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Study of aging properties of a wire chamber operating with high-pressure hydrogen

E.M. Maev*, V.A. Andreev, A.A. Fetisov, V.A. Ganzha, G.E. Gavrilov, A.G. Krivchitch, E.V. Kouznetsova, O.E. Maev, G.E. Petrov, G.N. Schapkin, G.G. Semenchuk, A.A. Vorobyov

High Energy Physics Division (HEPD), St. Petersburg Nuclear Physics Institute (PNPI), Orlova Roscha, Gatchina 188350, Russia

Abstract

The project for a precision measurement of the μp-capture rate (μCAP experiment) is based on an application of a multi-wire proportional chamber (MWPC) operating in ultra-pure hydrogen at 10 bar pressure. A special test setup was constructed at PNPI to investigate the MWPC performance under the expected experimental conditions. The aging studies of the MWPCs were performed with intense irradiation from an α-source (^{241}Am) and a β-source (^{90}Sr). After 45 days of continuous irradiation by α-particles no changes in the currents, in the signal shapes, and in the counting rates were observed. It was demonstrated that the MWPCs can operate without degradation at least up to accumulated charges of 0.1 C/cm wire. These irradiation conditions are much more severe than in the real experiment. During the study of the MWPC we have observed an appearance of short duration signals with amplitudes an order of magnitude larger than those of normal signals from the α-particles. The number of such signals ("streamers") strongly depend on HV. We shall continue these tests in the future with the goal of obtaining more detailed information about aging properties of MWPCs operating with high-pressure hydrogen.

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Keywords: Hydrogen; Aging; Multi-wire chambers

1. Introduction

The project for high-precision studies of muon capture in hydrogen [1] is based on an application of a special multi-wire Time Projection Chamber (TPC) for detection of the incoming muons and the outgoing decay electrons.

The idea of using the TPC as an active target for this experiment is based on the 10-year experience of work with a TPC operating in ionization mode. With these chambers, the processes of dd- and dt-muon catalyzed fusion were studied and the rate of μ-capture by ^{3}He was measured very precisely [2]. The transfer to the proportional regime was prompted by the necessity to simultaneously register the heavily ionizing particles (slow muons and recoil nuclei of μ-capture on impurities) as well as weakly ionizing particles (the decay electrons). This is possible with a gas gain $\sim 5 \times 10^3$. As the world-wide experience with using MWPCs in hydrogen at such conditions is very

*Corresponding author. Tel.: +7-812-71-46191.
E-mail address: maev@pnpi.spb.ru (E.M. Maev).

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limited [3–5] we had to carry out detailed investigations of their performance.

2. Aging studies of MWPC and TPC

The experimental studies were performed with the setup shown in Fig. 1. Two multiwire proportional chambers (PC1 and PC2) and a TPC were placed inside a vessel filled with hydrogen at 10 bar pressure. The geometrical parameters are listed in Table 1.

The chambers were irradiated with electrons from a ^{90}Sr (intensity $\sim$500 kHz) source and with α-particles from an ^{241}Am (5.5 MeV, intensity $\sim$10 kHz) source. The β-source was placed outside the test volume behind a thin (120 μm) kapton window. In the studies with α-particles, the source was placed near the cathode of the MWPC. The electrons were detected with PC1 and PC2 in coincidence, thus providing a trigger for the TPC. The signals were amplified and shaped with low-

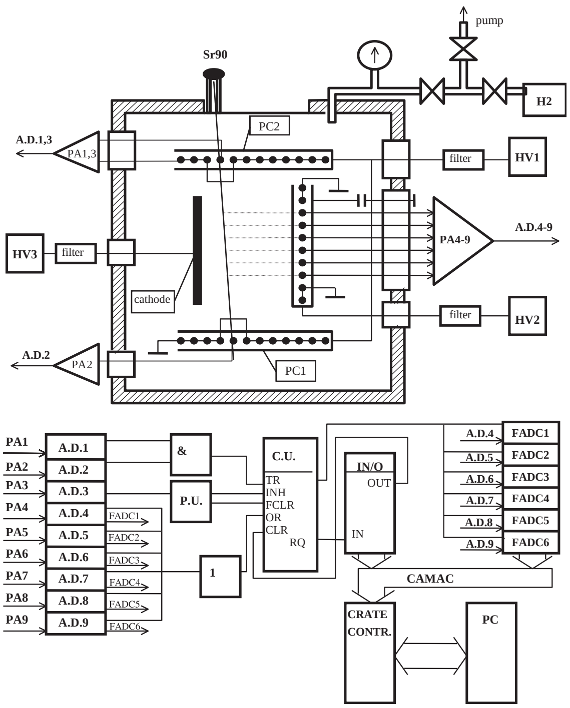

Fig. 1. The test setup for studies of MWPCs and TPC in hydrogen.

Table 1
The geometrical parameters of the MWPCs

Parameters	MWPC, variant 1	MWPC, variant 2
Wire length (L)	100 mm	100 mm
Anode–cathode gap (H)	3.5 mm	2.5 mm
Anode wire spacing (S_a)	4 mm	2 mm
Anode wire diameter (D_a)	25 μm	25 μm
Cathode wire spacing (S_c)	0.5 mm	0.5 mm
Cathode wire diameter (D_c)	55 μm	55 μm

noise preamplifiers (PA). The peaking time of the shaped signals was $T_{peak} = 100$ ns (response to a δ-function). The noise level was $\sigma_N = 300$ e. The shaped signals were sent to discriminators (A.D.). The discriminator levels for the threshold A.D. were set to $\sim$2000 e. The signals from all chambers were counted by the read-out system with a fast 6-bit 100 MHz ADC (FADC). Each FADC signal was analyzed with a special algorithm that provided the following information:

- A—amplitude of the signal above the pedestal.
- T_{start}—arrival time of the signal defined as the crossover of the fitted signal shape with the pedestal line.
- T_{stop}—the end of the fast part of the signal.
- E—the area of the signal integrated over the time interval $T_{start} \leqslant t \leqslant T_{stop}$.
- $T_{stop} - T_{start} \simeq 400$ ns.

The chambers were tested in a vessel filled with clean hydrogen at 6.5–10 bar pressure with gas contamination (N_2, O_2, H_2O) of the order of 10 ppm. The MWPCs showed stable operation up to HV = 7.0 kV providing a gas gain (GG) up to 2×10^4 and 5×10^3 when detecting relativistic electrons and α-particles, respectively. The difference in gas gains between β- and α-particles is due to the space charge effect (Fig. 2). For example, the charge in an avalanche from an α-particle is more than 10^8 electrons. In this figure the result of the absolute measurements of the integrated signal (E-value) normalized to the number of primary ion pairs ("experimental gain") is presented as a function of HV. Note, that the charge induced on the anode wire during the integration time of

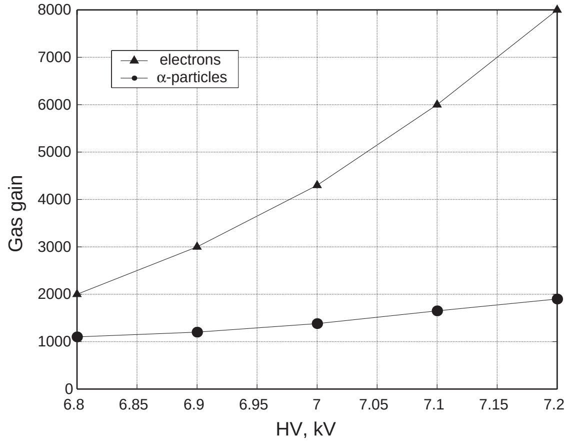

Fig. 2. "Experimental" gas gain vs. HV. Measurement with an MWPC (H = 2.5 mm, Sa = 2 mm) operating in 10 bar hydrogen gas under irradiation with an α- and a β-source.

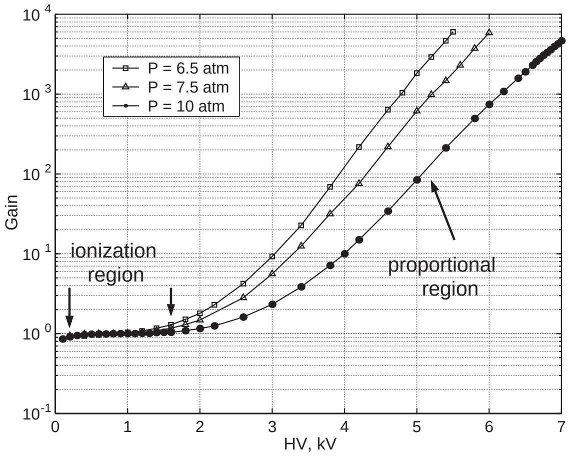

Fig. 3. Gas gain vs. HV. Measurement with an MWPC ($H = 3.5$ mm, $S_a = 4$ mm) operating in 6.5, 7.5 and 10 bar hydrogen gas under irradiation with an α-source.

about 400 ns constitutes only 50% of the total charge in the avalanche so that the "experimental gain" is expected to be a factor of two less than the full gas gain.

Fig. 3 shows the dependence of the gas gain on HV at 6.5, 7.5 and 10 bar of pressure. These measurements were carried out with the α-source. The gas gain was determined as the ratio of the current at a given HV-value to the ionization current measured at HV ~ 1 kV. The absolute current (I) was measured with a pico-amperemeter from the ionization region ($I \sim 50$ pA) to the proportional region ($I \leqslant 1$ μA). The nominal high voltage was chosen to be 6.5 kV. At this HV-value, the detection efficiency for the relativistic electrons was close to 100%.

The aging studies of the MWPCs were performed under intense irradiation from the α- and β-sources. The current from the chamber (determined by the α-source intensity and HV = 6.5 kV) was 360 nA. The maximum current from a single wire was 50 nA. These currents are comparable with the currents in the μCAP experiment with a 50 kHz muon beam. For example, the current in the entrance muon chamber will be 5 nA per wire (that is an order of magnitude less than in our tests) and in the TPC the current per wire will be about 20 nA. Note that the signals from α-particles have much higher amplitude than even the signals from the stopped muon on the wires. The main result is that after 45 days of continuous irradiation by α-particles with four intermediate gas refillings we did not see any changes in the currents, in the signal shapes, and in the counting rates. It was demonstrated that the MWPCs can operate without degradation at least up to accumulated charges of 0.1 C/cm wire.

The electron microscopic and X-ray analysis of the anode and cathode wires revealed no serious signs of destruction of the wire surfaces. However, in several radiation tests an appearance of dark currents (up to 10 μA) was observed, the nature of which is not yet clearly understood. The current explanation is an appearance of some microdeposits on the cathode wires due to some traces of oil in the pumping system.

We would like to point out one interesting effect which was observed recently during the aging studies. We have instrumented the MWPC in the test setup described above with a FADC that provided us with detailed amplitude and timing parameters of the signals. When we set the HV below 6 kV, only the normal signals from α-particles were observed (Fig. 4). However, when we increased the HV, some short-width signals, such as shown in the left part of Fig. 5, appeared.

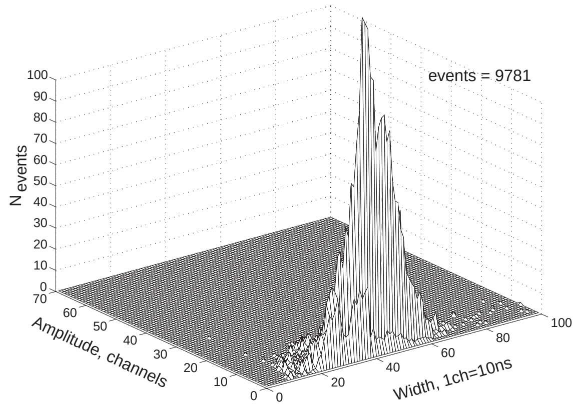

Fig. 4. The amplitude–width correlation of the signals obtained with α-source at HV = 5.9 kV.

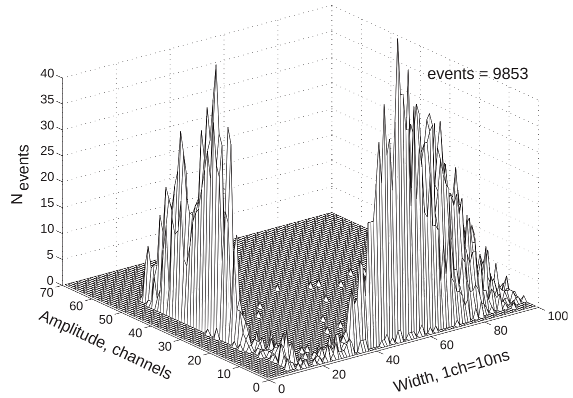

Fig. 5. The amplitude–width correlation of the signals obtained with α-source at HV = 6.5 kV.

Their amplitudes are larger than for the normal signals of α-particles (Fig. 5). Their intensity strongly depends on HV. Below 6 kV they are absent, and at 7 kV they contribute ~50% of the total number of the α-pulses. A possible interpretation of such signals might be the development of "limited streamers" when the ionization density around the anode wire exceeds some limit. This effect may be important for aging properties of the MWPCs in hydrogen, and it deserves further studies.

3. Conclusion

We conclude that MWPCs can operate reliably in hydrogen with lifetimes considerably exceeding the running time of the future experiment. Note that these studies have been done with a contamination of the hydrogen of 1 ppm just after the filling to about 10 ppm several days after the filling. We plan to repeat these studies in ultra-clean hydrogen with a concentration of impurities less than 0.1 ppm using a special circulation system.

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