Computer Physics
Communications

Gas support systems for hadronic high-rate detectors -

the example of the Inner Tracker of HERA-B

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Elsevier use only: Received date here; revised date here; accepted date here

Abstract

The challenge to avoid aging in the new generation of hadronic high-rate detectors at DESY and CERN requires that new and higher standards for material quality and cleanliness be maintained, not only for the new detectors, but also for the gas support systems. The effort that is necessary to test materials for detectors must also be extended to all parts of the system that come into contact with the gas. These detailed and critical investigations must also include the traditional materials and equipment that have been used up to now without any problems. It appears that a number of parts contain outgassing material, which has been negligible so far, but can cause fast aging under high-rate conditions. In addition, quenchers in these conditions can become chemically reactive and limit the number of usable gas system components even further. The gas systems for HERA-B fulfill those requirements, and the Inner Tracker (ITR) gas system is presented as an example.

1. Introduction

Recent developments in experimental high-energy physics point to dramatic changes in the radiation environment for experiments and detector technology. HERA-B [1], a fixed-target experiment at DESY, is the first of a number of experiments designed to accumulate radiation doses in the range of 1 Mrad per year. The experiment consists of a forward spectrometer originally built to measure CP violation. The spectrometer has an inner tracking detector (ITR) [2], an outer tracker (OTR) [3], and a special tracker made of gaseous pixel chambers and carbon-loaded straws for high-p_t measurements. The ITR has 184 GEM-MSGC detector units installed perpendicular to the beam pipe at 10 different distances from the target and covers distances up to around 30 cm around the beam pipe. The OTR, made of gold-plated honeycomb drift tube layers, is also installed perpendicular to the beam pipe and covers distances from the ITR acceptance up to the outer dimensions of the spectrometer. The OTR has a recirculating gas system [4] employing PID technology for automatic pressure regulation with a capacity of 22 m^3/h. The ITR has a single-pass system that also uses a fully automated PID control system to maintain a regulation accuracy of ±10 µbar [5].

2. Radiation Conditions

Figure 1 shows nominal radiation conditions at HERA-B and those that will be reached at LHC experiments, both as a function of radial distance from the beam pipe. Particle fluxes of 10^6 cm^2 s^{-1} are encountered, which represent 4 orders of magnitude higher fluxes compared to previous experiments at HERA and LEP.

3. Layout of the ITR gas system

The ITR gas system covers a large experimental area with height differences of about 20 m and overall pipe lengths of about 200 m, 50 m of which are flexible tubing. After mixing at ground level in front of the experimental hall, the gas is sent down into the hall and split into 16 circuits at the top of the electronics trailer to support 20 half stations along the beam pipe. The gas system layout at this level is shown in Fig. 2 and some parameters are collected in Table 1.

Volumes
$V_{MSGC} \sim 300, 330$, and $340\ cm^3$
$V_{gas} = V_{MSGC} + V_{pipes}$ = 58 lit. + 117 lit. = 175 lit.
Flows
Normal flow 10 cm³/min. => 1 Vol./30min.
Max. flow 50 cm³/min. => 1 Vol./5min.
Pressures
$P_{measured}$ = +100 µbar above atm.
$\Delta P_{measured}$ = ±10 µbar

Table 1. Some parameters of the ITR Gas System.

4. Final Gas Mix

Originally, the preferred gas was Argon/DME 50:50. DME is Dimethylether (C_2H_6O) and is a flammable gas, but has good HV stability, sufficient drift velocity and produces small cluster widths. It is known that DME is an aggressive gas and acts as a solvent for numerous hydrocarbons, creating ideal conditions for aging. Its usage dramatically increased the difficulties in finding suitable materials for both the detector and gas system. The advantages, however, were assumed to justify the price. A subsequent turn of events occurred when the irradiation of large surfaces of detector prototypes led to fast aging [6]. Previously, only small areas, such as those formed by collimators in high energy experiments, had been irradiated with equivalent doses. Consequently, the gas mixture had to be changed to Argon/CO_2 70:30. At that point in time, the gas system had already been fully designed for Argon/DME and most of the components had been delivered before this change of the gas mixture took place, so no modification in the gas system was made to accommodate the new gas.

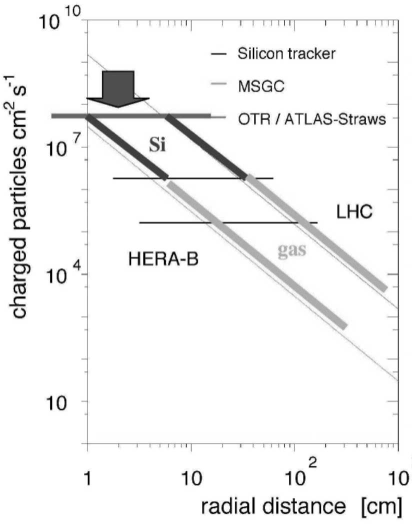

Fig. 1. Radiation conditions at HERA-B and LHC.

5. Basic Considerations

The basic considerations for the design, treatment, and testing of gas system components are as follows:

1. Reality Problem: A real system will always contain some dirt and pollution despite all prior investigations and precautions taken.

2. Context Problem: Aging is always a result of the sum of all properties affecting a detector. A material can be harmless in one context and harmful in another. Therefore, a final acceptance test with the final configuration is necessary, even if all used

materials and components have already passed earlier aging tests. The aging that occurred when large surfaces were irradiated in the presence of DME is an example of this problem.

3. Granularity Problem: Modern tracking detectors differ from traditional experiments in that they consist of up to several hundred smaller segments instead of one big vessel. Different personnel in different laboratories produce them at different times, and the quality of the final components can vary significantly.

4. Pollution Measurement Problem: It is very difficult to measure pollution quantities below certain thresholds, so the exact outgassing of most of the materials in use is unknown. The resources and possibilities to measure gas traces in high-energy physics are usually restricted to a combination of gas chromatography and/or mass spectrometry (GC/MS). The typical measurement thresholds for this technique is around 1 ppm.

To measure the appearance of polar (electronegative) molecules, e.g. freon gases, it is possible to use electron capture detectors (ECDs) in combination with gas chromatography, which allows measurements down to about 1 ppb sensitivity. That means that the total number of molecules of an undetected component in the gas can still be between 10^{13} and 10^{16} molecules per liter depending on the type of pollution. Taking this into account, the phrase ‘outgassing’ gets a more differentiated meaning. The attribute ‘not outgassing’ just means equal or smaller amounts than the corresponding limits.

5. Acceleration Problem: Most radiation tests have to be strongly accelerated (~factor 20-50) in order to get results in a reasonable amount of time. This raises the problem of deviations between testing and reality. Typical reasons for such deviations may be:

- Different avalanche dynamics
- Different type of particles
- Different charge density
- Different spatial distribution of particles and charge
- Different particle energies leading to different material behavior (e.g. number of spallation products and alphas)

Note that the context problem is strongly related to the acceleration problem because aging is a function of the chemical components in the gas, material surfaces, plasma physics in the avalanche, and free radical reactions outside the plasma.

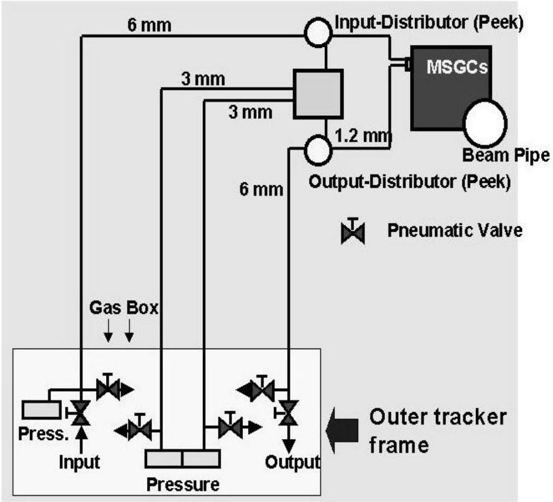

Fig. 2. ITR Gas System components at each half station.

6. Choice of Material

Table 2 is a list of materials that are usually considered for building detectors such as the HERA-B trackers and the appropriate gas systems. After the investigations by HERA-B, and the use of resources at DESY, CERN, PSI, SLAC, Fermilab, various universities, and NASA, only a few suitable materials remain.

These were further reduced by price considerations and by the fact that some materials exist in a manifold of derivates. An example is Kalrez, which has the derivates Chemraz, Paroflour and Aegis. They all differ because different companies produce them. As a result of our investigations, the list shrunk finally to the *winner materials* (underlined and marked with a `*’) in Table

2. Surface areas and some bulk volumes of the materials inside the gas volume of the ITR are listed in Table 3.

Metals	
Brass (pressure reducer, fittings)	
Copper (pipes)	
Stainless steel (pipes, fittings)	*
Hasteloy (steel for valve membranes)	*
Hard Plastics (i.e. for seats in valves, frames)	
Teflon [PTFE] (everywhere, ball valves)	
PEEK (Polyetheretherketone; good for machining, no glass)	*
G10 [FR4, AT8000] (glass-loaded epoxy, extremely strong)	*
Nylon	
Kel-F [PCTFE] (valve seats)	*
Kynar [PVDF] (Polyvinylidene fluorides)	
Ultem (PEEK like, can be injection molded)	
Vespel (special polyamide, used in analytical chemistry)	
Elastomeres (gaskets and O-rings)	
Viton [FKM]	
Buna-N [NBR]	
Chemraz [FFKM]	
Kalrez® 4079 [FFKM] (Copolymer of tetrafluoroethylene + Perfluorovinylether)	*
Parofluor [FFKM]	
Aegis [FFKM]	
Silicone [MQ, PMQ, VMQ, PVMQ]	
Teflon [PTFE]	
EPDM (Copolymer of ethylene and propylene)	
Neoprene	
Fluorosilicone	
Polyurethane	
Glues	
Araldite Types	
Locktite Types	
H72	*
Eccobond	*
Stycast 1266	*
Silicon grease (vacuum grease)	

Table 2. Possible materials before special investigations. Winner material is underlined and marked with a `*'.

7. Final selection of used materials

The last and deciding step was a radiation test made with as final as possible detector prototypes. The test setup is sketched in Fig. 3. In these MSGC tests at Heidelberg, a full-size chamber prototype was irradiated with an X-ray source at the Cu-K_α energy under a maximum acceleration of 40-fold HERA-B rate. The integrated dose corresponded to 5 years of nominal running at HERA-B rates. A HERA-B year is defined as 10^7 seconds, so the test took 15 full days of accelerated irradiation. The measure used for the simulated operation time is the accumulated charge per centimeter of anode strip [7]. The test materials were placed into a clean stainless steel box in the gas flow. No sign of aging was observed.

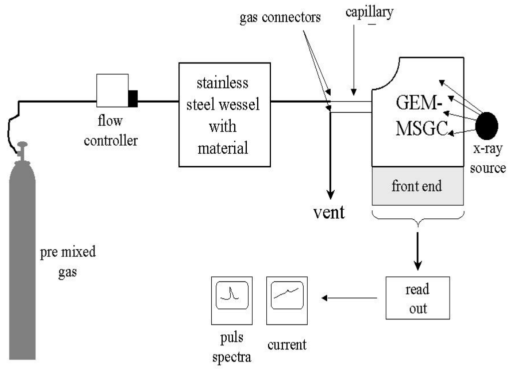

Fig. 3. Radiation Test Set Up

8. Consequences of the material exclusion

The final ordering of parts for the gas system could not start before the determination of the winner materials. The technical selection criteria of the gas system components not related to the aging question are not reported here, but are given in [8]. About 80% of the parts had to be modified in some way compared to the standard delivery specifications, so that the whole process of specifying the final orders for the complete system lasted about 2 years. The modifications ranged from special treatment during production at the factories to major mechanical changes of instruments in the workshop of the Heidelberg laboratory [5].

9. Examples

The following cases illustrate in which ways the usage of typical components and methods had to be reviewed to cope with current conditions. The examples are chosen at random. A more complete discussion of cases and their reasons is given in [9].

- Ring-corrugated tubes:

Due to the infrastructure conditions of the experiment, flexible stainless steel tubes (see Fig. 4) were necessary to connect the movable platforms of the detector with the electronics and gas trailer. Some 150 of these pipes with an overall length of 7.5 km were installed for the whole experiment. The ITR required 32 pipes with a total length of 1.6 km. The advantages of these tubes are radiation hardness, robustness, inert behavior without diffusion and no "outgassing" if they are sufficiently clean inside. The latter, however, is a problem because the tubes had to be manufactured with a lubricant that had to be washed out afterwards with an appropriate solvent. For HERA-B, a special solution was developed in direct negotiations with an interested company [9], which also indicated that a lubricant-free version of this tube would be available in the future.

ITR with 184 GEM-MSGC	
Substrate:	14.00 m^2
Copper:	29.00 m^2
Kapton:	1.60 m^2
G10:	1.10 m^2
Stycast 1266:	0.10 m^2
H72:	0.10 m^2
Eccobond:	0.04 m^2
Total:	45.00 m^2
Pipes:	
Stainless Steel TCC Quality	17.60 m^2
Ring-Corrugated Tubes:	64.00 m^2
Total:	80.00 m^2
Plastic bulk:	
Kalrez O-rings:	70 cm^3 of bulk material 85 cm^2 surface
Valve Seats:	8 cm^3 of bulk Kel-F
PEEK:	1.2 lit. of bulk PEEK 0.6 m^2 PEEK surface

Table 3. Materials, volumes, and surfaces of the 184 GEM-MSGC modules in the ITR.

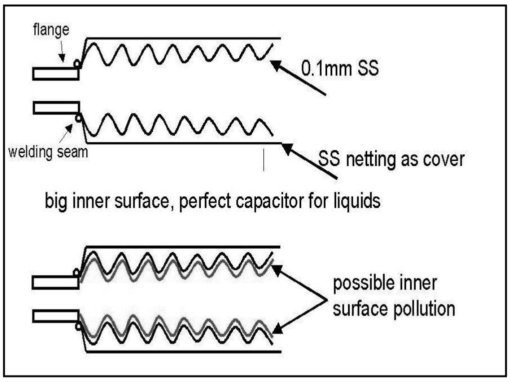

Fig. 4. Cross section of the end of a ring-corrugated tube

- The outside of gas tubes:

The outside of the gas tubes is in contact with the gas at the tube ends, as illustrated in Fig. 5, which shows a typical gas fitting. Hundreds of these were used in the system to connect tubes. Consequently, not only the inside, but also the outside of the tubes must be cleaned before usage. This is particularly an issue, because companies use organic markers to label their pipes on the outside with the company name and pipe specifications.

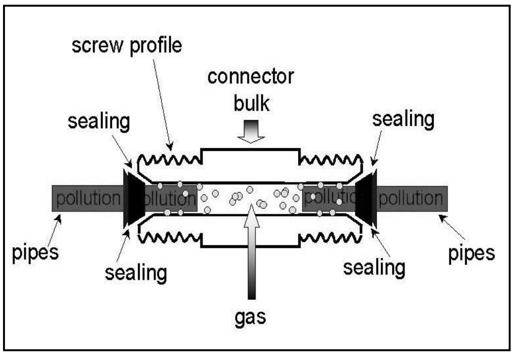

Fig. 5. Cross section of a typical pipe connector

- Pumps:

Pumps generally produce a lot of problems because they have many internal moving parts, which can produce abrasion. They are usually quite hot inside and are a potential source of outgassing materials. In addition, they are often used in recirculating systems, where the outgassed material is accumulated. The necessary modifications for the ITR gas pumps are described in [9].

- Mounting and storage:

It should be taken as a given fact that in the future much cleaner conditions for the mounting and storage of chambers will be required. This is especially true at the experiments where the environmental conditions can be difficult due to accumulated dirt and frequent ‘on-the-fly’ mounting. For storage, clean and air-sealed storage systems must be used, and a back tracking of component history must be maintained.

10. Summary and conclusion

The radiation environment of future hadronic high-rate experiments has already been reached at the HERA-B experiment. The development of this detector was a milestone for radiation-hard detector technologies, especially in the field of tracking detectors. A number of painful experiences were encountered, which can serve as guidelines for current and future detector development. This also holds true for the design of detector gas systems, which must also advance to match the demands of the detectors.

The thresholds of tolerable impurities in the operating gas mixtures continue to decrease in such a way that standard analytical methods become more and more unusable for quantifying the danger of aging. Therefore, a simple straightforward method (“the golden rules”) turned out to work very efficiently in praxis:

- Exclude all materials which may be dangerous, using help and information from all available sources.

- Build a detector and gas system prototype as soon as possible.

- Irradiate the prototype in an appropriate way and iterate this procedure until no aging is found after a lifetime-equivalent dose.

For the final step, the actual building of the full system, maximal cleanliness for all processes and quality control for all parts, as well as for the work process, is of vital importance.

At the time of this workshop, the HERA-B tracking detectors have seen approximately 5% of their expected lifetime dose and so far do not show any indication of gas aging.

Acknowledgements

The author, on behalf of the Physikalisches Institut Uni-Heidelberg, would like to thank DESY and ZMEA6 (especially W. v. Schröder and W. Zoch) for their ongoing support for HERA-B. Further thanks are addressed to Mar Capeans, Carsten Krauss, and the organizing committee of the workshop.

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