IONIZATION BEAM PROFILE MONITOR DESIGNED FOR CSNS*

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Abstract

A set of IPM system will be built on RCS of CSNS to measure vertical and horizontal beam profiles. Detailed conceptual design of an IPM system for CSNS is described in this paper. Wire electrodes are introduced to get a more uniform electric field, and a 'C' type electromagnet is designed to exert a uniform magnetic field to the ionization area. The magnetic field is parallel with the sweeping electric field and will inhibit the defocusing effects of space charge field and recoil momentum.

INTRODUCTION

China Spallation Neutron Source (CSNS) mainly consists of an 80MeV H^- linac accelerator, a 1.6GeV proton Rapid Cycling Synchrotron (RCS) and a tungsten target station. For the RCS，after the pre-accelerated H^- beam is stripped and injected, proton beam will be accumulated and accelerated to 1.6GeV with a repetition of 25Hz and beam power of 100kW. Different kinds of beam diagnostic devices including Beam Position Monitors (BPM), Beam Loss Monitors (BLM), Beam Current Monitors (BCM) and Beam Profile Monitors (BPrM) will be built to ensure a successful commission of RCS and to do machine studies [1]. Ionization Profile Monitor (IPM) is one type of BPrM, which has been widely applied to many proton and heavy ion accelerators, such as the RCS of J-PARC, the accumulator ring of SNS, RHIC of BNL owing to its advantages of non-destructive and fast response [2-4]. Two sets of IPM devices will be set up at CSNS-RCS to measure beam profiles, one for horizontal profile, the other one for vertical profile. The IPM devices will be located at the positions where beam acceptance aperture is 180mm×120mm (H×V) for horizontal IPM and 120mm×180mm for the vertical one. Detailed design of IPM device for CSNS-RCS will be presented in this paper.

DETECTOR FRAME

IPM uses electrons or ions formed by beam ionization of residual gas to measure beam profile. Therefore, the detector includes 3 basic parts, an electric field system to sweep the ionization particles, a magnetic field system to inhibit the defocusing effects of beam space charge field and ionization recoil momentum and a primary signal collecting and amplifying system.

Figure 1 is a schematic frame for the horizontal IPM detector of CSNS-RCS. A rectangle stainless steel chamber with dimension of 600mm in width and 300mm in height is used as the carrier of the detector. Two copper electrode plates, one for ground voltage and the other one for minus high voltage lie above and below the center of the chamber respectively. Uniform electric field is generated between these two plates. Next to the lower plate, a Micro-Channel Plate (MCP) and an anode collector board are mounted, which are insulated from the chamber. The MCP is used to primarily amplify the signal of collected electrons or ions and the board is to achieve position resolution of beam profile. An Electron Generator Arrays (EGA) is mounted behind the upper plate to calibrate the gain uniformity of the MCP. To let the electrons or ions penetrate the plate to arrive at MCP， each plate has a central hole area of 160mm×80mm covered with copper mesh. The EGA and MCP must work under high voltage. Two feedthroughs are installed on the right wall of the chamber: one is used as high voltage collecting lines insulator, and the other one as signal collecting lines insulator. A 'C' type electromagnet is also installed in the surrounding region of IPM chamber to supply magnetic filed which is parallel with the electric field.

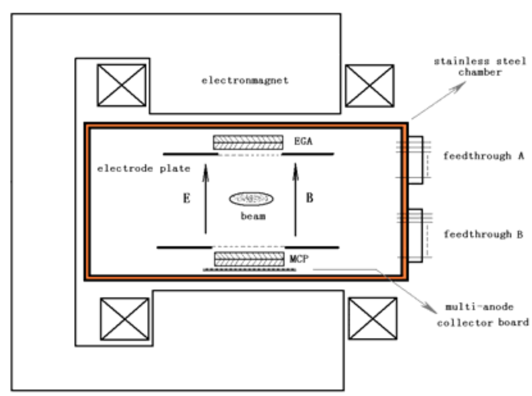

Figure 1: Horizontal IPM detector frame of CSNS-RCS.

ELECTRIC FIELD DESIGN

In our IPM design, the sweeping electric field amplitude of E_y is about 100 kV/m, which is 24 kV high voltage applied to two plates with gap of 240mm. A uniform electric field is necessary to achieve accurate beam profile measurements. Specially, the horizontal electric field component E_x which is normal to beam moving direction should be as small as possible for horizontal IPM detector. To improve the electric field uniformity between the two parallel plate electrodes, two groups of wire electrodes with diameter of 2.5mm are added in the left and right edge regions of beam

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ionization area with equal space separation respectively. Wire electrodes in each group are connected with 100MΩ resistors and fixed with 2 ceramic cylinders which connect the 2 plates. The structure of electric field system shows in Fig. 2.

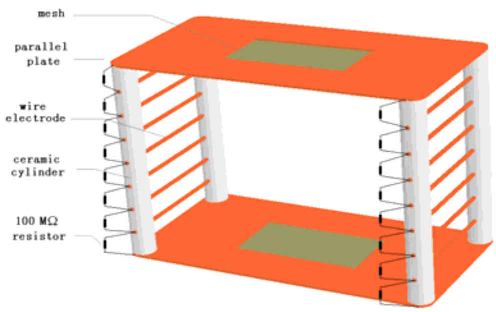

Figure 2: Schematic diagram of electric field system for IPM of CSNS-RCS.

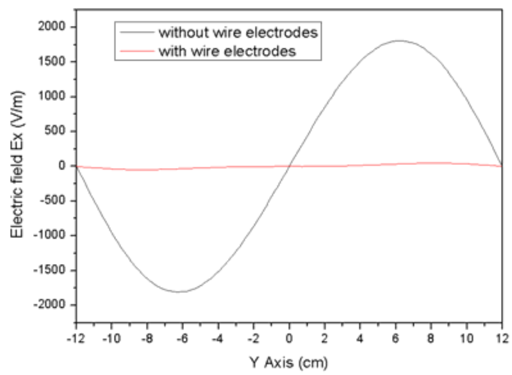

Figure 3: Calculated E_x amplitude versus y position for one edge before and after wire electrodes were added.

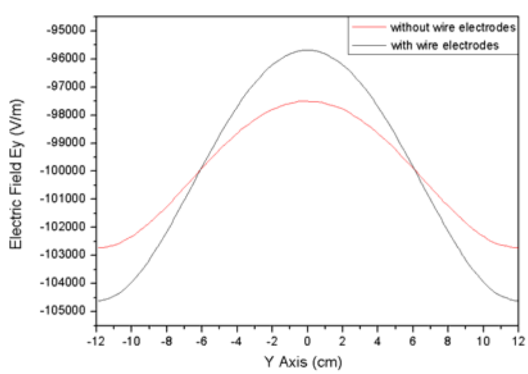

Figure 4: Calculated E_y amplitude for the edge before and after wire electrodes were added.

To verify the effect of wire electrodes, the electric field has been computed with a 3D TOSCA Electrostatic program. Figure 3 shows the calculated results of electric field component E_x on one edge of x=8cm and z=4cm in our interested area before and after wire electrodes were added. With wire electrodes added, the maximum amplitude of E_x on the edge is less than 50V/m, which is about 1/36 of the value for E_x on the same edge before wire electrodes were added. For most of the measurement area, E_x amplitude is much less than the maximum of 50V/m, which indicates that adding wire electrodes can significantly improve the uniformity of electric field and ensure accurate beam profile measurements. Figure 4 shows the comparison results of the sweeping electric field E_y amplitude for the same edge before and after wire electrodes were added.

MAGNETIC FIELD DESIGN

To save space for installing feedthroughs for signal collecting lines and high voltage collecting lines, a 'C' type electromagnet is designed to generate uniform magnetic field. The magnet field design considerations are given as follows.

Magnetic Flux Density Determination

The magnetic field is designed to inhibit the defocusing effects resulted from beam space charge field and recoil momentum of primary ionization particles. For CSNS-RCS, there are 2 proton beam bunches with energy from 80MeV to 1.6GeV and beam emittance of 350πmm·mrad at injection. Therefore, with $1.56\times10^{13}/2$ protons per brunch, the maximum space charge electric field component E_x for horizontal IPM is about 2×10^4 V/m at the IPM location. Under combined action of E_x and B, the maximum moving distance in x-direction from an electron generation point to its final impact point on MCP can be computed by

$$R = E_x m / qB^2 \ . \tag{1}$$

Designed magnetic field B_y of 0.1T will confine electron within gyration radius of 12μm, which is far less than the width of collecting anode. Therefore profile broadening from beam space charge field is insignificant.

As to the defocusing effect of the ionized particles primary recoil momentum, the inhibition of magnetic field can be calculated by Larmor radius:

$$r = \sqrt{2mE} / qB \ . \tag{2}$$

Under the magnetic field of 0.1T, electrons with primary ionization energy of 10eV will move in the range with a maximum distance of 0.1mm in x direction for horizontal IPM, which is less than the anode width of collecting board.

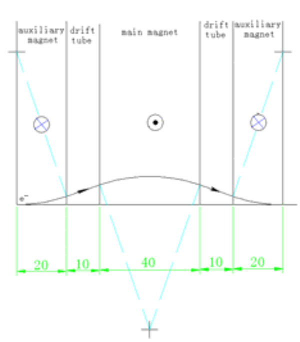

Figure 5: Schematic diagram of IPM magnets.

Beam Orbit Correction

IPM magnetic system will make beam bunches move away from designed orbit. In order to correct beam orbit deviation, two auxiliary small electromagnets are added upstream and downstream to the main electromagnet, respectively. Each auxiliary electromagnet has a magnet field opposite to main electromagnet and causes half of the beam deflection as in the main magnet of IPM. These three magnets together make beam move in a bumped orbit. The overall beam deviation by IPM magnetic field is on a level that could be corrected by other steering correctors. Figure 5 shows the structure of IPM magnets.

Electromagnet Design and Structure Optimization

A 3D TOSCA magnetic program is used as a tool for electromagnet design and structure optimization. The poles of all the magnets are 70cm in width and 15cm in height. The main magnet and the auxiliary magnets are 40cm and 20cm long, respectively. All 3 poles are shimmed and modified to improve the field quality. Figure 6 shows the magnetic field distribution of B_y on the central plane for horizontal IPM. In between -6cm and 6cm in x direction and -4cm and 4cm in y direction which beam envelop lies in, a relative deviation of B_y from $B_y(0)$ is less than 1×10^{-3} along x axis and less than 6×10^{-3} on the whole area. In the longitudinal direction, the integral value of $B_y(0)$ along z axis is zero, and the maximum integral value of B_y is less than 120 Gs·cm for the whole area, shown as Fig. 7.

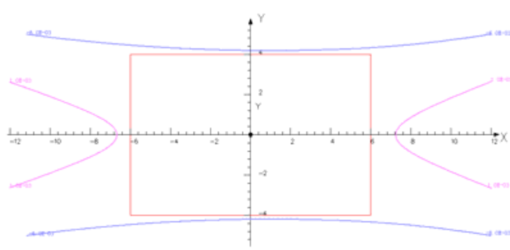

Figure 6: Relative deviation of B_y f rom $B_y(0)$ on central plane.

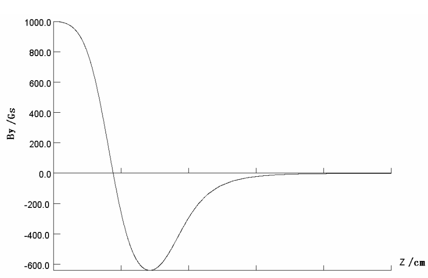

Figure 7: Magnetic field $B_y(0)$ distribution along z axis, integral value is zero.

SIGNAL INTENSITY

The energy loss of high-energy particles from the ionization of surrounding medium can be calculated by Bethe-Bloch formula [5]:

$$dE/dx = 0.3071[MeV/(g\cdot cm^{-2})] \times \rho[g\cdot cm^{-3}]\frac{1}{\beta^2}[\ln(\frac{W_{\max}}{I}-\beta^2)], \qquad (3)$$

Where $W_{\max} = 2m_e c^2 \frac{\beta^2}{1-\beta^2}$, and I is mean ionization potential of the atom of residual gas. For the RCS, energy loss of a proton in ultra high vacuum surroundings is so extremely small that the signal of ionization is very weak. Therefore, primary signal amplifying device is indispensable. MCP is a good choice. A type of MCP assembly has a collecting length of 3.1cm and gain of 10^6 [6]. Under ultra high vacuum surroundings, electrons and ions are mainly the products of primary ionization. We take ionization yield of a proton under STP and energy with minimum ionization energy loss as 10 ion pairs /cm [7]. Then the total signal amplified by MCP under real pressure from a beam bunch is about 5×10^{-10}C. For single bunch profile measurement, the maximum integral time is about 500ns, and mean integral current of an anode is about 10μA, which can be easily detected.

To realize single bunch profile measurement, timing signal of RCS is employed to trigger the high voltage power supply of the sweeping electric field and signal readout devices. Beam profile could be measured with multi-channel signal readout devices.

CONCLUSIONS

Conceptual design of IPM for CSNS-RCS is presented in this paper. Sweeping electric field distribution and external magnetic field distribution are analyzed and optimized with electrostatic and magnetic models of a 3D TOSCA program respectively. The results show that wire electrodes can improve the uniformity of electric field distribution and pole shimming can improve magnetic field quality. Signal intensity is also evaluated, and mean integral current of 10μA could be easily detected.

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