Development of Position Sensitive Multi-wire Gas Detectors for Nuclear Physics Experiments

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Over the last few decades, a variety of gas detectors have been developed in BARC for use in heavy-ion induced nuclear physics experiments at Pelletron-LINAC Facility (PLF). Here we discuss about our recent accomplishment in the development of two-dimensional position sensitive multi-wire gas detectors. The position measurement has been carried out by employing delay-line read out method and the resolution is about 1.0 mm both in X and Y directions. The velocity of the fission fragments (FFs) are measured by employing time of flight (TOF) methods. Fission fragment mass distributions have been measured by employing two similar Multi-wire Proportional Counters (MWPCs). These indigenously developed detectors are the key instruments for carrying out experiments to investigate fission dynamics in heavy-ion induced reactions.

Introduction

Historically gas detectors were the first electrical devices, developed for the use in nuclear physics experiments as radiation detectors. They are economical, simple to operate and incur low maintenance cost. These detectors exhibit several advantages over the existing solid state and scintillation detectors in respect of versatility of construction, large area coverage, immunity to radiation damage and pulse height defect etc. Moreover, the flexibility in changing the detector thickness by varying the gas pressure is very useful to detect different charged particles produced in nuclear reactions.

In BARC, the nuclear physics research using gas detectors started in 1960’s with the development of a Twin gas ionization chamber for the detection of Fission Fragments (FFs) produced by using thermal neutrons from APSARA and CIRUS reactor facilities. This detector has been used extensively in several experiments for the understanding of nuclear fission process from the coincidence measurement of both the fragments along with neutrons, light charged particles, X-rays and gamma rays [1-4]. In mid-eighties, there had been renewed interest in the development of gas detectors for the utilization of heavy-ion beams from Pelletron LINAC facility PLF, BARC-TIFR. Different types of hybrid detector telescopes, position sensitive gas ionization chambers were developed in various configurations for the detection of fission fragments and projectile-like particles [5-9]. These detectors are used in studying heavy-ion reaction mechanism and fission process by measuring the mass, charge, kinetic energy and angular distributions of heavy ion reaction products [10-16].

In comparison to the ionization chambers, the gas proportional counters provide fast timing signals and are found to be suitable in high counting experiments. Since the invention of the MWPC (Multi-Wire Proportional Counters) by Charpak et al. [17], these detectors are extensively used in high energy physics experiments for particle localization. The MWPC detector has very good timing characteristics and is commonly used for the velocity measurement. Because of the good position resolution and detector efficiency, position sensitive multi-wire proportional detectors have also been used for nuclear physics experiments in different sizes and geometries, in particular for heavy ion induced fission reaction studies. In these experiments, the velocity of the fission fragments are determined by combining accurate measurement of the path length and the time of flight (TOF) by using two MWPC detectors.

The precise measurement of the fragment velocities are very crucial for obtaining the mass distribution of FFs. The accuracy of the time intervals of the signals in a pair of detectors separated by flight distances is important for the velocity measurement, and the uncertainty in the time measurement can be minimized by using two detectors having fast timing response. The mass measurement by employing the TOF technique using MWPC is more accurate in contrast to the double energy (2E) measurement by using ionization chamber or semiconductor detectors. The mass distribution is broadened significantly due to the emission of prompt neutrons in case of the double energy measurements, whereas it is less influenced for double velocity (2v) measurements. Therefore, the overall mass resolution in 2v method is better than the double energy measurements.

Development of multi-wire cathode strip detector (MCSD)

A gas filled bi-dimensional MCSD has been developed for the detection of fission fragments (FFs). The main body of the MCSD mounted inside a bell-jar setup is shown in Fig. 1. The detector has three electrode planes consisting of cathode strips, anode wires and split-cathode wires. More details of the construction of the detector and the performance characteristics have been reported earlier [18]. High impedance discrete delay line (developed in BARC) read out method [19] was employed for extracting position information in X and Y-directions.
The MCSD has been used in various experiments in PLF for the measurement of PFs produced in heavy-ion reactions. In these reactions, various projectile-like fragments (PLFs) are produced in addition to the PFs. We have operated the detector with P-10 gas (90% Ar + 10% CH₄) at a pressure of 15 Torr and the energy loss of the PFs is very small in comparison to the PFs. Thus, the PFs provide negligible signal and only the PFs are detected in the MCSD [18]. The rise time of the anode, X and Y signals were ~ 20 ns after shaping by using timing filter amplifiers. The maximum pulse heights of the signals were ~ 100 mV, after the amplification by fast amplifier (without using any Timing Filter Amplifier). Since the pulse height of the signals from MCSD were relatively small, it was not efficient enough to detect the fission fragments of lower energies.

Development of Multi-wire gas Proportional Counters (MWPC)

As the signals from MCSD are slow, these detectors are not suitable for mass distribution measurements using time of flight (TOF) method. We have developed two large area (17.5 cm × 7.0 cm) position sensitive Multi-Wire Proportional Counters (MWPCs) for the measurement of fission fragment mass distribution using heavy ion beams at Pelletron-LINAC facility, TIFR. The detectors were characterized using PFs from ²³⁵U source to obtain position information by employing delay-line read out method.

The MWPC consists of total five wire planes. It has one anode (A) wire plane, two sense wire planes (X and Y) for position information and two cathode (C) wire planes. The schematic sketch of the cathode, anode, X and Y sense wire planes, along with their geometric separations are shown in Fig.2. The separation between the anode wire plane and X (or Y) planes are 2 mm, while the separation between X (or Y) and the cathode plane is 4.8 mm. The wires were fixed on PCB board of thickness 1.6 mm. The main body of the MWPC is made of aluminum to mount all the wire planes inside it. The mounting arrangement of the wire planes and the electronic connectors inside the detector main body is shown in Fig.3.

Each wire is essentially independent and behaves like a proportional counter. The anode plane consists of gold plated tungsten (Au-W) wires having 10 μm diameter and the separation between two adjacent wires is 2 mm. Both the cathode, X and Y sense wire planes were also made of Au-W wires having 50 μm diameter and are fixed at a separation of 2 mm. The orientation of the X and Y sense wire planes are orthogonal to each other.

A Stretched Mylar foil of thickness ~ 1 μm and of size 17.5 cm × 7.0 cm was used as entrance window of the detector. The window foil was supported by stainless steel wires of diameter 0.5 mm by fixing on a PCB frame at a separation of 10 mm in both X as well as Y directions. Two gas feed-throughs were connected to the detector for operating the MWPC in gas-flow mode. The flow of the gas was maintained at a constant low pressure (2-3 Torr) by using an automatically controlled gas-flow system supplied by M/s Alpha Pneumatics, Thane, India.

### Table 1: Typical Voltages Applied to the MWPC

<table>
<thead>
<tr>
<th>Voltage (V)</th>
<th>Cathode 1</th>
<th>Cathode 2</th>
<th>Anode</th>
<th>X</th>
<th>Y</th>
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<tr>
<td>-260</td>
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<td>-350</td>
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<td>-260</td>
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Gas inlet: Gas outlet = 4.8 mm
Gas inlet: Anode = 2.0 mm
Gas inlet: X = 2.0 mm
Gas inlet: Y = 4.8 mm

Fig. 2: Schematic drawing of the vertical cross-sectional view of MWPC showing 5 wire planes. The separation and typical voltages applied to the cathodes and anode are also shown in the figure.

The X-sense wire plane has 100 wires with a pitch of 2 mm, while 40 wires of 2 mm pitch are used for Y-sense wires. We have employed the delay-line read out method for deriving X and Y position information of the detector. The delay between the successive X-sense wires is 2 ns, while that between the Y-sense wire is 5 ns. Using the anode signal as “Start” and X-signal as “Stop”, the time difference between these two signals gives the X-position of the detector. Similarly, the time difference between the anode and Y-signal defines the Y-position.
A wide band fast timing pre-amplifier (Fast PA) was used to amplify the negative anode pulses. The X and Y sense wire signals have positive polarity and were also amplified by two fast timing pre-amplifiers. We have measured the rise time of the signals with and without the timing filter amplifiers (TFA) as shown in Fig. 5(a) and (b) respectively. The rise time of the anode, X and Y signals were ~ 6 ns immediately after the fast amplifier and is about ~ 9 ns after the TFA, using suitable integration and differentiation time of about 10-20 ns.

The TOF measurements were carried out using a BaF$_2$ scintillator and a MWPC detector. The schematic diagram of the experimental set up is shown in Fig. 6. A $^{252}$Cf source was mounted on a flange inside a scattering chamber, which was evacuated to a vacuum of 10-3 Torr. For the detection of FFs, the MWPC detector was mounted on a platform inside the vacuum chamber at 54.5 cm and 85.5 cm from the source in two different measurements. The BaF$_2$ detector was mounted outside the flange of the vacuum chamber at a distance of 1.0 cm from the source. In spontaneous fission of $^{252}$Cf, about 10 prompt $\gamma$-rays are also emitted along with the FFs. The gamma rays are detected by the BaF$_2$ detector, which gives a fast signal and was used as “Start signal” for the ‘TOF experiment. After traveling the flight path in vacuum, the fission fragments reach the MWPC and lose energy in the gaseous medium. It gives a fast timing signal from the anode that was used as “Stop signal” in the experiment.

**Timing characteristics of the signals from MWPC**

The detector was tested in the laboratory with $^{252}$Cf source for the uniformity of the position readouts, and also for checking correlation between the timing of anode pulse and position (X,Y) delay-line signals. The MWPC detector has been operated with isobutene gas at a pressure of 3 Torr. The E/p ratio, was high enough (~ 300 V cm$^{-1}$ Torr$^{-1}$) to produce secondary multiplication of the primary electrons produced in the region between the cathodes and the sense wires. The secondary electrons enter the region between the sense wires and the anode. Due to the large electric field near the anode wires, it causes a localized avalanche of electrons and ions in the vicinity of the anode, which produces a fast rising negative pulse at the anode and positive signals at the sense wires.

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**Fig. 4:** Electronic block diagram of the setup used for the TOF measurement.

**Fig. 5:** (a) Pulses taken by a digital oscilloscope from the fast pre-amplifier of the anode, X and Y planes after shaping with suitable integration and differentiation using TFA. (b) Pulse shapes of the signals immediately after the fast pre-amplifier.

**Fig. 6:** Schematic diagram for TOF measurement setup.
A wide band ORTEC VT120A type fast timing pre-amplifier (Fast PA) was used to amplify the negative anode pulses. The X and Y sense wire signals have positive polarity and were amplified by two ORTEC VT120B type fast timing pre-amplifiers.

Typical anode pulses from VT120A pre-amplifier with $^{252}$Cf source were 500 mV for FFs and less than 5 mV for alpha particles. Since the anode signal is primarily used for the timing measurements of fission fragments, its output from fast pre-amplifier is directly fed to Constant Fraction Discriminator (CFD) for further processing. The timing outputs of the sense wire signals (X and Y) were about 150 mV, which were filtered through timing filter amplifiers (TFAs) and fed to CFD. After the TFA, the pulse height of the signals were about 950 mV. The output signal of the anode CFD becomes the “Start” pulse for two Time-to-Amplitude Converters (TACs) that are used for X and Y position measurements. It was also used for generating master gate pulse through a gate & delay generator (GDG). The output of the CFDs of the X and Y sense wires are suitably delayed and used as “Stop” pulses for obtaining position information from the corresponding TAC modules. The output pulse heights of both the TACs are proportional to the delay between the anode and sense wire signals, which translate the position information of the detector in two dimensions.

The linearity of the position signal has been checked by putting a mask on the face of the detector. There were 11 opening holes in X direction of the mask with 1.0 mm diameter and the separation between the center of the two adjacent holes was 10 mm. In the Y-direction, 8 opening holes of 1.0 mm diameter, with a separation of 5 mm were used. The peaks corresponding to X and Y directions are shown in Fig. 7. The mean peak position and width have been obtained by fitting the distribution with Gaussian function. The peak channel number corresponding to the center of each opening hole, has been plotted as a function of hole position (in mm), also shown in the same figure (right Y-axis). The error in the Gaussian fitting of the intensity profile and hence in the position measurement is within the size of the circle. It is observed that the position peak channels show linear behavior with the peak position. The position resolution (FWHM) both in X and Y directions are obtained from the fitting of the peaks and are found to be about $1.04 \pm 0.03 \text{mm}$ and $1.06 \pm 0.04 \text{mm}$ respectively.

The position sensitivity of the detector in two dimensions has been tested with FFs from $^{252}$Cf fission source and by putting a mask of “BARC” (acronym of Bhabha Atomic Research Centre) in front of the detector. Each alphabet of the mask “BARC” was realized in a dot matrix format by drilling small holes of 1.0 mm diameter. The center to center distance of the holes for straight portion of each alphabet is 5 mm and for the curved portions it is 2.5 mm. The 2-D position spectrum as shown in Fig. 8, gives a clear image of the acronym “BARC”, demonstrating very good performance of the detector for position measurement in two dimensions.

**Timing characteristics of the BaF$_2$ detector for gamma rays**

A BaF$_2$ detector of length 2.5 cm was used in the present experiment. It is of conical shape geometry, having 2.5 cm diameter in the front and 3.8 cm in the back face, which is coupled with a photomultiplier tube. The light output pulse from the de-excitation of BaF$_2$ has two components: one with a decay time of 630 ns and another with a decay time of 0.6 ns. The fast component only accounts for 20% of the total light output of BaF$_2$, the remaining 80% is made up by the slow component. The time resolution of the BaF$_2$ detector has been obtained by using two identical detectors and measuring the two coincidence gamma rays of energies 1.173 and 1.332 MeV, emitted from a $^{60}$Co source. Positive bias voltages (+1700 V) were applied in both the detectors using two independent HV supplies. The energy of the gamma rays was measured by amplifying the signal using a shaping amplifier. The output pulses from the BaF$_2$ detectors were found to be sharp, in having rise time of ~ 3.2 ns and amplitude of around 500 mV. The pulse was directly fed to CFD without any shaping and amplification. The output pulse from the CFD of one BaF$_2$ was fed to the “Start” of the TAC and the pulse from the CFD of other BaF$_2$ was delayed through a delay box and eventually given to the “Stop” of the TAC. The time resolution (FWHM) obtained for the BaF$_2$–BaF$_2$ detector system in this experiment is about $233 \pm 6 \text{ps}$. 
Measurement of the TOF and velocity distribution for fission fragments from $^{252}$Cf

For the TOF measurement, one of the MWPCs is mounted inside a scattering chamber on a rotatable arm of the chamber with one of its ports extending outside the chamber and the fission source ($^{252}$Cf) is mounted on its flange from inside (see Fig.6). A BaF$_2$ scintillation detector placed outside of the flange that detects the prompt gamma rays emitted from the fission fragments. Fig. 6 depicts the schematic diagram of TOF setup. The path length from fission source to MWPC is 54.5 cm. and the experiment has been repeated for 85.5 cm path length of the fission fragments.

The prompt gamma rays emitted from the fission fragments were measured by using a BaF$_2$ scintillation detector in coincidence with the signals from the MWPC. The TAC spectrum was obtained by using the “Start signal” from the BaF$_2$ and “Stop signal” from the anode of the MWPC detector. The measurement was repeated by extending the flight path to 85.5 cm, using a stainless steel tube of known length of 31 cm. From the known path length and measured TOF, the velocity was obtained after processing the event by event LIST mode data and calculating the flight path by using the following equations:

$$D = (x^2 + y^2 + d^2)^{1/2}$$

and

$$v = D \ (cm)/\tau \ (ns)$$

Where, the flight path (D) of the fission fragments are calculated from the known distance of the MWPC center point (d) from the $^{252}$Cf source and the position co-ordinates (x,y) in the MWPC. Here v is the velocity and ‘τ’ is the TOF of the fragments.

The energy signals from the cathodes were amplified by a charge sensitive preamplifier (PA) followed by shaping amplifier. Fig. 9 shows the 2D plot of TOF versus Energy of the fission fragments for the flight path of 54.5 cm. It is observed in the 2D spectrum, both the fission fragment groups are clearly separated as the lighter fragments move faster than the heavier ones. The TOF distribution spectra obtained for both the distances are shown in Fig. 10. By using double Gaussian fit to the timing spectrum, we have obtained the width of the TOF distribution. It is observed that the time spread is large for the heavy fragments as compared to the light fragments due to the velocity dispersion. We have also plotted the velocity distribution data in Fig. 10 and the measurements are found to be consistent for both the distances. The mean of the most probable velocities ($V_l$ and $V_h$ respectively refer to light and heavy fragments) measured for both the distances are $V_l = 1.035 \pm 0.003 \text{ cm/ns}$ and $V_h = 1.378 \pm 0.004 \text{ cm/ns}$ respectively.

Measurement of the mass distribution of the fission fragments in heavy-ion reaction

For the measurement of FFs mass distribution employing the double velocity (2$v$) method, two identical MWPC detectors were used in an in-beam experiment at BARC-TIFR Pelletron-LINAC accelerator facility, Mumbai. Pulsed beam of $^9$Si having 154.6 MeV energy with 1.5 ns width and a period of 107.3 ns was used in this measurement. The Fission fragments produced in $^9$Si + $^{197}$Au reaction, were detected in coincidence by using two position-sensitive MWPC detectors mounted inside the general purpose scattering chamber of diameter 1.5 meter, on two movable arms as shown in Fig. 11. The anode plane was normal to the particle trajectories passing through the center of the detectors.

The target was $\sim$ 250 $\mu$g/cm$^2$ self supporting gold foil. One of the detector was placed at a distance of 55.0 cm (MWPC1) from the target ladder, while the other at a distance of 27.5 cm (MWPC2).
Isobutene gas at a pressure of 3.0 Torr was used inside the MWPCs for the detection of fission fragments. The X,Y positions, the energy loss in each of the detectors, the time difference between the arrivals of coincident fragments at the detectors and individual time of flight of the fragments with respect to RF beam bunching signal were recorded event by event. The position calibration of the detectors were carried out using the known positions of the edges of the detectors, when the events were collected in singles mode using $^{133}$Cs source.

The velocities were reconstructed from the timing and position information obtained in X and Y directions. To obtain mass distribution, the conservation of momentum was used and the velocities were transformed to center of mass frame. The mass distribution for $^{28}$Si + $^{197}$Au reaction has been obtained from the measurement of the TOF of the correlated fragments by both the MWPCs. From two dimension plot of $\Delta E_1$ (energy loss in MWPC1) and $\Delta E_2$ (energy loss in MWPC2) as shown in Fig. 12, it is clearly seen that the FFs are separated from the projectile-like fragments. The analysis procedure for obtaining velocity distribution and fission fragment mass distribution from the measurement of TOF has been discussed in a recent publication [20].

Summary and Conclusions

In summary, we have developed two different types of multiwire gas proportional detectors viz. MCSD and MWPC for the detection of FFs produced in nuclear fission. These detectors were characterized in the laboratory using $^{133}$Cs spontaneous fission source. The anode pulses from the MWPC is very fast (rise time $\sim$ 6 ns). The position information has been obtained by using the delay-line method and the resolution is about 1.0 mm in both X and Y directions for MWPC. The velocity distribution of fission fragments produced in spontaneous fission of $^{133}$Cs source has been measured by TOF method using a BaF$_2$ detector as "Start" and MWPC as "Stop" detector. Two similar MWPCs were used for studying the FFs mass distribution in heavy ion induced reactions, from the simultaneous measurement of the velocity distribution of the fragments simultaneously.

Acknowledgements:

Authors acknowledge Dr. B.V. John, Dr. B.N. Joshi and G.K. Prajapati for their fruitful discussions on this work. We are grateful to the staff of MDPS, BARC workshop for the design & fabrication of the mechanical structure of the MWPCs. We are also thankful to the Pelletron-LINAC accelerator operating staff for facilitating smooth separation of the machine during the experiment.

References: