CAPACITIVE LINEAR-CUT BEAM POSITION MONITOR DESIGN FOR ION SYNCHROTRON AT KHIMA PROJECT

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Abstract

The high precision beam position monitor is required to match and control the beam trajectory for the beam injection and closed orbit in synchrotron. It was also used for measuring the beta function, tune, and chromaticity. Since the bunch length at heavy ion synchrotron is relatively long, a few meters, a boxlike device with long plates of typically 20 cm is used to enhance the signal strength and to get a precise linear dependence with respect to the beam displacement. In this paper, we show the electromagnetic design of the electrode and surroundings to satisfy the resolution of 100 um, the criteria for mechanical aspect to satisfy the position accuracy of 200 um, and the measurement results of linearity by using the wire test bench.

INTRODUCTION

The the Korea Heavy Ion Medical Accelerator(KHIMA) project, a pproton and carbon therapy accelerator based on synchrotron, is currently under construction in Korea [1]. It can provide a low intensity proton and carbon beams with an energy in the range of 110 to 430 MeV/u for carbon beam and in the range of 60 to 230 MeV for proton which corresponds to the water equilibrium beam range of 3.0 to 27.0 g/cm^2 [2].
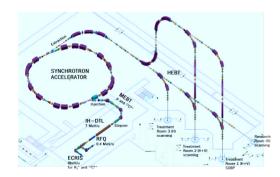

Figure 1: The layout of KHIMA accelerator.

The accelerator consists of the injector with RFQ and IH-DTL linacs, medium beam transport line, synchrotron, and high energy beam transport line. The high precision beam position monitor, which has a position resolution of $\sim$ 100 um, is required to match and control the beam trajectory for the closed orbit in synchrotron.

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ELECTROMAGNETIC DESIGN

Since the beam intensity after the injection and capturing process in the synchrotron is low, $\sim 7.4^8$ particles for the carbon beams and $\sim 2.07 \times 10^{10}$ for the proton beams [3], the design of the beam position monitor which has the position resolution of 100 um and accuracy of 200 um is critical. The linear-cut beam position monitor was chosen to satisfy this requirements and it has the large linearity range [4]. The linear-cut beam position monitor consists of the two metal electrodes, the body for maintain the structure of the electrode, holders for combining the body with the vacuum chamber, and the vacuum chamber. The transverse and longitudinal dimension of the beam position monitor is limited because it would be installed inside the steering magnet. In order to increase the signal strength, the transverse dimension of the electrode was kept as large as possible within a limited chamber size. The 3D drawing of the designed beam position monitor is shown in Fig. 2.

Figure 2: 3D drawing of the beam position monitor.

Since the cross-talk between two electrodes determines mainly the position resolution of the beam position monitor, the distance between two electrodes is investigated to achieve lower cross-talk value that is shown in Fig. 3.

As shown in Fig. 3, the cross-talk is almost saturated when the distance between the electrodes is larger than 5 mm. Then the distance between the electrodes is determined to be 6 mm to achieve the cross-talk of less than -40 dB within an operation frequency of the beam position monitor from 0.48 MHz to 3 MHz.

The linearity of the beam position monitor is also calcu-

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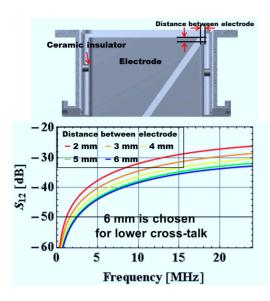
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Figure 3: Cross-talk(S_{12}) as a function of the distance between two electrodes.

lated by using CST-PS with the impedance of the 50 ohm that is shown in Fig. 4 [5].
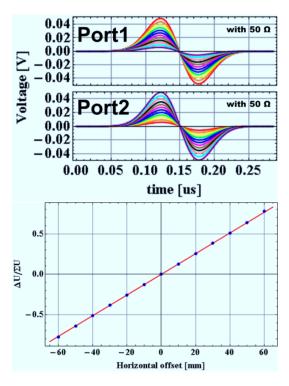

Figure 4: Linearity of the beam position monitor.

The beam position is determined by the ratio of difference and sum of the signals generated by the two electrodes that is given in Eq. 1.

$$x = a_0 \frac{\Delta U}{\Sigma U} + a_1 = a_0 \frac{U_{left} - U_{right}}{U_{left} + U_{right}} + a_1, \qquad (1)$$

where a_0 is coefficient which is proportional to the trans-

verse dimension of the electrode, a_1 is coefficient which presents the mechanical central position, the U_{left} and U_{right} are voltage output from the left and right electrodes, respectively. In our case, the Ideal values of a_0 and a_1 are 72 mm and 0 mm, respectively. Due to the internal structure, such as the insulator and surroundings, the beam position monitor, however, has the a_0 and a_1 coefficients of 78.10 mm and -72.7 um. It is enough to satisfy the target position accuracy of 200 um.

FABRICATION AND MEASUREMENT

The gap between the electrode and body is 8 mm to increase the signal strength by reducing the capacitance of the beam position monitor. The triangular shape electrodes is made by copper, and the body, holder, and vacuum chamber is made by stainless steel. The alumina-ceramic is chosen as the insulator material which is used to fix the electrodes inside the body. The picture of the fabricated beam position monitor is shown in Fig. 5.

Figure 5: Picture of the fabricated beam position monitor and He leak test.

Based on the electromagnetic and mechanical design result, the beam position monitor is fabricated and the vacuum leakage is performed by using the He leak detector to confirm the the defect during the welding process to use it for vacuum pressure of 10^{-9} Torr. By this measurement, the severe leakage is not observed. The cross-talk between two electrodes is measured by using Vector Network Analyzer that is shown in Fig. 6.
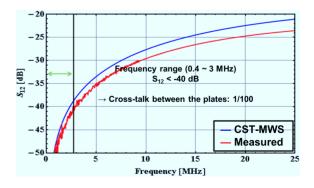

Figure 6: Measurement result of the cross-talk.

As shown in Fig. 6, the measured cross-talk is lower than the -40 dB in the range of operation frequency, $0.48 \sim 3$ MHz, which is required to achieve the target position resolution. The measured result agrees with the calculated result.

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By using the wire test bench, the signal response as a function of the offset was measured to confirm the linearity of the beam position monitor.
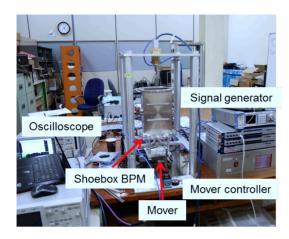

Figure 7: Picture of the test by using wire test bench.

Since the signal frequency is low then there has high frequency noise from the surroundings. Then the higher frequency noise signal is filtered by digital lowpass filter during the data processing. The most simple lowpass filter is the ideal lowpass. It suppresses all frequencies higher than the cut-off frequency and leaves smaller frequencies unchanged:

$$H(x) = \begin{cases} 1, & \text{if } x \le f_c \\ 0, & \text{if } x > f_c \end{cases} \quad (2)$$

where the $H(x)$ is the filter function and f_c is the cut-off frequency. In our case, the cut-off frequency, f_c, was set to 4 MHz to remove the high frequency noise component since the signal frequency on the wire is 3 MHz. The raw and filtered signal from the left and right electrodes are shown in Fig. 8.

The clear signal was obtained after the noise filtering by lowpass filter on frequency domain. Based on the filtered signal and Eq. 1, the $\Delta U / \Sigma U$ as a function offset in the range of -28 mm to 28 mm is calculated in order to get the linearity coefficients, a_0 and a_1 that is shown in Fig. 9.

As shown in Fig. 9, the linear response of the beam position monitor in the range of -28 mm to 28 mm with the interval of 2 mm was confirmed. The measured a_0 and a_1 coefficients are 80.64 mm and 475 um, respectively.

CONCLUSION

The electromagnetic design study of the linear-cut beam position monitor, which will be installed in the synchrotron ring of KHIMA, is performed to achieve the target position resolution of 100 um and the accuracy of 200 um. It was fabricated based on the design values and the laboratory tests, such as the vacuum leakage test by He leak detector, the measurement of the cross-talk by the Vector Network Analyzer and linearity measurement by the wire test bench, were performed to confirm the performance. The
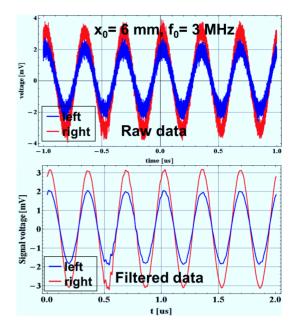

Figure 8: The raw (top) and filtered (bottom) signal with the signal frequency of 3 MHz and the offset of 6 mm.
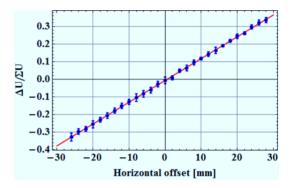

Figure 9: Measurement for the linearity of the beam position monitor in the range of -28 mm to 28 mm with the interval of 2 mm.

severe leakage is not observed and the measured cross-talk is less than -40 dB in the operation frequency from 0.48 MHz to 3 MHz. The measured a_0 and a_1 coefficients are 80.64 mm and 475 um, respectively. It agrees well with the designed parameter by the numerical simulation using code CST-MWS and CST-PS.

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