DESIGN STATUS OF BEAM POSITION MONITORS FOR THE IFMIF-EVEDA ACCELERATOR

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Abstract

The IFMIF-EVEDA accelerator [1] will be a 9 MeV, 125 mA CW deuteron accelerator which aims to validate the technology that will be used in the future IFMIF accelerator. Non-interceptive Beam Position Monitors pickups (BPMs) will be installed to measure the transverse beam position in the vacuum chamber in order to correct the dipolar and tilt errors. Depending on the location, the response of the BPMs must be optimized for a beam with an energy range from 5 up to 9 MeV and an average current between 0.1 and 125 mA. Apart from the broadening of the electromagnetic field due to the low-beta beam, specific issues are affecting some of the BPMs: tiny space in the transport line between the RFQ and cryomodule (MEBT), cryogenic temperature inside the cryomodule, phase and energy measurement in the diagnostics plate (DP), and debunching and big vacuum pipe aperture at the end of the high energy beam transport line (HEBT). For this reason different types of BPMs are being designed for each location (MEBT, cryomodule, DP and HEBT). In this contribution, the present status of the design of each BPM will be presented, focusing on the electromagnetic response for high-current low-beta beams.

INTRODUCTION

The design of the beam position monitors for the high-current low-energy accelerator IFMIF-EVEDA is facing important challenges due to the broadening of the electromagnetic detectors, the radiation environment and the debunching along the line, as described in [2]. The main use of the beam position monitors will be the monitoring of the transverse position of the beam centroid along the accelerator by calculating the differential signal from the vertical and horizontal pair of electrodes of the device. This parameter will be used to correct the dipole errors of the different elements and transport safely the beam along the accelerator. In addition, the bunch phase will be also measured in order to tune the rebuncher and the superconducting cavities. Last but not least the beam position monitors in the diagnostics plate will be in charge of measuring the mean energy of the particles by using the Time of Flight technique. The BPMs are expected to provide sufficient phase accuracy (using the sum signal) for this measurement.

The main beam parameters in which these monitors will work are summarized in Tab. 1. In normal operation, the accelerator will work with CW beams but during commissioning time the beam will be mostly pulsed with low duty factors. Therefore, both CW and pulsed operation has to be foreseen during the design phase. For a proper design of the monitors a first rough estimation can be done by implementing simple analytical models. However, powerful 3D electromagnetic software should be used for a more careful optimization of the geometry, the monitors response and the coupling to the beam. Presently these tools are being used for the design of the monitors all along the accelerator. The status of the design will be presented hereafter.

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Table 1: Range (approx.) of the Beam Properties for the BPMs at IFMIF-EVEDA

Beam parameter	**Min. Value**	**Max. Value**
Energy E (MeV)	5	9
$\beta = v/c$	0.0727	0.0975
Peak current I_b (mA)	10	125
Average current $\langle I_0 \rangle$ (mA)	0.1	125
Pulse length T_p (ms)	1	CW
Duty factor (%)	0.1	CW
Bunch length σ_z (ns)	0.1	1.7
Transverse size $\sigma_{x,y}$ (mm)	1	20

LAYOUT AND REQUIREMENTS

Global Layout

Figure 1 sketches the distribution of the different types of beam position monitors inside the accelerator. A total of 18 monitors will be placed on the accelerator, distributed in at least four types of monitors (see Tab. 2) due to the different requirements at each section as detailed hereafter.

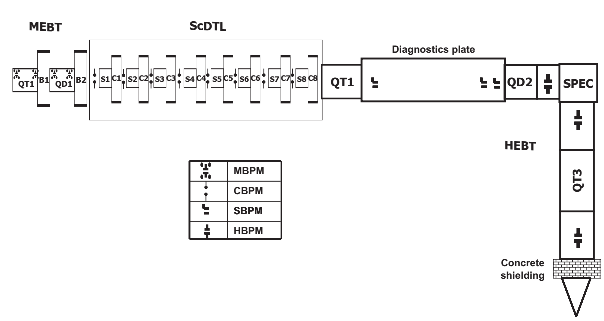

Figure 1: Distribution of the Beam Position Monitors along the accelerator.

Table 2: Summary of BPMs at IFMIF-EVEDA

Beamline	Aperture	Number
MEBT	48 mm	4
scDTL	50 mm	8
D-Plate	100 mm	3
HEBT	130 – 200 mm	3
TOTAL		18

Matching Section

Due to the beam dynamics requirements and the compactness of the beamline, the Beam Positions in the line between the RFQ and the cryomodule (MBPMs) will be located inside each quadrupole, like done for the SPIRAL2 project [4]. To maximize the charge induced in the electrodes, lobes are used instead of buttons. The mechanical assembly is simplified by using capacitive electrodes instead of striplines (either shorted or matched). The latest will make more complex the design and assembly of the monitor inside the quadrupoles. Small coaxial connectors -i.e. SMA- will be used as electrical vacuum feedthroughs to limit the mechanical interference with the poles of the quads.

Cryomodule

The BPMs inside the cryomodules (CBPMs) are located between each superconducting Half Wave Resonator and superconducting solenoid. The most important criteria to choose the proper monitor in this area is the reliability of the assembly. For this reason, button feedthroughs used for other accelerators will be installed in this area. To maximize this criteria the same button feedthroughs installed at the LHC [5] have been chosen as first option. They provide a 60° subtended angle in the center of the button (button diameter of 24 mm and the same vacuum aperture.

Diagnostics Plate

Apart from helping to the transport of the beam, the BPMs in the DP (SBPMs) are devoted to measure accurately the beam phase in order to tune the rebuncher cavities and the superconducting cavities during the different commissioning phases of the elements in the accelerator. The other main goal of the beam position monitors in this region is the measurement of the Time of Flight between the monitors. Three monitors will be used for that purpose. Two of them will be located as far as possible from each other, and the third one very close to one of the other two. The goal of the last monitor is to limit the a priori knowledge of the mean energy of the beam. In this way the number of bunches between the monitors is known. The distance between the first two monitors can be evaluated by assuming a certain phase accuracy of the BPMs -2°- and length accuracy -100 μm-. A distance of monitors between 2 m and 3 m is chosen. That gives an energy resolution of less than 10 keV for 5 MeV and 20 keV for 9 MeV. In addition, the distance gives a safe margin in case the accuracies are worse than expected.

HEBT

Three are the main issues for the monitors in this region (HBPMs): 1) the debunching of the beam coming from the last superconducting cavity [2], 2) the big beam pipe aperture and 3) the transverse beam size [6]. The first two decrease the output signal level and the resolution of the monitors. Only the fundamental harmonic -175 MHz- will be left at the end of the beamline. The last one modifies the sensitivity of the monitor and an analytical expression has to be used as given in [7].

ELECTROMAGNETIC SIMULATIONS

To evaluate the signal response of the monitors to the IFMIF-EVEDA beam and optimize the design, several codes are being used. For a realistic 3D simulation of the model with a low-beta particle beam as excitation source, the wakefield solver inside the code CST PARTICLE STUDIO$^{\text{TM}}$ is used. It provides the time response of the monitor to a certain pencil beam. The main results obtained are summarized in the following.

CBPMs

The sensitivity of the BPMs is simulated with the 3D solver by moving horizontally the excitation (particle beam) and evaluating the response at each of the four buttons. Figures 2 and 3 show the results of those simulations for the Δ_H/Σ, $S_{\Delta_H/\Sigma}$, and log-ratio, S_{dB}, method respectively for the fundamental frequency and the first harmonic (175 and 350 MHz) for horizontal $x = 0$ and diagonal $x = y$ beam movements.

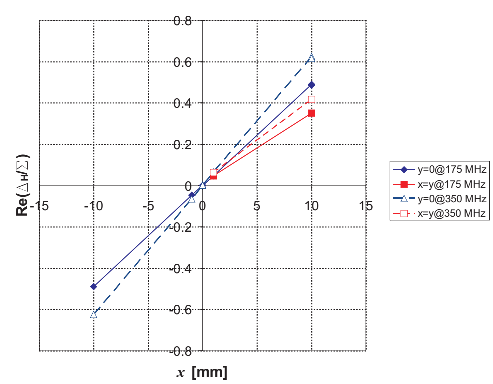

Figure 2: Simulation of the real part of the Δ_H/Σ method for the CBPM at $\beta = 0.0728$ with $\sigma_z = 15$ mm for the fundamental and first harmonic.

To crosscheck the results of the electromagnetic simulations an estimation of the log-ratio sensitivity can be given with the approximative analytical formula as given in [8].

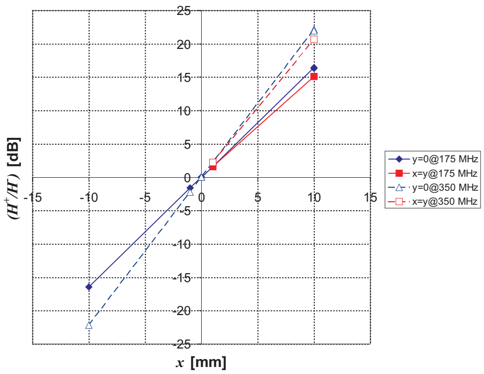

Figure 3: Simulation of the real part of the log-ratio method for the CBPM at $\beta = 0.0728$ with $\sigma_z = 15$ mm for the fundamental and first harmonic.

Table 3 summarizes the calculated horizontal sensitivities of the first CBPM at $\beta = v/c = 0.0728$ for different transfer function methods (Δ/Σ and log-ratio) [7]. The agreement between the simulated and analytical expressions is reasonable. It has to be noticed that the analytical expression is given for a cylindrical electrode and not for a button one. That could explain the slight discrepancy between the simulated and the analytical values.

Table 3: Comparison of Simulated and Analytical Sensitivities of the First CBPM for Different Transfer Fuctions

Energy E	5 MeV
Bunch length σ_b	15 mm
Simulated $S_{\Delta/\Sigma}$@175 MHz	0.0489 mm^{-1}
Simulated S_{dB}@175 MHz	1.6394 dB/mm
Analytical S_{dB}@175 MHz	1.57984 dB/mm
Simulated $S_{\Delta/\Sigma}$@350 MHz	0.0621 mm^{-1}
Simulated S_{dB}@350 MHz	2.2098 dB/mm
Analytical S_{dB}@350 MHz	2.1856 dB/mm

SBPMs

In this section the monitors require the best resolution and accuracy to achieve the best beam characterization. Stripline monitors are the present choose due to the high mechanical stability and good phase response for different beam offsets [3]. The geometry of the four lobes coaxial lines are simulated to match the dipolar and geometrical mode of the line to the external load $Z_0 = Z_{dip} = Z_{geom} = \sqrt{Z_{sum} Z_{quad}} = 50\ \Omega$. In this way the monitors could be used not only with narrowband electronics but also with broadband [9, 10]. Figure 4 shows the optimization of the angular geometry of the striplines to match the dipolar and geometrical impedances with the external load as function of the body radius (external radius of the coaxial line). The angle of the electrodes is fixed to two values: 45° and 60°, and the internal radius of the line to 50 mm. For 60° angle, the optimum is found between 64 and 66 mm.

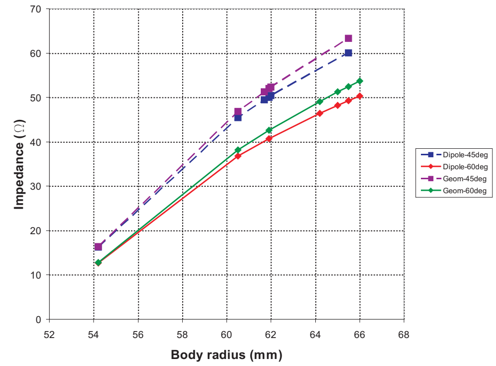

Figure 4: Optimization of the geometry of the four short-end stripline monitor.

CONCLUSIONS

Beam Position Monitors will be essential devices for the tuning and operation of the IFMIF-EVEDA accelerator. Although the low-energy affects the quality of the measurement, the simulations of the BPMs presented here have shown that they perfectly adapted for the measurement of the IFMIF-EVEDA beam. After finishing the design optimization of all the devices, some prototypes will be constructed in the next future and will be characterized in a test bench to verify the results obtained in the simulations.

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