nevertheless the beam position still could be detected using the Schottky noise of beam current.

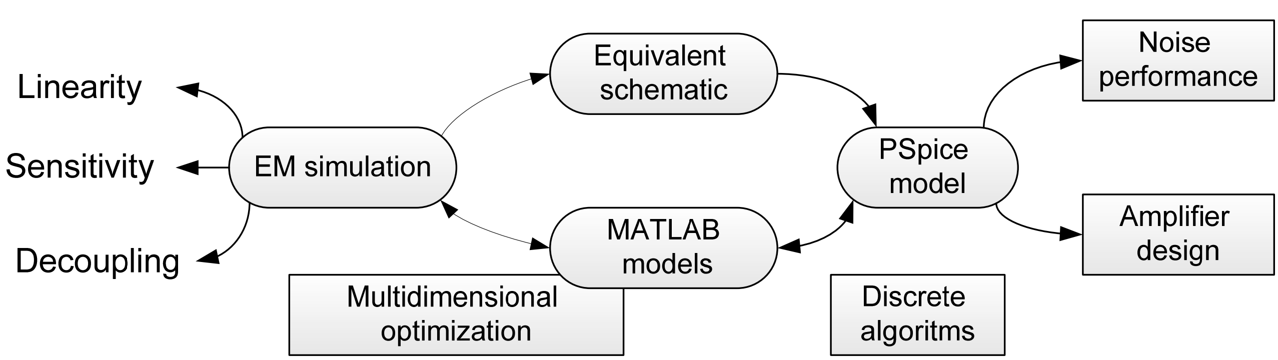

Figure 4. Design flow and models interconnection.

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SIGNAL PROCESSING

The structure of the CR BPM data processing in FPGA based processing module is shown on Fig.6. This meet to requirements of reliable evaluation of BPM data for all modes of operation. The input stage is a data deserializer from input serial ADC data stream to parallel 12-bit word. A synchronization module with adaptive phase locked loop mechanism allows compensating of all thermal and temporal instabilities of the high throughput serial receiver implemented in the FPGA. A most critical data then stored as a raw stream in the data buffer for further investigation.

The first stage is a digital down converter equipped with numerically controlled oscillator NCO. By setting the NCO frequency one can investigate different phenomena, like closed orbit position, betatron oscillation etc. The next module is a data rate decimator which is a multirate low pass CIC filter and which reduce the sampling rate down to 1MSPS per channel. 1024-point FFT module generates a new spectrum with millisecond period. The conversion time is less than 100 microsecond and same FFT module is used for all four channels by multiplexing the input data. This data is useful for low-level application, when full spectrum containing also noise data is a subject of interest. With relatively clear spectrum the data pass to the second decimator and reduced down to several samples per millisecond for real-time position data analysis.

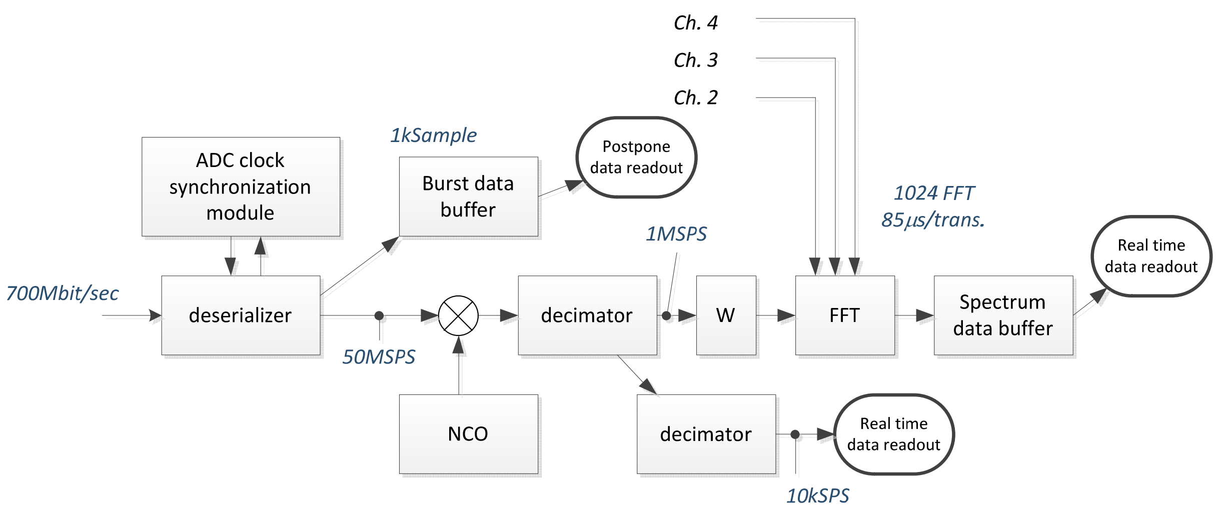

Figure 6. Data processing elements.

CONCLUSION

A large amount of simulation work has been done to optimize every component of BPM system of the FAIR collector ring. It was proved that performance of the whole system is sufficient for operation under nominal eam parameters condition. Further work will be an optimization of mechanical design, estimation of design tolerances, prototyping of the antenna and signal chains.
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