1. INTRODUCTION

Thin-walled drift tubes (TDT or straws) are widely used in accelerator experiments as detecting parts of trackers at registration of charged relativistic particles, what is mainly determined by their small radiation thickness and good radiation hardness. The examples of such usage are the transition radiation detector—tracker at ATLAS Inner Detector, tracking detectors at COMPASS, LHCb and others [1–3]. Straw detectors can have large sensitive surface, high gas-tightness and are capable to operate at flushing with a gas mixture at a pressure up to 5 bar.

High pressure straw coordinate detectors are capable of operating both at a proportional or limited proportionality mode and at a self-quenching streamer mode. When registering charged particles at current detecting mode at the CERN SPS a spatial resolution of near 40 μm was achieved at a gas mixture pressure in the range of 3–4 bar [4, 5]. The article presents the results of investigation of this operation mode, as well as studying straw radiation ageing in the mode.

2. HIGH PRESSURE STRAW OPERATING MODE

2.1. Bench Setup

Straws with an inner diameter of 9.53 mm were wound by two kapton strips. The inner strip was made of carbon-loaded XC-160 foil with 40 μm thickness; the outer one was made of HN50 12.5 μm thick foil with ~0.2 μm thick aluminium coating. The straw wall thickness was ~60 μm. A gold-plated tungsten wire with a diameter of 30 μm and a resistance of 70 Ω per meter was employed as an anode.

The straw operating mode investigation was carried out at the test bench with irradiation by gamma quanta with the energy of 5.9 KeV of the Fe-55 source and by electrons with the energy of 3.55 MeV of the Ru-106 source. The straws were flushed with a gas mixture Ar/CO2 (80/20) at its absolute pressure of 3 bar.

Amplifiers based on an MSD-2 circuit with an amplification of 35 mV/μA and a rise time of 4 ns identical to those used in the radial coordinate measurement [5, 6] were used for the anode signal registration. Pulses from the amplifier output led to the analog-to-digital converter of DRS4 [7], which digitized these pulses at a rate of 5 GHz and stored signal amplitude and shape; then they were transferred to the PC for processing amplitude spectra. At registering high energy electrons from the Ru-106 source the event selection was made on the base of matching signals from the straws and a scintillator counter. The set-up scheme is presented in Fig. 1.

2.2. Investigation of the Straw Operating Mode

Straw operating modes were studied at a pressure of 3 bar within the anode voltage range of 2.7–3.2 kV, in which the spatial resolution σ was improving from ~60 to ~40 μm with the anode voltage increase [5].

It has been known that with the increase in gas mixture pressure in drift detectors the possibility of setting a mode of high current, capable to convert into a so called self-quenching streamer (SQS) mode, rises [8]. Whereas at a normal pressure, an anode wire diameter of 30 μm and a gas mixture used in the straw SQS mode is almost not observed up to the maximal possible anode voltage.

2.3. Registration of Gamma Quanta from the Fe–55 Source

The signal spectra of the Fe–55 source gamma quanta from the straw at a pressure of its gas filling of
At a voltage ranging from 2.7 to 2.8 kV the escape peak begins to merge with the total-absorption peak, which indicates a transition from the limited proportionality mode to the saturation signal mode. At a voltage of about 2.9 kV high current signals begin to appear and their quantity becomes dominating as the voltage increases up to 3.05 kV, and at a voltage of 3.2 kV the straw almost fully operates in high current mode. The spectra shown in Fig. 2 are in good agreement with the spectra from [8].

The dependence of the $\gamma$-quantum signal amplitude on the anode voltage is presented in Fig. 3. Lower curve 1 shows the signal values in the proportional mode (at a voltage below $\sim$2.85 kV) and further up to $\sim$3.2 kV in limited proportionality/saturated modes. The transition mode from low current to high current signals is observed in the range of $\sim$2.9–3.2 kV, further signals in SQS mode are observed (Curve 2). The signal amplitudes increase with respect to signals in the proportional mode with a factor up to 10.

The quantitative ratio of the low and high current signals (curves 1 and 2, respectively) and the change in the value of the straw current with the anode voltage increase (curve 3) are shown in Fig. 4. Beginning with the anode voltage of $\sim$2.8 kV the high current signals appear in amount of several percent, and at a voltage of $\sim$3.2 kV they become saturated and produce a space charge in the irradiation area, that affects the straw local efficiency. Curve 3 shows the average current in the straw as a function of the anode voltage. It is seen that in the voltage ranging from 2.6 to 3.2 kV the average current increases by a factor of 35 at a fixed
gamma-ray quantum flux, rising from ~4 up to ~140 nA. At a voltage of 3.05 kV the current increase is not more than 10 with respect to a voltage of 2.8 kV, which is in agreement with the signal amplitudes correlation in Fig. 3. The ratio of low current signals to high current ones at a voltage of 3.05 kV is 20/80%.

2.4. Registration of Electrons from the Ru-106 Source

Dependences analogue to those obtained at the registration of gamma quanta were obtained at the registration of high energy electrons from the Ru-106 source. The dependences of signal amplitudes on the anode voltage at the registration of electrons with the energy of 3.55 MeV are shown in Fig. 5. It can be seen that the transition from low current to high current signals (bottom 1 and top 2 curves, respectively) begins with the anode voltage 100 V higher than that at the registration of gamma-ray quanta.

The quantitative ratio of the low and high current signals (curves 1 and 2, respectively) and the change in the current value in the straw with the anode voltage increase (curve 3) at the electron registration are shown in Fig. 6. Beginning with the anode voltage of ~2.9 kV the increase in high current signals is observed; they come up to ~60% at a voltage of 3.15 kV.
At a voltage of 3.05 kV the ratio is 30/70%. The same ratio is observed for the anode voltage of ~2.9 kV at the registration of the Fe-55 source quanta. The point graph in Fig. 6 shows the average current value per one registered event depending on the anode voltage. The value makes 50 nA at a voltage of 3.05 kV, but it is ~2 times skewed upwards as it also comprises the average current from non-detected low-energy electrons with the energy of 39.2 KeV emitted from the source.

2.5. Summary

For the gas mixture Ar/CO₂ (80/20) at a pressure ranging from ~3 to 4 bar the straw operation is possible in the mode of transition from the limited proportionality (saturation) mode to the high current mode. With that both types of signals are registered in their stable ratio and the ratio value depends on the anode voltage. The spatial resolution of the straw in this operating mode of the detector can be improved up to ~40 μm [5]. In this case the factor of the straw current increase is not more than 10.

It should be mentioned that at registration of gamma-ray quanta and charged particles at similar values of their energy losses switching to the transient mode is observed for quanta at a lower anode voltage.

3. STRAW AGEING STUDY

3.1. Bench Set-Up

An essential factor affecting efficiency of detectors is their radiation ageing. The working medium of straws is renewed constantly, therefore the ageing effects of gas-filled detectors determined mostly by the charge accumulated in them stem from polymerization of sediments on the anode and/or the cathode as a result of possible chemical reactions with active radicals, which leads to change in the detector’s parameters.

In order to test the straws’ readiness for long-term operation in the transient mode their radiation stability was checked by X-ray irradiation at the test bench.

At the test bench (Fig. 7) there were investigated two prototypes containing 11.3 cm long straws identical to those described above. The straw of the other prototype served as a monitor detector (MD) and was used for obtaining comparative amplitude characteristics with the irradiated straw when it was tested. The monitor straw with the Fe-55 collimated source permanently situated in its middle was irradiated at a load of ~100 Hz per 1 cm of the anode length, which eliminated the risk of ageing effects. Both prototype straws were placed close to each other and were flushed under testing sequentially with the gas mixture Ar/CO₂ (80/20) at a rate of ~100 cm³/h and a pressure of 1 bar, which eliminates the possibility of difference in their gas gains due to changes in the partial pressure of the gas mixture’s components and external parameters—ambient temperature and pressure.

The anode voltage of the straw under the irradiation was 3.05 kV at an average current of ~3 μA with an average load of ~340 kHz (~30 kHz/cm of the anode length).

3.2. Results

Before the investigation began the test mode for the irradiated straw had been set at a gas mixture pressure of 1 bar and gas gain ~2 × 10⁴. The signal amplitude of the Fe-55 source gamma throughout the length of the straws was 100 mV as well as for the monitoring straw. Then irradiation uniformity with respect to the first straw length was checked by scanning with X-rays from the RT through a slit collimator. The difference in the irradiation intensity in the middle and at the ends of the straw did not exceed 15%.

With every accumulated ~0.5 C/cm of the charge in the irradiated straw it was tested by measuring the signal amplitudes and energy resolution throughout the anode length with using the Fe-55 source and these values were compared to results of the monitor straw.

For ~2600 h of irradiation the average charge per 1 cm of the straw length made 4.2 C. The final results of scanning the monitor and irradiated straws are presented in Fig. 8 by curves 1 and 2, respectively. There can be seen a low radiation ageing effect, that consisted in reduction of signal amplitude less than ~8% along the irradiated straw towards the gas mixture flow.
Degradation of the energy resolution was not observed.

The gas mixture in the irradiated straw (volume of \(~8.1 \text{ cm}^3\) at a flow rate of \(20 \text{ cm}^3/\text{h}\) was completely renewed in \(24 \text{ min}\); i.e. the irradiation of the gas in the \(1 \text{ mm}\) layer orthogonal to the anode had increased \(\sim10^3\) times by the moment of its release. It shows the possibility of increased polymerization along the straw due to low flow rate when the straw is irradiated throughout its length. Besides it may be noted that the transient mode current at the registration of gamma-quanta is higher than at the registration of minimum ionizing particles as it was described above.

Thus the results of the irradiation test with gamma quanta with energies of \(8 \text{ KeV}\) showed feasibility of the high pressure straw for the long-term operation in the transient mode.

CONCLUSIONS

The study of the transient mode between the low current and high current modes for straws filled with \(\text{Ar/CO}_2\) gas mixture at a pressure of \(3 \text{ bar}\) showed its feasibility for high-precision registration of charged particles. The transient mode does not develop in the self-quenching streamer mode at the pressure within this range and at an anode diameter of \(30 \mu\text{m}\) or less and also has high stability and enough radiation tolerance.

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