A large ultra-clean gas system with closed loop for the high-rate Outer Tracker at HERA-B

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Abstract

The gas system for the Outer Tracker of the HERA–B experiment at DESY produces the desired counting gas mixture Ar/CF_4/CO_2 65:30:5 and circulates it through the detector at a flow rate of 20 m^3/h, i.e. ∼1 vol/h. It controls flows and regulates pressures in all 26 OTR half–superlayers, purifies the gas upon return from the detector, and automatically performs a quantitative analysis of main and trace (O_2, N_2, H_2O) gas components for the common input and the outputs of all half–superlayers. The first running experience and the strategies employed during system construction to avoid any detector aging possibly induced by the gas system are discussed. The large system with major gas purification stations was constructed using only non–outgassing, "clean" materials and devices, such as stainless steel, PEEK, baked Viton, and metal bellows pumps. An epoxy glue was used extensively as a non-outgassing sealing material in applications with up to 100 bar pressure.

Key words: gaseous detector, gas circulation, CF_4, clean materials, purifiers, molsieve

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1 Introduction

The high bunch–crossing rates at modern machines such as HERA, the Tevatron in Run II, or the future LHC require small drift distances and the use of fast counting gases in large–area tracking detectors to avoid pile-up effects. For current detectors, the high electron drift velocities are typically achieved by adding tetrafluoromethane (CF_4) to the counting gas, as the drift velocity for pure CF_4 exceeds 100 μm/ns in electrical fields larger than 1 kV/cm [1–4].

However, a considerable disadvantage of CF_4 is its high cost (∼ \$40/kg), which poses a problem for detectors with large volume and/or high gas-flow rate. The CF_4 must either be recuperated after passing through the detector or the counting gas has to be recirculated continuously. Recuperation with sufficient purity requires considerable cryogenic efforts. In a circulating system the pollutants,

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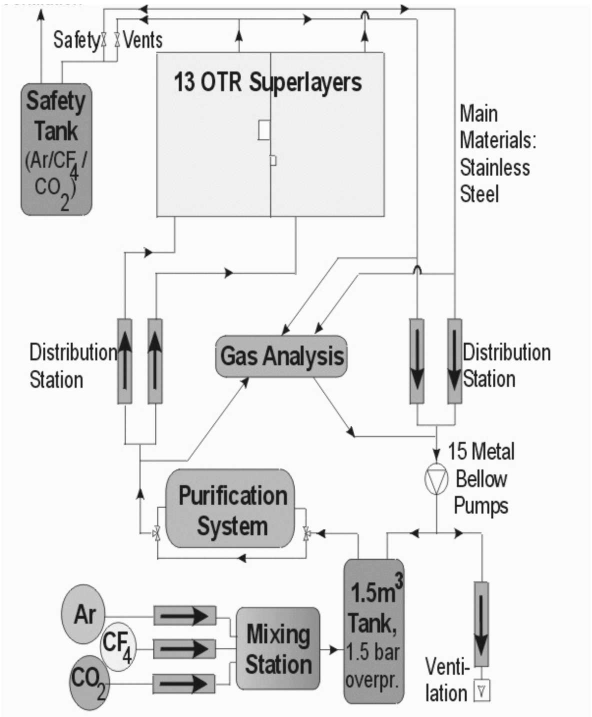

Fig. 1. Overview of OTR gas system.

such as products from plasma chemistry processes in the avalanche, material outgassing, and air from unavoidable leaks accumulate in the counting gas. They compromise detector performance and can cause detector aging. Constant gas purification is needed to avoid such detrimental effects. These considerations set the basic framework for the design of gas systems for large, state-of-the-art gaseous detectors.

2 Functions & operation of gas system

The overview in Fig. 1 shows that closed-loop gas circulation with purification is employed on a large scale in the gas system for the Outer Tracker (OTR) of HERA-B. Design, aging studies, and performance of this detector, which was built for 40 MHz interaction rate and ~ 30% maximum occupancy, are described in detail elsewhere[5–9].

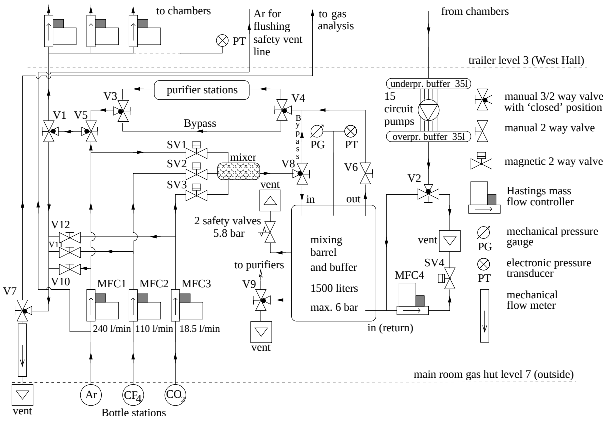

Fig. 2. Detailed design of gas mixing station.

The OTR gas system performs several functions to ensure proper detector operation. It produces the required counting gas mixture Ar/CF_4/CO_2 (65±1):(30±1):(5±0.2) in the mixing station (Fig. 2), distributes it to the 26 separate OTR half-superlayers (Fig. 3), and circulates it through the entire detector at a flow rate of 20 m^3/h, equivalent to about one volume exchange per hour for the whole detector. The system controls flows and regulates pressures in all 26 chambers to 0.5 mbar above atmospheric pressure by means of mass flow controllers, pressure transducers and a programmable logic controller. In case of pressure alarms, active normally-open safety valves and a large safety tank prevent dangerous over- or underpressures in the chambers while at the same time minimizing the entry of air into the chambers (Figs. 1,3). The system continuously performs automatic quantitative analyses of all main and certain trace (O_2, N_2, H_2O) gas components for the common input and the outputs of all half-superlayers by means of gas chromatograph[10], oxygen meter[11], and moisture meter[12].

It purifies the gas upon return from the detector by removing oxygen and water in regenerable purifiers (Figs. 4,5). A newly regenerated purifier station containing ~ 60 kg of purifier material[13] for oxygen removal can keep the oxygen content at levels below 200 ppm for about 10 days during normal oper-

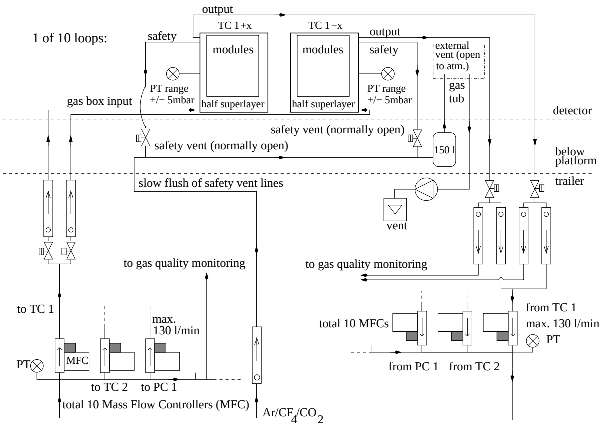

Fig. 3. One of ten gas distribution branches.

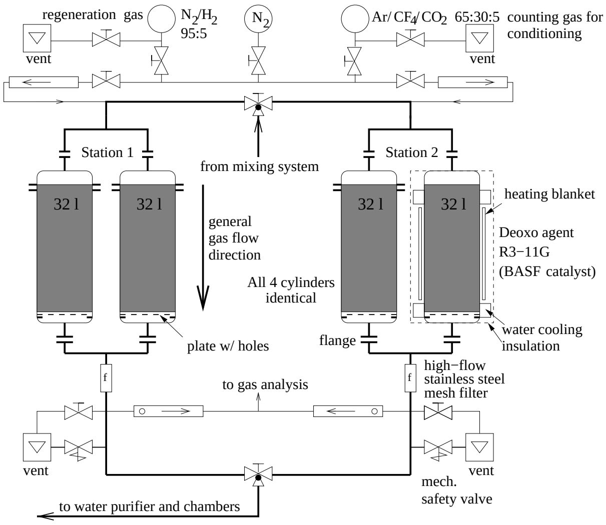

Fig. 4. Design of oxygen removal station.

Fig. 5. Purifier stations for O_2/H_2O removal.

ation (Fig. 6). Regeneration in parallel of a second, exhausted oxygen station takes about 3 days. During system commissioning it was found that the purifier material for oxygen removal also absorbs significant amounts of water so that the detector was operated with very dry gas ($c(H_2O) < 20$ ppm) even after the second purifier station dedicated to water removal with a molsieve material[14] had been excluded from the system.

The N_2 concentration in the gas is kept at ≤ 2000 ppm by continuously venting 0.5–2% of the circulating gas per hour and adding freshly mixed gas, which caused a CF_4 consumption of about 400 kg/month in 2000. Fig. 6 shows the measured concentrations of main and trace gases during the first run period of HERA–B in 2000 illustrating a good system performance.

3 Minimizing the potential for aging

The following strategies were consistently employed throughout all design and construction phases of the gas system to minimize the potential for any aging effects in the OTR:

- *Maximize* the use of the few materials guaranteed to be clean and proven to be safe from outgassing (e.g.[15,16]) when selecting system components: *stainless steel, glass, PolyEtherEther-Ketone (PEEK)*, and *non-outgassing epoxy.*
- *Avoid* all contact of gas with any sort of lubrication, Teflon, or any other outgassing plastics or elastomers in system components. Modify components if necessary.
- *Test* any unproven materials in prior aging tests if forced to use them.

All piping is done with stainless steel (ss) tubes joined either by external orbital weld-

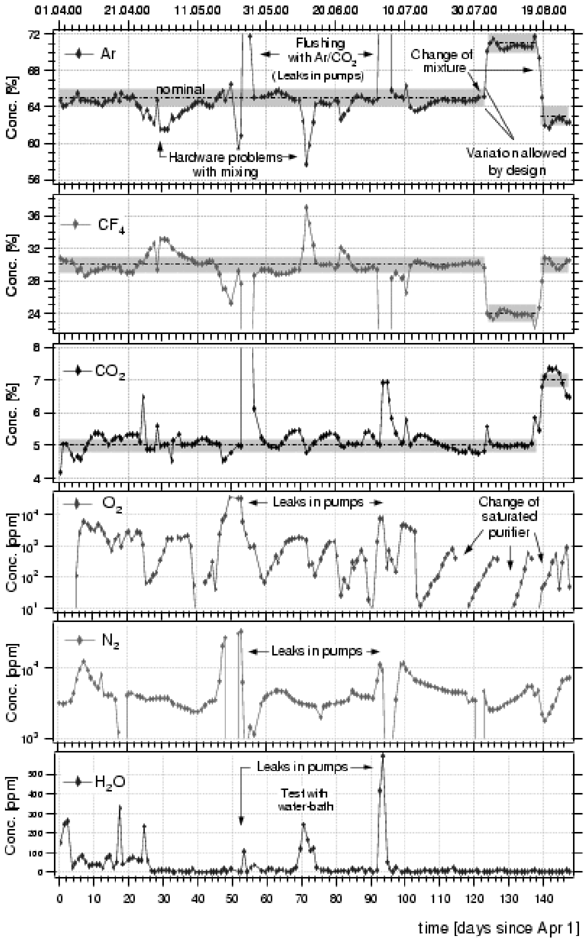

Fig. 6. Concentrations of main and trace gases in the OTR gas mixture during the running period in 2000. Unusual events are indicated.

ing or ss-fittings[17] providing a pure metal-seal. The only exceptions are applications where non-conductive piping is required, e.g. to electrically insulate the chambers from the gas system; here short PEEK tubes are used. Where pipes need to be movable, e.g. on detector superlayers that can slide in and out of position or on circuit pumps, flexible ss-pipes are used. These pipes were produced and cleaned in industry following a procedure developed by the DESY gas group[18] to ensure removal of any detrimental chemicals from production. The inner pipe surfaces were inspected endoscopically near the ends and all pipes were evacuated to check for vapor pressure from outgassing remnants before installation.

A 1.5 m long ss-tube of 5 cm diameter is filled randomly with ss nuts and bolts and mixes the 3 gas components by creating turbulent flow. Filters downstream from the purifiers prevent loose purifier materials from being carried with the gas stream to the detector. A filter unit contains a cylindrical ss-mesh welded (not glued) into ss-seats and placed in a ss-holder. Preinstalled Buna tubes at the measuring ports of pressure transducers[19] installed on the chambers were manually replaced by stainless steel tubes.

Under no circumstances is Teflon tape used to seal fittings. Any fittings that require additional sealing material are sealed by applying Stycast 1266 epoxy glue[20] to the fitting threads before assembly. This glue is proven not to outgas[15,16] and is used in the construction of the OTR detector modules themselves. This sealing technique is not only used in low-pressure applications such as fittings for ball flowmeters, but also in high-pressure connections. Fig. 7 shows examples of these applications, such as seals for CF_4 pressure cylinders at 100 bar, for the input connectors to Ar (6 bars), CF_4 (100 bar), and CO_2 (15 bar) pressure regulators, or for adapting a pipe to the large fitting of the system buffer tank. It even works under strong vibrations and at 50^o C, as encountered with the circuit pumps.

Only non-lubricated ss-valves are used. In the large ball valves[21] used in the mixing and purification stations all standard lubrication was manually removed and the standard Teflon seals and seats were replaced by special-order PEEK seals and seats. The circuit pumps employ special steel bellows[22] as shown in Fig. 8 that completely isolate the counting gas from the unavoidable lubricants needed in the pump motors.

In a few devices, such as needle valves in ball flow meters, mass flow controllers, and pump valves, elastomer seals are hard to avoid

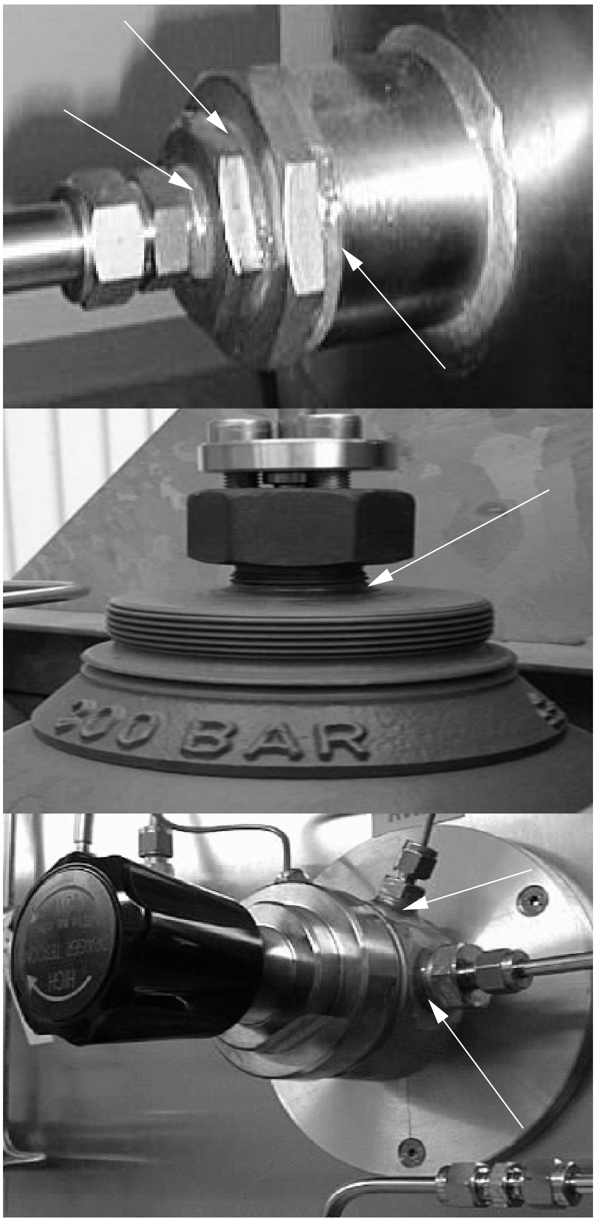

Fig. 7. Examples for applying non-outgassing epoxy (Stycast 1266 [20]) as seal for gas fittings. Arrows indicate exact locations where epoxy is applied. Note that epoxy is mainly applied within threads of connecting fittings which provides the seal. Top: adapters for pipe connection to 1.5 m^3 buffer tank (appl. press. 2.5 bar abs.); middle: CF_4 gas bottle (100 bar); bottom: CF_4 pressure regulator (100 bar on high-pressure side).

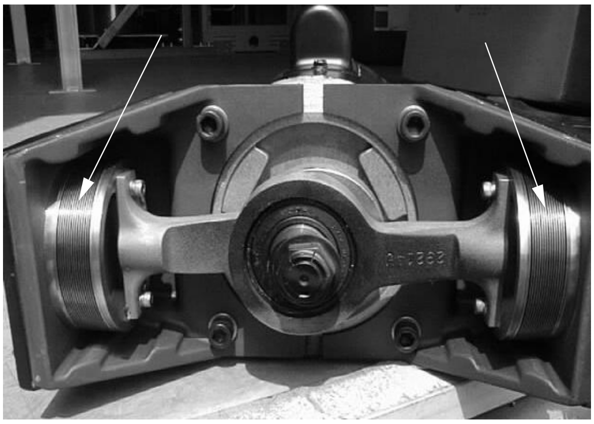

Fig. 8. One of 15 system pumps[22] with cover removed to show steel bellows (arrows).

completely if costs are to be kept at a reasonable level in a large system. In these cases, the strategy is to use only a *single* type of sealing material in all devices. Here Viton, a fluorinated copolymer, was chosen as it is a standard sealing material and reasonably priced. It is rated as ‘usually good’ based on extensive outgassing tests reported by other authors [23,24]. Nevertheless, before selecting this material for the gas system it was extensively validated by using it in various aging studies[9,25]. As a preventive measure, any large Viton pieces were baked out at 65^{o}C under steady nitrogen flow for at least 60 hours before installation in the gas system.

The choice of purifier materials was guided by many years of positive experience with catalyst[13] and molsieve[14] agents in other HERA experiments, H1[26] and HERMES[27]. However, in a system that circulates gas with a large CF_4 component through a high-rate detector, these materials may be chemically attacked by aggressive products from CF_4 cracking and may release further, potentially harmful pollutants into the gas stream. Consequently, the stability of gas purifiers must be carefully tested before putting them into operation with a full-size detector. A prototype gas system with circulation and purification was constructed following the same strategies outlined above. It operated with OTR test modules for 3000 hours without indication of significant aging due to the purification system[25], which validated the selection of the purifier materials.

4 Running experience and conclusions

The main operational problem with the system are leaks occurring in the metal bellows of about half of the 15 circulation pumps that run in parallel. The leakages are mainly due to motor grease or metal shavings getting wedged in the outside of the moving bellows causing a mechanical rupture in the long-term. However, the possibility that aggressive fluorine compounds or radicals corrode the bellows from the inside and ultimately also cause ruptures is under study. To maintain operation, a leak detection system was installed for the pumps in 2001 using an oxygen meter and valve system to pinpoint any leaking pump so that it can be isolated quickly from the system in case of rupture.

Another problem is the malfunctioning of several mass flow controllers (MFCs) after about a year of operation. The suspected cause is a swelling of the Viton seals in the MFC due to long-term exposure to CF_4. The affected MFCs have to be refurbished and recalibrated by the manufacturer.

Overall, the system performs all its functions well and no aging has been observed in the OTR after two years of operating it at HERA-B with this gas system. This result so far confirms the validity of the strategy chosen to construct and operate the system.

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[11] Teledyne Inc., Los Angeles, CA 90064, USA; fuel-cell based Oxymeter 316.

[12] Shaw Moisture Meters; Bradford, BD1 3SQ, UK; Super-Dew hygrometer with blue sensor.

[13] 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.

[14] 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.

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