A long-term aging study of honeycomb drift tubes for the HERA-B Outer Tracker using a circulated and purified CF_4 gas mixture

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The Outer Tracker of HERA-B uses a gas mixture containing CF_4 to obtain high electron drift velocities. The high cost of this gas makes it necessary to circulate the gas mixture which must then be purified to avoid accumulation of air and pollutants. However, the usage of gas purifiers poses the danger of outgassing pollutants from the purifiers themselves into the gas stream. Purifiers could also be attacked chemically by the aggressive products from the cracking of CF_4 molecules in the plasma avalanches of the detector. This could potentially release further harmful pollutants into the gas stream. To test for such effects, a long-term irradiation study of about 3000 hours was carried out with the honeycomb drift tubes that are used in the Outer Tracker. This provided a check of the long-term stability of the gas purifiers before putting them into operation for the full-size detector. We report on the experimental setup, procedures and obtained results.

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1. Introduction

The HERA-B experiment was designed as a fixed-target experiment with a high interaction rate (up to 40 MHz) to be achieved by a high bunch-crossing rate (∼10 MHz) and up to four interactions per bunch crossing in several targets. Under those conditions the Honeycomb Drift Tube Chambers (HDC) that comprise the Outer Tracker (OTR) would have to withstand a high particle rate of about 10^5 $cm^{-2}s^{-1}$ in the hottest area. Because of the 96 ns bunch-crossing time at HERA-B a fast counting gas providing a sufficient electron drift velocity is needed. A gas mixture of $Ar/CF_4/CO_2$ with the ratio 65:30:5 provides the required drift velocity as well as maximum hit and track efficiencies in CF_4-based gas mixtures for the specific conditions of the OTR[1].

The total gas volume of the OTR is about 22 m^3 and due to the relatively high price of CF_4 (∼ $40 per kg) economy requires a recirculating gas system. A closed-loop gas system has the disadvantage of increasing the air contamination of the gas volume due to unavoidable minute leaks in detector and gas system. In contrast to an open gas system, the contamination will accumulate within a closed gas system and the gas has to be constantly purified. The design details and performance of the OTR gas system are described in [2]. Any gas purifier to be included in a gas system could be chemically attacked by aggressive pollutants from cracked CF_4 and release further harmful pollutants into the gas stream. Consequently, one has to carefully verify the stability of such gas purifiers before using them in a gas system for a full-size detector with an expected running time of several years. Here we describe such a study performed with a small-scale setup that simulates the OTR and its gas system[3].

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2. Experimental test setup

The study was performed with a standard aging setup using a small honeycomb detector module and only moderately accelerated irradiation conditions ($\sim$ factor 2). We paid special attention to a very clean gas system avoiding any materials that are known to outgas following the guidance provided in Refs. [4,5].

2.1. Honeycomb test-module

A small-scale HDC of 40 cm length, mounted into a clean, gastight box made of aluminum, was irradiated with X-rays from an X-ray tube with Cu-anode running at 20 kV. The box was covered with a thin aluminized Mylar foil serving as a window to hold back air and diffusing water from the surrounding atmosphere while allowing radiation to enter. Gas was flushed through the gas box at 1 volume/h and entered the drift tubes via diffusion through open endpieces on both ends of the drift tubes. The module was constructed in the same way as the final modules for the OTR, except for the shorter drift tubes and a smaller number of layers.

2.2. Gas system and gas monitoring

The gas system could be run either as an open system or as a closed-loop system with the chamber pressure regulated at 1 mbar above atmospheric pressure. We were able to connect or disconnect the purifiers in order to clearly separate their influence on the gas compositon and pollution. All tubing was completely made out of stainless steel. Any other materials used, such as o-rings, glues etc., are classified as "non-outgassing". Unavoidable PTFE packing in stainless steel valves was subjected to a "bake-out" procedure. The packages were heated to 65^o C in a gastight box for several days and continously flushed with nitrogen. Main and trace gas components were monitored with a gas chromatograph [6], a dewpoint sensor [7] for H_2O, and an oxygen sensor [8].

2.3. Purifiers

We used commercial gas purifiers which have been used succesfully in long-term applications at other high-energy physics experiments such as H1 and HERMES at DESY. The difference to the use in HERA-B are lower irradiation rates as well as different gas compositions [9,10]. In these experiments, CF_4 was either not used at all (H1) or only used in low concentration (HERMES).

For removing O_2, we employed the BASF-Catalyst R3-11G, consisting of 46 % Cu in highly dispersive form, stabilized with certain support materials and being activated by different additives [11]. It removed oxygen from the gas stream via the reaction 2 Cu + $O_2 \rightarrow$ 2 CuO.

The other purifier was a molsieve 3A [12], in which a molecule with a diameter smaller than the 3 Angstrom pore diameter of the molsieve such as water is able to move inside the cavity of the molsieve structure, where it is trapped by the van-der-Waals force.

3. Operation and procedures

The gas system was mainly operated in closed-loop with both purifiers included in the loop. Premixed gas from a bottle served as the counting gas. The nominal gas exchange rate was set to one volume per hour as in the OTR, with 1-3% of the gas box volume being replaced by fresh gas from the bottle every hour. The irradiation dose could be adjusted by varying the cathode current of the X-ray tube and/or placing massive attenuators in front of the beam exit window. The beamspot size was about 12 cm in diameter and had a circular shape. Table 1 gives an overview of the various run parameters.

3.1. Gain measurement

We monitored the pulseheights for several chamber wires as a function of time. Any decrease that could not be explained by changes in ambient pressure or temperature, or in gas quality would indicate a performance loss of the detector, i.e. aging. Consequently, these environmental parameters were monitored as well. Pulseheight spectra were recorded every 10 minutes and analyzed online by calculating the mean in a specified window around the maximum value in each spectrum. This mean value was our measure for the gain. The gain values were corrected offline for

variations in P and T according to the equation:

$$G_i = G_i^* \cdot \left(\left\langle \frac{1}{P} \right\rangle \cdot P_i \right)^{F_1} \cdot \left(\frac{1}{T_i} \cdot \langle T \rangle \right)^{F_2}, \qquad (1)$$

where $G, G^*, P_i, T_i, \left\langle \frac{1}{P_i} \right\rangle, \langle T_i \rangle$ are the corrected gain, measured gain, pressure, temperature, and corresponding averages, respectively. F_1, F_2 are parameters which are found by minimizing the standard deviation of the corrected gain follwing a procedure outlined in Ref.[4]. In addition, the total chamber current was monitored to obtain information about the current density as well as the accumulated charge per length. This also provided a cross-check on the quality of the pulse-height measurements.

3.2. Gas quality monitoring

Main and trace components in the circulating counting gas were monitored with a two-column gas chromatograph. Each column was connected to a separate detector, a mass-selective spectrometer with sensitivity in the ppm range and an electron capture detector with ppb sensitivity for detecting electronegative species [13]. In addition, we used a commercial oxygen measurement device (range: 1 ppm to 10000 ppm) based on a fuel-cell detector and a commercial dewpoint sensor (range: 1 ppm to 20000 ppm), which measures the water content in the gas via capacitance measurements of a porous Al_2O_3 dielectric. The gain of a stainless steel Single-Wire Proportional Chamber (SWPC), placed downstream of the OTR prototype and exposed to a low-rate ^{55}Fe source, provided an additional monitor of gas quality.

4. Results

Fig.1 shows uncorrected gain and anode current vs. time providing an overview of the time periods when the OTR detector module was irradiated. The total exposure time in this study was about 3000 hours.

After achieving appropriate running conditions, we started tests without purification at moderate irradiation densities. The first part of these tests was mainly devoted to testing the functionality of the recirculating gas system. After about 140 hours we increased the radiation intensity and simultaneously the applied high voltage and gain (see middle of "Period 1" in Fig.3)

In the second period, we switched in the molsieve as a stand-alone purifier. We noticed an immediate, significant loss of gain (Fig.2) which we traced to a change of gas composition. Although the manufacturer claims that the molsieve does not remove CO_2, we observed a decrease of this component in the gas mixture from 5% to below 4%. After we disconnected the molsieve, the gas mixture slowly returned to its original composition due to continued addition of fresh gas. Consequently, the molsieve had to be taken out of the closed loop, pre-saturated with CO_2, and then conditioned with counting gas before putting it back into the gas stream.

We started with long-term irradiation using the molsieve and applying high rates (corresponding to 0.2 μA/cm) in period 3. We observed a gain drop of approximately 10 % due to an increasing content of oxygen in the gas stream. This was caused by small leaks in the barrel that held the molsieve. In addition, in this period we had decreased the fresh-gas renewal rate from 10 % per hour to the 2% per hour rate used in the full-scale OTR. This caused an increase in N_2 and O_2 trace components and a further gain-loss. However, the gain stabilized after a certain time as a new N_2 and O_2 equilibrium was reached.

Next, we integrated the Cu-catalyst into the gas stream in period 4. The gain recovered slightly and went back up to about 95% of the initial gain. These were the conditions up to the end of the study. Within this main test period, the gain behaved relatively stable for a period of about 2000 hours of irradiation. Any deviations could be explained with increased oxygen content due to new leaks and increasing saturation of the Cu-catalyst with oxygen. After regeneration of this purifier the gain always recovered.

During test periods 3 and 4, the detector modules accumulated about 1.8 C/cm while operating at stable gain. This charge is equivalent to what would be accumulated in the hottest region of the OTR detector over three years of HERA-B operation under nominal conditions at 40 MHz

Period	Fresh gas rate %/hr	Current density μA/cm	Purification	Impurities ppm O_2 \ ppm H_2O
1.)	10	0.07	none	1500 \ 300 - 500
2.)	10	0.20	Molsieve3A	1500 - 3000 \ 10
3.)	2	0.20	Molsieve3A	$\leq$100 \ 10
4.)	2 $\rightarrow$ 1.5	0.20	Molsieve3A+R3-11G	$\leq$100 \ 10

Table 1
Settings for the various run periods.

interaction rate. We interpret this result as a strong indication that a recirculating gas system using the tested purifiers can indeed successfully supply counting gas to a high-rate drift-tube detector. Based on these results, the same purifier types are employed on a large scale in the full-size OTR gas system with similar success [2].

As an additional stress test for the detector, we irradiated a previously unused part of the module at much higher radiation density while recirculating the gas without purification. The goal was to check for effects due to an increase in the concentration of impurities in the gas stream. We alternated between high ($\sim$1 μA/cm) and low ($\sim$ 0.2 μA/cm) radiation densities in order to correlate any new effects (Fig.4).

We observed dark pulses occuring at kHz rates in the detector after one high-intensity period. At that point, the GC detected impurities in the gas stream (CH_2Cl_2 and $C_2H_6F_2Si$). Both dark pulses and impurities disappeared when switching the gas system to an open loop. When we switched back to recirculation, this time using the purifiers, neither dark pulses nor impurities could be observed at high radiation rate.

5. Summary and Conclusion

We irradiated a small-size honeycomb drift-tube module of the HERA–B Outer Tracker at rates slightly higher than those encounterd by the OTR in the hottest area under design operating conditions. We employed a recirculating gas system with gas purifiers (Molsieve 3A and Cu-catalyst) and accumulated a total charge of 2.3 C/cm in about 3000 hours. This is equivalent to more than three years of nominal HERA-B operation in the hottest region of the OTR at 40 MHz interaction rate. The gain remained stable within $\pm$5% of the mean and any observed deviations could be explained with changes in gas composition and/or ambient parameters. We conclude that the tested gas purification scheme should be reliable for operating the HERA-B OTR at nominal rates for at least three years.

REFERENCES

1. R. Pernack, Diploma thesis, U. Rostock (1998).
2. M. Hohlmann, A large ultra–clean gas system with closed loop for the high-rate Outer Tracker at HERA-B, these proceedings.
3. K. Dehmelt, Diploma thesis, U. Hamburg (1999).
4. M. Capeáns, U. Santiago de Compostela, Spain, Ph.D. thesis (1995).
5. M. Capeáns, these proceedings.
6. Hewlett Packard Inc., HP 5890 II Series Gas Chromatograph.
7. Shaw Moisture Meters, Rawson Road, Westgate, Bradford, BD1 3SQ, UK; Super-Dew hygrometer with blue sensor.
8. Teledyne Inc., 16830 Chestnut Street, City of Industry, California 91748, USA; fuel-cell based Oxygen Meter 311.
9. S. Masson, Tech. Hochsch. Aachen Report PITHA 94/50, Ph.D. thesis (1994).
10. D.M. Thiessen, Simon Fraser U., Vancouver, Canada, M.S. thesis (1996).
11. BASF AG, 67056 Ludwigshafen, Germany; catalyst R3-11G, 46% copper oxide in highly

dispersed form, stabilized on a carrier and activated, pellets 5×3 mm.

12. UOP Llc. (formerly Union Carbide), Des Plaines, IL 60017, USA; molecular sieve – Type 3A, $K_9Na_3[(AlO_2)_{12}(SiO_2)_{12}] \cdot XH_2O$, $3 \cdot 10^{-10}$ m nominal pore diameter, Type A crystal structure, pellets 4-8 mesh.
13. A. Zlatkis and C.F. Poole (eds.), Electron Capture: Theory and practice in chromatography, Elsevier Scientific Publishing Company, Amsterdam (1981).

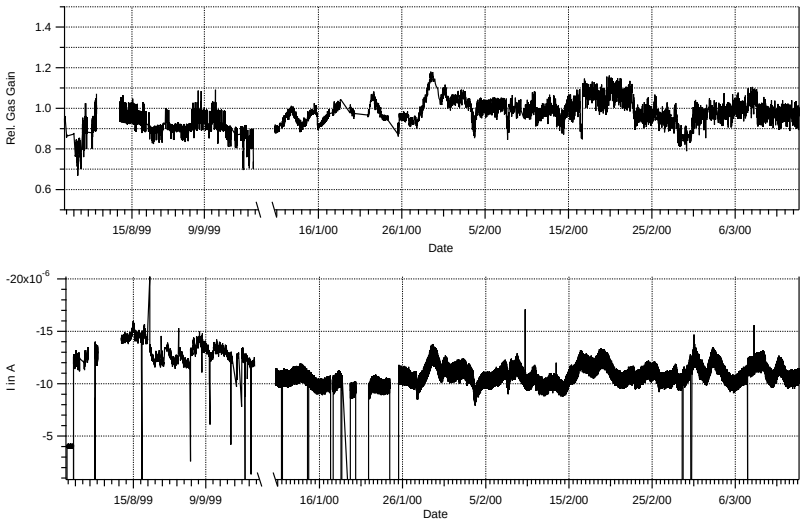

Figure 1. Overview of all irradiation periods. The upper figure shows the uncorrected relative gain, the lower figure shows the corresponding anode current.

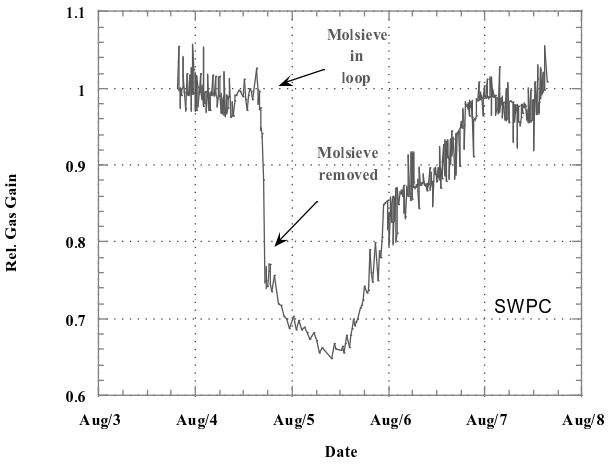

Figure 2. Gain loss with unconditioned molsieve due to drop in CO_2 concentration, as observed in a SWPC.

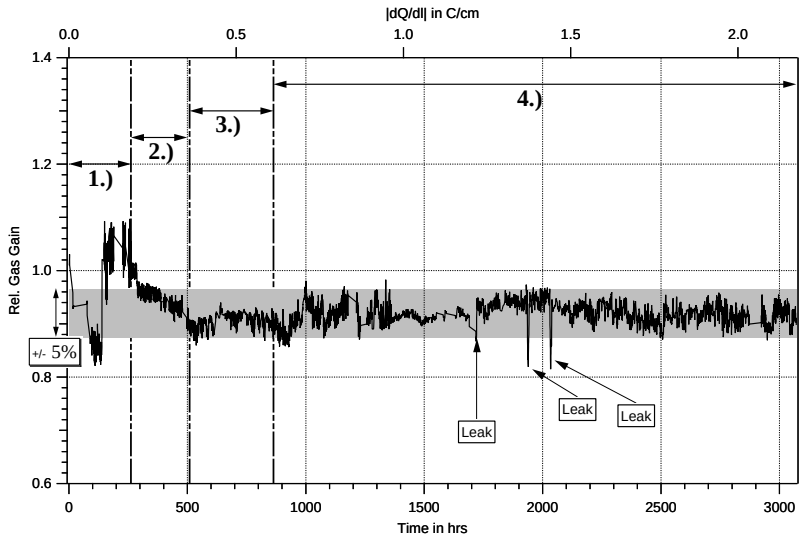

Figure 3. Relative gain for all run periods with conditions according to table 1, corrected for temperature and pressure variation according to eq.1. The gain in periods 2-4 is normalized to the initial gain of period 2, whereas the gain from period 1 is normalized to the initial gain of period 1.

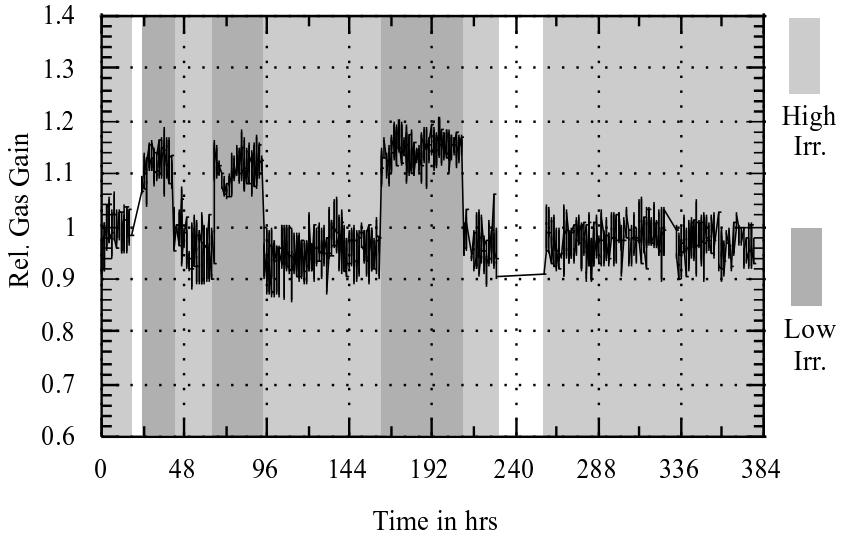

Figure 4. Relative gain under high irradiation rate alternating with standard irradiation rate using the recirculating gas system, but without purification to increase the rate of impurities in the gas. A 15% gain loss due to space-charge effects is observed.