DEVELOPMENT OF THE ION CHAMBER AND TRANSRESISTANCE AMPLIFIER FOR INTENSITY OF SYNCHROTRON RADIATION

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Abstract

A parallel plate ion chamber (PPIC) and a high gain trans-resistance amplifier have been built for measuring the intensity of synchrotron radiation in Pohang Light Source (PLS). The guard plates are installed at both sides of collection plate to compensate secondary electrons. The trans-resistance amplifier has been built with discrete elements and operational amplifiers. This amplifier has capability of measuring range from 1pA to 1μA with good linearity. A microprocessor was installed to interface amplifier with the computer, and control the circuits. The various characteristics of the PPIC and amplifier such as linearity, sensitivity, stability, etc. have been investigated, and its results are presented in this paper.

INTRODUCTION

In some of the experiments with synchrotron radiation, it is so desirable that the intensity of the incoming beam be precisely measured before the actual experiment [1]. A parallel plate ion chamber (PPIC) has been widely used for this purpose so far. A PPIC is composed of a high voltage electrode, a charge collection electrode and guard electrodes. A PPIC and a high gain trans-resistance amplifier have been built for measuring the intensity of synchrotron radiation in PLS. The amplifier for the low current of a PPIC is required to have ultrahigh open-loop gains to achieve the desired degree of linearity, together with ultra-low noise for good SNR[2]. Developed detector assembly had been tested for linearity, stability, and sensitivity at 4C2 beam-line in PLS, and the results were presented.

DETECTOR FABRICATION

The structure of PPIC are shown in Fig. 1 and the dimensions of electrodes in Table 1. The electrodes are made of 6061-T6 aluminum. The guard plates are fabricated in each side of collection plate to compensate secondary electrons which are produced in active area, but not arrived at collector. The insulator between electrodes is acetal resin of which volume resistance is about 10^{15} Ω-cm .

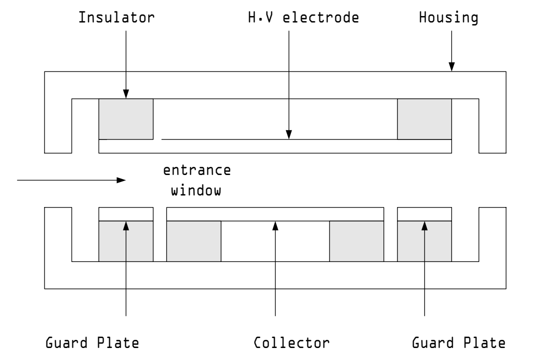

Figure 1: Structure of parallel plate ion chamber

Table 1: The size of electrode in mm

H.V	Collector	Width	separation
76.20	60.32	63.50	11.11

ELECTRONICS

The block diagram of the detector is shown in Fig. 2. The detector consists of an ion-chamber, a CPU module, a HV supply, a precision amplifier, V/F convert, and so on. The micro controller C8051F060 from Cygnal Co. containing analog and digital peripherals and on-chip RAM was used. This controller also has on-chip debug circuits, which facilitates in-circuits debugging. One of the two ADCs included in C8051F060 was assigned for reading current and the other for high voltage. The DAC used for setting the high voltage output from 0.15KV to 1.5KV. The control and monitor are possible through the RS232C.

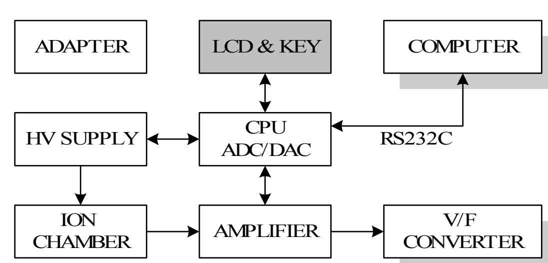

Figure 2: Block diagram of the detector.

The pre-amplifier was built with FET Cascode differential amplifier and a low noise operational amplifier OPA37. From this configuration, the open-loop gain was increased up to about 140dB. This Cascode configuration has merits: 1) it maintains a low V_{DG} on the input FET, thus the breakpoint of FET is not encountered; 2) the input conductance is reduced to $g_i = g_{gs1} + 2g_{gd1}$, so it minimize leakage current into the gate of the FET, where g_{gs} and g_{gd} are the gate-source and gate-drain conductance, respectively. In the case of general amplifier g_{gd} was multiplied by the practical voltage gain of FET amplifier instead of 2; and 3) the Miller effect can be minimized, so the input capacitance is reduced to $C_i = C_{gs1} + 2C_{gd1}$, which improve the gain-bandwidth, where C_{gs1} and C_{gd} are gate-source and gate-drain capacitances, respectively[3]. A voltage to frequency converter AD650 of Analog Devices Co. was built for the external counter where its linearity keeps about 0.01%.

The trans-resistance amplifier has seven ranges between $10^6 V/A$ and $10^{12} V/A$. The responses of the output voltage and frequency in 1pA range were shown in figure 3, using the 6430 Sub-Femto Source meter of KEITHLEY Co. We confirmed that the linearity of the amplifier is about 0.03%.

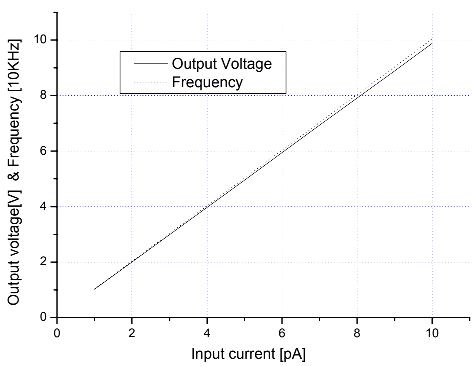

Figure 3: Output responses of the amplifier.

EXPERIMENTAL SETUP

The present experiments were carried out at the 4C2 beam-line in PLS which configuration was shown in Fig. 4. The PPIC and the current amplifier are installed on a X-Y stage controlled by the computer with precise resolution. Both high voltage output and amplifier gain of the detector were controlled by the computer through the RS232C.

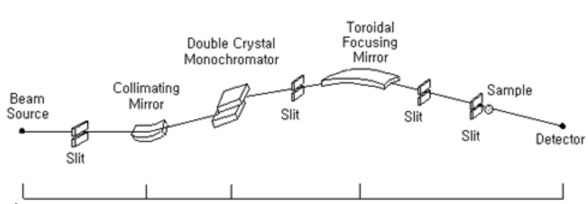

Figure 4: 4C2 beam-line configuration.

EXPERIMENTAL RESULTS

Operating Voltage

The high voltage output is increased by the step of 50V ranging from 150V to 1KV during experiment. The plateau ranges over 500V and its slope is under 3% as shown in Fig. 5. The leakage current was measured under about 0.2pA when operating voltage was set to 500V. We test the chamber characteristic in two conditions, air and He gas. Because of mass attenuation coefficient and the mean energy expended in a gas per ion pair formed, the sensitivity of He gas is measured lower than that of air.

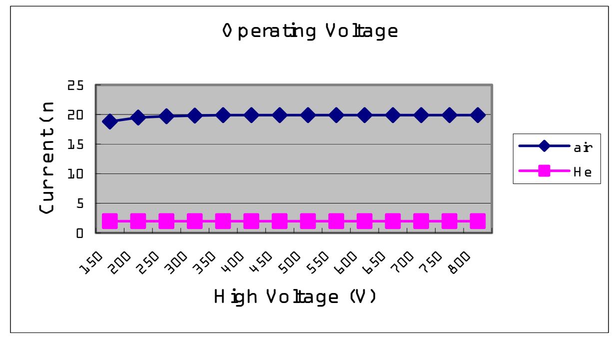

Figure 5: Measured plateau curve.

Linearity

The attenuators made of aluminum are used to measure linearity of the PPIC. Three different thickness of attenuator are tested - 18μm, 36μm and 54μm, respectively. The beam intensity penetrated through the attenuator was decreased exponentially as shown in Fig. 6. From this experimental result we can calculate that the mass attenuation coefficient of the attenuator is 54.702cm^2/g. The beam energy of 4C2 beam-line is estimated to 7.87keV using NIST data[4].

The lead collimator of which diameter of aperture is 1 mm is also used for linearity test. When the beam is limited to 0.785mm^2 through collimator, the measured current is 14.6nA. On the other hand the measured current is 38nA in the case of the uncollimated beam of which the size is 2mm^2. The ratio of two beam sizes is 0.3925 and one of the measured current is 0.3842. The deviation of 2.5% may attribute to the error of beam size.

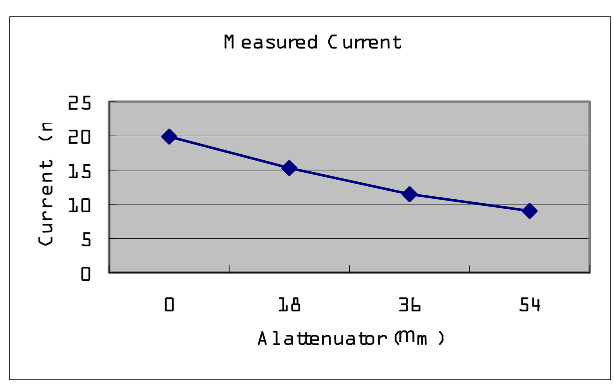

Figure 6: The results of the linearity test

Estimating Photon Flux from PPIC currents

The fraction of the photons of energy E that are transmitted between PPIC plates of length x is $\exp(-\mu(E)x)$, where $\mu(E)$ is the absorption coefficient of the gas. Therefore, the fraction of photons that contribute to the photocurrent is $1-\exp(-\mu(E)x)$. If N photons per second are incident into the ion chamber, they give rise to current $N(1-\exp(-\mu(E)x)\cdot(E/w)$, where w is the mean energy expended in a gas per ion fair formed, and is 33.97 eV in air. The absorption coefficient of air in 8keV is 1.138 x 10^{-2}/cm. Using this formula and parameters we may estimate the photon flux of 4C2 beam is 3.792 x $10^{9}/\mathrm{mm}^2\cdot\mathrm{mm}^2$.

CONCLUSION

The plateau of PPIC ranges over 500V and its slope is under 3%. When operating voltage is 500V, the leakage current is under about 2pA. The current of PPIC was proportional to beam intensity and the linearity of the amplifier was measured to about 0.03%. Using this detector assembly we estimated the beam energy of 4C2 beam-line was 7.87keV. The detector was controlled and monitored by a computer through RS232C. We are going to design a miniaturized ion chamber of 20mm long in near future using these developed circuits.

REFERENCES

[1] S.N. Ahmed, H.J. Besch, A.H. Walenta, N.Pavel, W.Schenk, “ High-precision ionization chamber for relative intensity monitoring of synchrotron radiation”, Nucl. Inst. and Meth. in Phy. Res. A 449(2000) 248

[2] J. Gustafsson, P. Kotilainen, V. Hanninen, E. Liukkonen and K.Kaski, “K130 beam current measuremnt system”, Nucl. Inst. and Meth. Phy. Res. A 342 (1994) 552-557.

[3] Boyogueno Bende, A., “A Very low-noise high-transimpedance preamplifier IC for regenerated optical data transmission systems”, AP-ASIC 1999, The first IEEE Asia Pacific Conference on August 1999. 87-90

[4] http://physics.nist.gov/PhysRefData/XrayMassCoef