DEVELOPMENT OF BEAM PROFILE MONITOR FOR CYCLOTRON*

K. H. Park #, W. W. Lee, Y. G. Jung, D. E. Kim, H. G. Lee, S. M. Hong
Pohang Accelerator Laboratory, POSTECH, Pohang, 790-784
B. K. Kang, Department of Electrical Engineering, POSTECH , Pohang, 790-784
J. S. Chai, Y. S. Kim, D. H. Ahn Cyclotron Application Laboratory, KIRAMS, Seoul, Korea

Abstract

A current sensor module was designed and fabricated to measure the beam profile of the cyclotron MC50 at KIRAMS. The sensors were made of a tungsten wire and they were assembled into an array type. The sensor wires were placed in parallel with the incident beam, while they were placed in the perpendicular direction to the incident beam in the conventional method. The current output of each sensor was amplified using a trans-resistance amplifier. The front-end stage of this amplifier was implemented using discrete circuit elements and can measure input current in the range of 1 pA to 1 μA. The amplifier had a resolution of ~ 20 fA and the temperature drift of ~ 0.5 pA/°C. Various test results of the amplifier and sensor module assembly are given in this paper. The measured current profiles of cyclotron beam line at KIRAMS are also given.

INTRODUCTION

To perform a successful experiment using the beam flux, it is important to measure the exact beam position and intensity. These beam characteristics were measured at many laboratories using the wire-scan method [1-2]. In the wire-scan method, the beam position and intensity are measured using a sensing wire or an array of sensing wires, which is placed inside the vacuum chamber. The wire picks up the beam current when it crosses the beam. When the wire is scanned across the beam, the beam position and intensity are obtained from the measured output current of the wire. To the present, all sensing wires were placed in the perpendicular direction to the incident beam, as shown in Fig. 1(a). The wire in this configuration measures the average beam current along the wire and it is difficult to obtain the beam position accurately, although various arrangements of wires were investigated to increase the measurement precision or to reduce the scan time or direction. This problem can be overcome if the wires were placed in the configuration shown in Fig. 1(b). In this new architecture of the beam profile monitor (BPM), an array of sensor wires was placed in parallel with the incident beam. Each wire detects the beam intensity at the given position. So, by scanning the array vertically, whole beam profile can be determined accurately.

The current from the each sensor wire was converted into the voltage by the cascode differential amplifier (CDA) and the voltage was digitised to determine the beam properties. When we use the commercial amplifiers such as the OPA128 from Burr-Brown Co. and the LMC6001 from National Semiconductor Co. for the beam detector, the circuit becomes very simple but it is difficult to achieve desired properties for the amplifier. A trans-resistance amplifier was designed to measure the positron beam intensity at the beam-line of cyclotron MC50. To measure an ultra low input current, it was implemented using a CDA. The CDA was built using n-channel junction field-effect transistors (JFETs) [3] and works as a front-end stage of the preamplifier for the wire sensor. The output of CDA was amplified to 20dB using an instrumentation amplifier at the second stage.

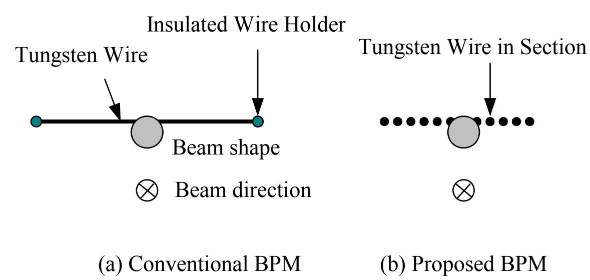

Figure 1: Shows conventional BPM and proposed BPM.

In this paper, the proposed sensor module assembly and a design of trans-resistance amplifier are described. The measured beam profile at the cyclotron MC50 at KIRAMS is shown.

BEAM PROFILE MONITOR

The BPM consists of the sensor module, the multiplexer and precision amplifier, and the data acquisition computer module, as shown Fig. 2. Twelve wire sensors are assembled into a sensor module. The output current of each wire sensor is multiplexed to select one at a time. The multiplexer was fabricated using the 9011 miniature reed relays from COTO Technology, which has an insulation resistance higher than 1 TΩ. A higher insulation resistance was required to minimize leakage current because the output current of the wire sensor is in the range of pA.

* Work supported by Ministry of Science and Technology of Korea.
# pkh@postech.ac.kr

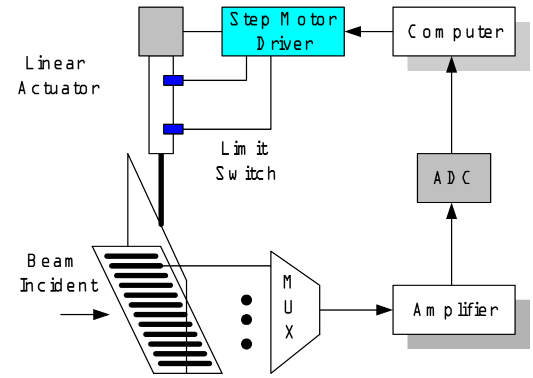

Figure 2: A block diagram of the beam profile monitor.

The sensor module was mounted at the end of rod of a linear actuator BLM-275-4 from MDC Co., as shown in Fig. 2. The linear actuator moves the sensor module from the dormant to measurement position or vice versa. The travel length is about 100 mm. The required thickness of a copper plate to block a 50 MeV incident beam flux is ~ 6.7 mm. To shield the incident beam, the sensor wires were installed behind a 12 mm thick copper plate, as shown in Fig. 3.

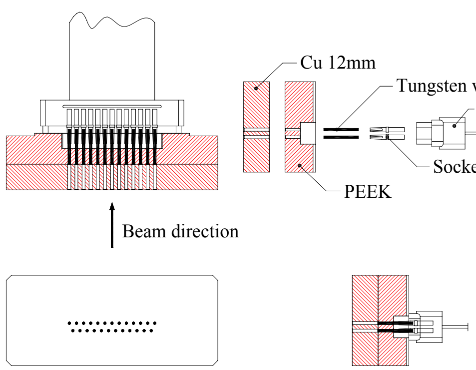

Figure 3: Decomposed sensor module.

The copper plate has 25 through holes for detecting the incident beam. The diameter of each hole was 1mm. The sensor module assembly was aligned such that the direction of holes and wires was parallel with the incident beam. Thus, some portions of incident beam can pass through the holes and reach the wire sensors, which are located behind the copper plate and aligned with the holes. The wires were installed on a PEEK polymer plate for electrical insulation, which was attached behind the copper plate. The overall configuration of hole was a dual-in-line configuration, which matches a commercial 25-pin D-shell type connector.

TRANS-RESISTANCE AMPLIFIER

The trans-resistance amplifier designed for the beam current detector is shown in Fig. 4. It uses a CDA as a front-end stage. The CDA has the following advantages; it keeps the drain-to-gate voltage V_{DG} low and prevents breakdown of JFET. The input conductance of CDA is reduced to $g_i = g_{gs1} + 2g_{gd1}$ because of the Miller effect, and the gate leakage current of the input JFET is minimized. Here, g_{gs1} and g_{gd1} are the gate-source and gate-drain conductances of the input JFET.

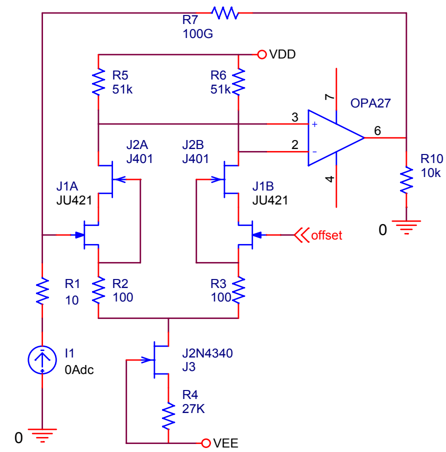

Figure 4: A circuit diagram of the trans-resistance preamplifier.

The CDA was implemented using a JU421 dual JFET from Vishay Inc. because it has a low gate leakage current. The specified gate leakage current of JU421 is 0.2 pA in maximum at $V_{DG} = 10$ V and $I_D = 30$ μA. The gain of CDA is defined as $A_{vc} = (v_{d1} - v_{d2})/v_{id} = -g_{m1}R_L$. Because $g_{m1} = 0.3$ mS for JU421 and $R_L = 51$ kΩ, the CDA has a voltage gain of ~ 23 dB. The open loop gain of the operational amplifier OPA27 is 117 dB. Thus the two-stage preamplifier provides a total open-loop gain A_{OL} of ~ 140 dB. It is very close to the simulated value of 146 dB using PSPICE. The loop gain T is close to A_{OL} if $R_i \geq R_F$. When R_i = 3.4 TΩ and R_F = 0.1 TΩ, Z_i becomes ~ 10 KΩ, which is much smaller than that the output resistance of the open-circuits wire-cut sensor. The output resistance of the wire is very high like open circuits.

EXPERIMENTAL RESULTS

To check the variation of amplifier gain due to a temperature drift, a constant input current of ~ 4.86 nA was applied to the amplifier using the 6430 Sub-Femto Source meter and the measured output voltage was observed. The measured output voltages were converted into current values and the results are shown in Fig. 5. This experiment was performed for a time period of 12 hours. The temperature change during the 12 hr period was ~ 3 °C. From the Fig. 5, one observes that the measurement error due to temperature drift is ~ 0.5 pA/°C and the resolution for current measurement is better than 20 fA.

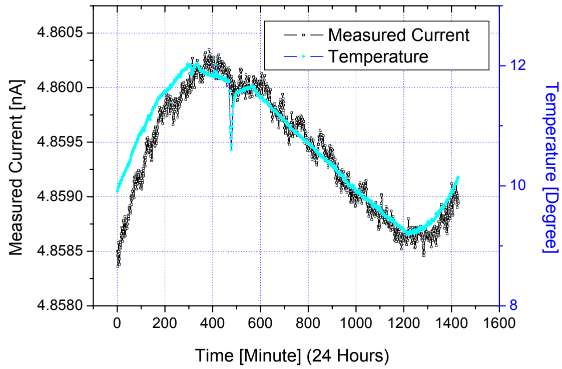

Figure 5: Amplifier drift due to a temperature variation.

The beam profile of the MC50 beam line at KIRAMS was measured using the proposed sensor module and amplifier. The detected beam current profile, which was measured using one sensor wire at a cyclotron beam current of 50 nA, is drawn in Fig. 6. The scan time from the start to finish corresponds to a scan length of 40 mm. The measured shape is a normal distribution, as expected. Because any post signal processing had not been performed on the measured signal, some noise current is observed.

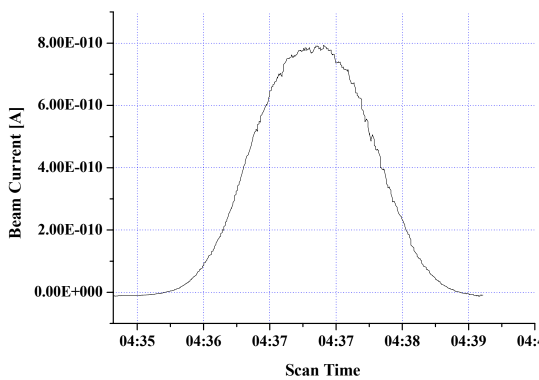

Figure 6: Measured beam profile at the beam line when cyclotron current set to 50 nA.

The linearity of the BPM was tested and the results are given in Table 1. From this result, one observes that the linearity of BPM was fairly good.

Table 1: Results of the BPM linearity test.

NO	Beam current of the cyclotron MC50 [nA]	Detected peak current at the beam line [nA]
1	50	0.7908
2	100	1.5751
3	200	3.3082

The whole beam profile measured with the BPM at the beam line of cyclotron MC 50 at a current of 60 nA was shown in Fig. 7. The peak current of 4.527 nA was sensed at the position where x-axis was 12 mm and depth 16 mm. The measured data were processed using a two-dimensional interpolation method in MATLAB. The profile has a little distortion at bottom, which may come from the system noise.

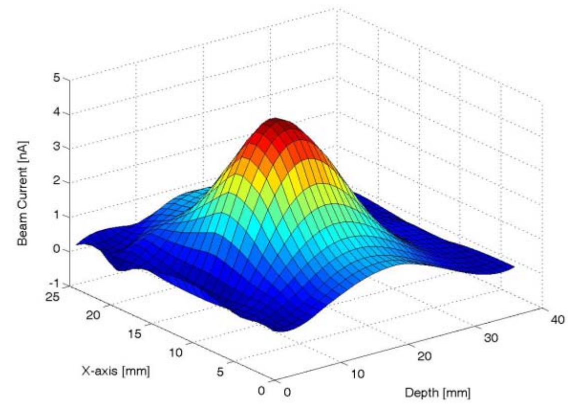

Figure 7: Measured beam profile at the beam line of the cyclotron MC50.

CONCLUSIONS

A current sensor module was designed and fabricated to measure the beam profile of the cyclotron MC50 at KIRAMS. The sensors were made of a tungsten wire and they were assembled into an array type. The sensor wires were placed in parallel with the incident beam. The current output of each sensor was amplified using a trans-resistance amplifier. The front-end stage of this amplifier was implemented using discrete circuit elements and can measure input current in the range of 1 pA to 1 µA. The amplifier had a resolution of ~ 20 fA, the temperature drift of ~ 0.5 pA/°C. The beam profile of the MC50 beam line at a current of 60 nA was measured with the proposed system. The experimental results show that the proposed system is appropriate for measuring the beam intensity of the MC50 beam line.

REFERENCES

[1] Susumu Igarashi, et al., "Flying wire beam profile monitors at the KEK PS main ring", Nuclear Instruments and Methods in Physics Research A 482 (2002) p. 32.
[2] G. Schmidt, et al., "First results of the high resolution wire scanners for beam profile and absolute beam position measurement at the TTF", Nuclear Instruments and Methods in Physics Research A 475 (2001) p. 545.
[3] A. Fazzi, et al., "Charge-Sensitive Amplifier Front-End with an nJFET and a Forward-Biased Reset Diode", IEEE Transactions on Nuclear Science, Vol. 43, No.6, December 1996. p. 3218.