DESIGN AND SIMULATION OF BEAM POSITION MONITOR FOR THE CADS INJECTOR I PROTON LINAC*

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Abstract

Beam Position Monitors (BPM) based on both capacitive and stripe line pick-ups are designed for the China Accelerator Driven Subcritical system (CADS) Injector I proton LINAC. The BPM will be installed to measure the transverse beam position in the LINAC, of which the beam parameters are listed as current 10mA, energy 10MeV and the repetition frequency 325MHz. This contribution presents the status of the BPM design and focuses on the geometry of the pick-ups and CST Particle Studio simulation results, including impedance, sensitivity, time domain, frequency domain response, etc. The main goal of the simulation is optimization of the mechanical design.

INTRODUCTION

The driver linac of the CADS consists of two injectors to ensure its high reliability. Each of the two injectors will be a hot-spare of the other. Although the two injectors that are installed in the final tunnel will be identical, two different design schemes, named injector I and II respectively are being pursued in parallel by the Institute of High Energy of Physics (IHEP) and the Institute of Modern Physics (IMP). The injector I proton linac is composed of an ECR ion source, a low energy beam transport line (LEBT), a radio frequency quadrupole accelerator (RFQ), a medium energy beam transport line (MEBT) and superconducting spoke cavities to boost the energy up to 10 MeV. Table 1 shows the main characteristics of the beam in injector I[1].

Table 1: The Beam Characteristics of CADS Injector I

Parameters	Value
Beam energy	3.5Mev~10MeV
Bunch frequency	325MHz
Beam pulse length	1ms-CW
Peak current	10mA

To monitor the parameters of injector I, Several beam diagnostic and monitoring instruments are used. BPM as an essential part of beam diagnostics was designed and manufactured to measure the displacement of the beam. The BPMs provide the basic diagnostics tool for commissioning and operation of accelerators. The BPMs will provide information about both the transverse position of the beam and the beam phase that can be used to detect energy on line using the time-of-flight (TOF) method [2]. 16 BPMs including 5 cold BPMs will be installed on the injector-I, which is under development in the IHEP.

This paper presents the status of the BPM design development and focuses on the design of the pick-ups and CST Particle Studio simulation results, including impedance, sensitivity, time domain, frequency domain response, etc. The main goal of the simulation is optimization of the mechanical design.

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STRIPE-LINE PICKUP DESIGN

Due to the beam energy varies from 3.5MeV to 10MeV, furthermore, the location of beam is in both normal temperature and cryostat. Two types of pick-ups are designed: the stripe line type and the button type. The stripe line type BPMs are used in normal temperature.

Mechanical Design

The stripe-line BPMs have four electrodes with one end shorted. According to the 4-electrode BPM geometry, there are four independent modes, namely a sum, horizontal dipole, vertical dipole, and quadrupole mode.[3] To optimize impedance for the sum and difference mode, one should makes the four independent mode satisfied the constraining equation. Given the symmetrical geometry, $z_{vert} = z_{horz}$.

$$R_0 = \sqrt{z_{sum} z_{quad}} = \sqrt{z_{vert} z_{horz}} \qquad (1)$$

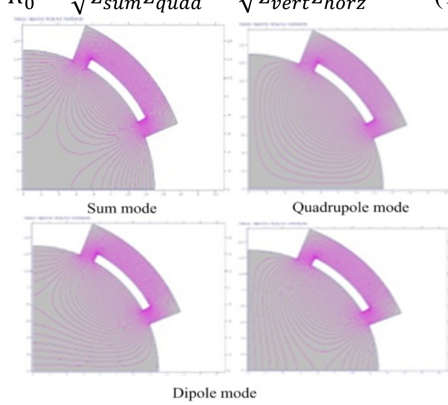

Figure 1: The four modes of one quarter of BPM geometry modelling in POSSION.

For the broadband performance, each mode must be matched to 50 Ohms. The analysis of the structures was carried in POSSION. Even through the separator is introduced to reduce the electrode coupling, it is hard to match each mode to 50 Ohms. After a series of computation in POSSION, the BPM geometry with four 32 degree electrode and 46 degree separators was

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determined as shown in Figure 2. The characteristic impedance of the geometry is 51.9 in sum mode, 50.3 in diploe mode and 49.7 in quadrupole mode. There is still small discrepancy characteristic impedance among different modes, because the weak coupling between each electrode still exists.

Due to the geometry of pick-ups and the space of the MEBT is limited. In order to save the room, BPMs are mounted directly in the quadrupole magnet as the figure 2 shows.

Table 2: The Stripe-Line BPM Specifications

Parameters	Value
Beam pipe diameter	30mm
Electron thickness	1.5mm
Electrode length	76mm
Electrode angle	32 degree
Separator	46 degree
Position accuracy	30um
Position resolution	100um

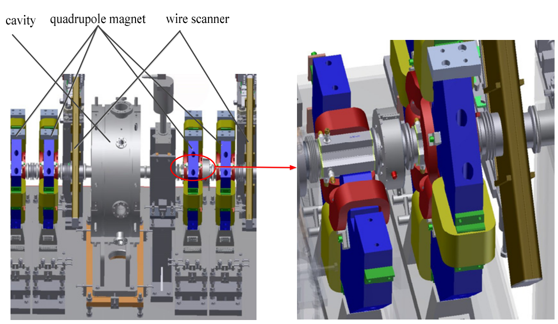

Figure 2: The position of the BPM in the injector I proton linac and the structure of BPM.

CST PS Simulation Result

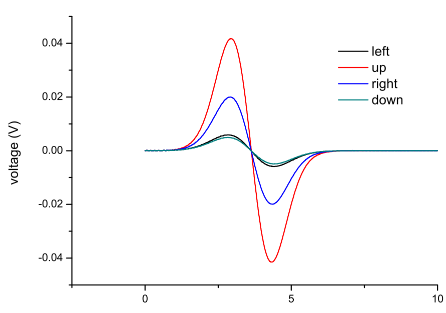

Figure 3: Voltages versus time during one period on four BPM electrodes from a passing transversely displaced (x = r/3; y =r/2) bunch.

As the geometry shown in Figure 2, numerical simulations were done by using the code CST PARTICLE STUDIO (CST PS) with the wake-field solver. The computation is finished with the help of IMP, which institute gets the copyright of CST software. The excitation source was defined by a Gaussian-shaped longitudinal charge distribution with the sigma 12mm, beam bunch charge 30.7pC, beam energy 3.5MeV. The signal induced by the beam is depicted in Fig. 3.

The simulations with the different displaced bunch were performed to get the linearity of BPM. Fig.4 gives the BPM linearity results simulated by CST PS, which are signal logarithmic ratio ln(R/L)/2 and difference-over-sum (R–L)/(R+L)[4]. From Fig. 4, it can be conclude that signal logarithmic ratio has a better performance in linearity than difference-over-sum.

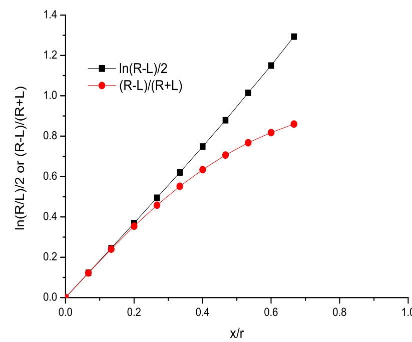

Figure 4: Horizontal ratio S of the signal harmonics at 325 MHz (top line for S =ln(R/L)/2, bottom one for S = (R-L)/(R+L) versus the beam horizontal displacement x/r, for the same vertical beam displacement y/r =0.

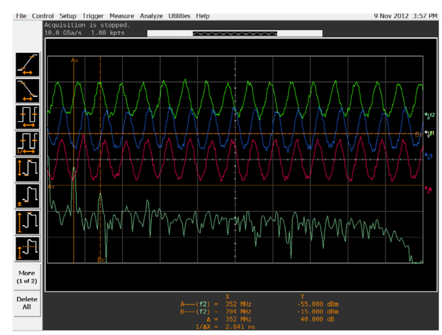

Figure 5: Output signal of the BPM on the test beam line. The bottom line is the frequency of the signal.

After calibrating on the test bench, the BPM is installed in test beam line with beam parameters frequency 352.2 MHz, energy 3.5MeV and the bunch length 25mm. the output signal of the BPM is shown in Fig. 5. The upper three are time domain signals of different electrode and the peak to peak amplitude of the signal is 12 mv. The bottom one is the frequency domain signal, in which the amplitude is -15 dBm and -55 dBm at the fundamental and the first harmonic frequency after 50 meters cable.

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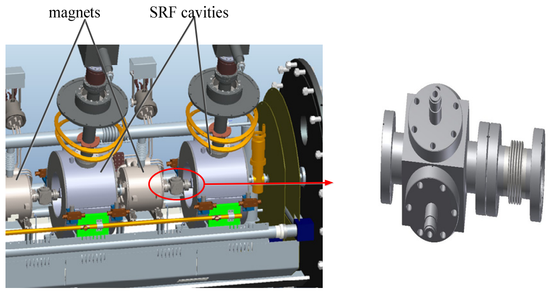

Figure 6: The position of the BPM in the cryostat and the structure of BPM.

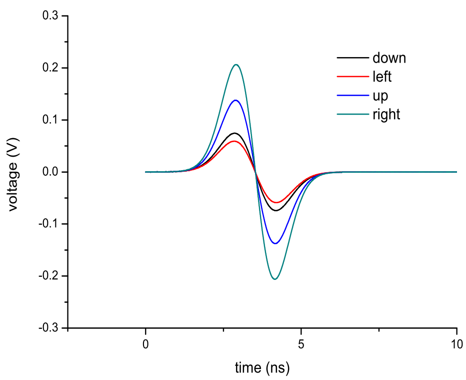

Figure 7: Voltages versus time during one period on four BPM electrodes from a passing transversely displaced (x = 2r/7; y =r/7) bunch.

THE BUTTON PICKUP DESIGN

As mentioned above, there are five BPMs for each cryostat. The button pickups are selected for cryogenic BPMs. Removable feedthroughs are used in the cold BPMs for maintenance and replacement. The button diameter is 10mm and the beam pipe is 35 in diameter. Also the cryogenic BPM is modelled and simulated in CST PS. Though the beam energy varies from the entrance to the exit of the cryomodule, we adopted the unique beam energy 3.5 MeV to compute the model. The signal induced by the beam is shown in the Fig. 7.

DISCUSSION AND SUMMARY

We optimize the stripe-line BPM mechanical design on bias of the POISSON 2-D electrostatic field computations, and the design with 4 one-end-shorted 32 degree electrodes and 46 degree separators was chosen. We simulated the model in CST PS, and the result of the computation are given include the time domain and frequency domain signal. Finally, experiment of the BPM prototype is done with the low beta proton beam in the test beam line, and the result is also shown in the paper. Furthermore, the BPM model is under fabricating. The model will be characterized after construction finishing in the future. In the other hand, the cryogenic BPMs are designed and the simulated in the CST software. More tests need be done to choose the suitable and reliable feedthroughs. The cable in the cryostat is another problem, because it is not easy to get high quality RF cables with good thermal properties. More studies, including other cold BPM test with liquid N2 temperatures will be performed in the future.

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