A study of aging effects in the gas-monitoring proportional counters of the BAC calorimeter in the ZEUS experiment

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The multi-cell proportional chambers in the backing calorimeter of the ZEUS experiment at the HERA storage ring are supplied with an Ar/CO_2 gas mixture by an open gas system. Flow proportional counters with built-in ^{55}Fe sources are used as gas system monitoring detectors. The results of the measurements of the aging effects of the gas-monitoring counters are presented.

1. Introduction

The problem of wire aging is as old as the use of gas detectors for particle registration [1]. The formation of the insulating layers on anode wires is still a major limitation of their use in long-term experiments [2]. The presence of an insulating deposit modifies the space-time distribution of the electric field near the wire surface where the avalanche formation takes place. It is known that aging processes depend both on gas mixture, cathode and anode materials and on the materials of detector gas system.

It was shown in laboratory tests with very pure gases and under otherwise clean conditions, that very low aging rates are obtained with the same primary gas mixtures that did not produce very good results when the gas purity was not controlled. These observations show that very small amounts of certain constituents in the gas mixture can have a large influence on aging processes. In big high-energy physics experiments in which the volume of a gaseous detector is a few cubic metres, made with various technologies and with the use of different materials, the control of the impurity level is very difficult or mostly impossible. In this case, at least a qualitative explanation of the experimental data, if not quantitative, and corresponding recommendations for the design and operation of proportional chambers should be proposed / suggested. In this report, we present the results of aging studies of monitoring proportional counters used in the gas system for the BAC Calorimeter of the ZEUS Experiment.

2. BAC - gas system

The backing calorimeter (BAC) of the ZEUS experiment at the HERA storage ring consists of over 5100 multi-cell proportional chambers (MCPC) with a total volume of about 50 m^3 placed in an iron yoke. A system of pipes feeds these chambers with the working gas mixture of Ar/CO_2. The concentration of CO_2 chosen is at a level of 10% to 15%. The gas system is open with an exhaust to the atmosphere. It exchanges the gas mixture in the BAC chambers up to a few times per day[4].

Due to the structure of the ZEUS detector the whole gas system has been divided into 79 branches. Each branch consists of about 65 proportional chambers connected in parallel. There are monitoring proportional counters both in the input of each branch and in the output of "the last chamber" of the branch, which is the chamber placed at the longest distance from the gas inlet. In these "last" chambers the worst condition of the gas exchange occurs. In total, we have 158 proportional monitoring counters (PC).

The control proportional counters [5] have the same cross-sectional geometry as one cell of the BAC MCPC (10x15 mm^2). The counters are irradiated with ^{55}Fe source with radioactivity about 10 MBq through special windows made of kapton foil, 0.1 mm thick. Gold-plated tungsten wires of 50 μm in diameter are used as the anodes. The operating voltage of the PC is the same as the HV (1780 V) applied to the MCPC of the same branch. This is equivalent to a gas gain of $\sim 7 \cdot 10^4$. The highest count rate was $\sim$ 1000 cps. The average collected charge per one day, per one centimeter of anode wire was 0.1 mC/cm/day. Spectra of ^{55}Fe - line (MnK$_\alpha$ - 5.9 keV) from all PC were collected four times per day.

The topology of the full gas system and of one branch is presented in Figs. 1 and 2, respectively.

The materials used in the construction of the detector itself and of its active gas system are among the most critical items that may affect the lifetime both of the MCPC and of the PC. This is because many plastic materials may outgas and the resulting contaminants are transported within the active gas flow, and may be deposited directly on the surface of electrodes or may lead to the growth of deposits in the vicinity of the irradiated regions. For obvious reasons, the use of glues, plastics and other organic materials is unavoidable in most particle detectors.

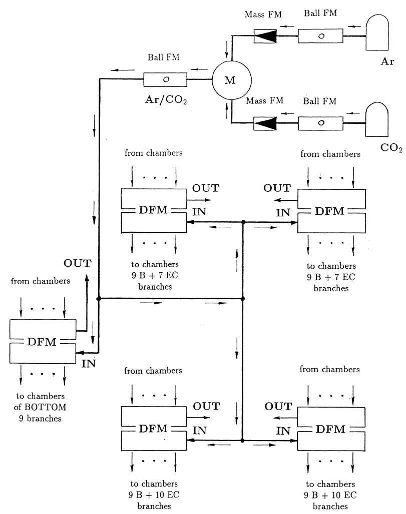

Figure 1. Schematic presentation of the BAC gas system. Its topology follows the structure of the ZEUS detector. FM - flow meter; M - mixer; DFM - differential flow meter; B - barrel of ZEUS detector; EC - end-cap of ZEUS detector. For details see Ref. [3].

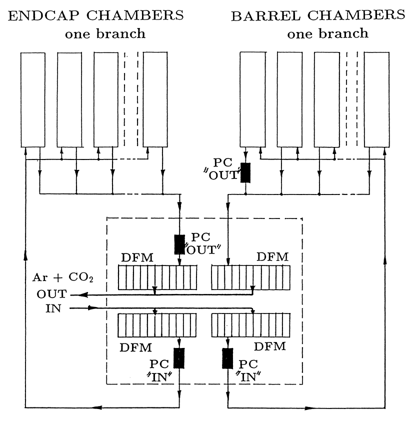

Figure 2. Block scheme of the allocation of monitoring proportional counters (PC). PC "IN" - monitoring proportional counter in the input of the branch. PC "OUT" - the same but in the output of the branch or in the output of "the last chamber".

2.1. Materials used in the BAC and its gas system

The working gas Ar/CO_2 is transported from the tanks to the mixing machine through stainless steel pipes, 25 m length. The mixing machine is made of stainless steal and brass valves, mass- and ball-flow meters with rubber o-rings, and of pressure gauges.

Many of them may contain silicon or another type of lubricant or seal. For example, GYROLOK connectors commonly used in the gas system contain plenty of Si vacuum oil, and in practice, it is not possible to clean them to the required level. The MCPC are fed with the gas by both Cu (25 m in length) and plastic Rilsan pipes (5 m in length). For detector construction the Araldite AW 106 and Hardener HV 953 glue have been used. Plastic pieces have been used to provide anode wire and pad location and fixation. Signal from the anodes are fed through printed circuits on a G 10 board [6].

3. Aging of monitoring counters

In the BAC calorimeter, there are 79 input and 79 output counters. For all these counters the pulse height distributions of ^{55}Fe line were measured during counter operation. Typical spectra representative of all the input and output counters used and for a same number of pulses, are presented in the Figs. 3 and 4 [7].

As can be seen, the characteristic behavior of degradation for the output counters is dramatically exhibited by the deterioration of the ^{55}Fe X-ray spectrum on the lower energy side of the main peak, Fig. 4. The left peak side becomes nearly exponential, the escape peak disappears and even an extra second peak is created. These observations are in a good agreement with those presented in Refs. [1][8][9].

It should be pointed out that the aging of the input counters is absolutely different from the aging of the output ones. An unexpected peak degradation is visible (Fig. 3). The undesirable changes in pulse height distribution appear on the higher energy side of the main peak.

The change in energy resolution as a function of collected charge per unit length of anode wire was also monitored. It was found that for both "IN" and "OUT" counters, degradation in energy resolution occurs at very different paces. For some counters, a small degradation was observed after 200 days of counter operation, while for others the energy resolution exceeded 30% (collected charge only 2 mC/cm) after a few days.

Some "IN" and "OUT" counters were left without HV for up to six months in air and for all of them an improvement in the pulse height spectra was seen. This effect strongly depends on the air moisture. The accumulation of water in the counter after exposure to the air leads to significant improvements of its energy resolution. Flushing the counter with dry working gas reproduces the aging effects. A similar improvement of analog response can be achieved by passing part of the counter gas through a bypass bubbler, which allowed us to add water vapour to the working gas.

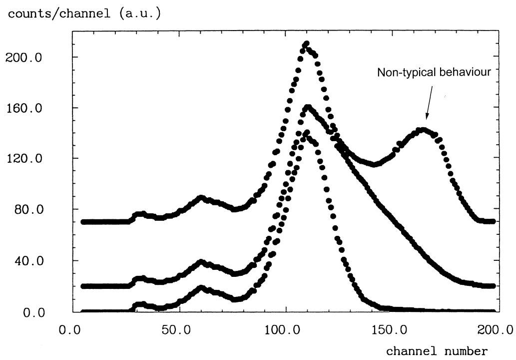

Figure 3. Averaged spectra of the ^{55}Fe - line for the "IN" counters. In comparison, the pulse height distribution for the new counter in the branch is given (the lowest curve). The two upper curves correspond to total collected charges of 15 mC/cm and 30 mC/cm, respectively. To distinguish between curves, the pulse height distributions for aged counters are arbitrary shifted in y-direction (two upper curves).

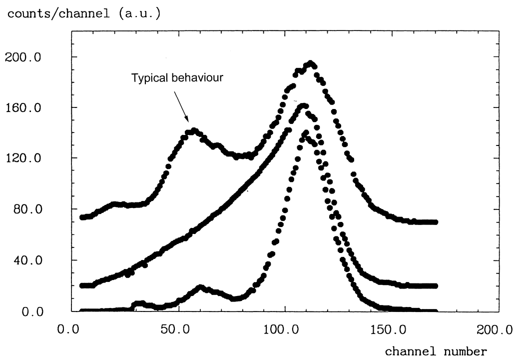

Figure 4. The same as Fig. 3, but for "OUT" counters.

4. Discussion

For all "OUT" counters there was a reduction in pulse height. The ^{55}Fe peak degraded as shown in Fig 4. Initially, the main peak dropped until the appearance of a second peak. This is a typical behavior of aged counters and is caused by the formation of insulating polymer layers on the anode wire. The gas passing these counters contains the vapours released by the construction element of the chambers. The deposits should be an image of the distribution of incoming radiation with respect to the sense wire [10]. The second peak corresponds to the radiation absorbed between the detector window and anode surface where the electrical field strength is reduced. The influence of water admixtures on aging phenomena has also been discussed in the literature [2]. Whereas there is some controversy about the eventual reduction of aging speed by water, in general there is an agreement about the improvement of analog response. The water tends to increase surface conductivity.

However, for all "IN" counters an increase in pulse height was observed. The ^{55}Fe peak degraded as shown in Fig 3. Initially, the main peak heightened up to a point where a second peak appeared. This is non-typical behaviour. The detailed analysis of the anode surface for both "IN" and "OUT" counters were made using an X-ray fluorescence method. On the anodes of both "IN" and "OUT" counters the following elements were identified: Si,C,O,Cl,S. In addition, results of the element analysis of the anode surface show the presence of Cu on the "aged anode" of the "IN" monitoring counters only. No Cu was found on the surface of the anode of "OUT" counters. This is the only difference found in element analysis between "IN" and "OUT" aged anodes. One can expect to find Cu in the form of CuO. The following process leading to an increase in gas gain is proposed:

$$CuO + h\nu \text{ (from the electron avalanche)} \\ \rightarrow (CuO)^{+} + e^{-}$$

The liberated electron contributes to the growth of the electron avalanche. The ionized $(CuO)^{+}$ leads to a local increase in the anode potential. Thus, one has an increase in gas gain and a deterioration in the energy resolution. The CuO itself is hygroscopic, which can explain the "self-regeneration" of aged counters kept in a humid environment.

5. Conclusions

The conclusions are based on the analysis of aging phenomena of 158 monitoring proportional counters.

• In laboratory tests [7] it was found that up to a collected charge of 1.8 C/cm no changes in the counter operation were observed; however, for some counters in the "real system" a degradation in energy resolution was observed after collecting a charge of 2 mC/cm. After nine months of operation and a collected charge $\sim$ 30 mC/cm, one hundred counters were aged and exchanged.

• All of the input counters were aged in the same way. A strong deformation of the ^{55}Fe spectrum on the right side of the main peak appeared.

• All of the output counters were aged in the same way. A strong deformation of the ^{55}Fe spectrum on the left side of the main peak appeared.

• Keeping the counters in moist air or adding water vapour to the working gas leads to temporary improvement of their analog responses.

• The closed-loop and the open gas-detector system should be flushed with clean working gas as long as possible (minimum 3 months) before applying high voltage to the detector.

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