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Gas recirculation systems for RPC detectors: From LHC experiments to laboratory set-ups

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ABSTRACT

The Resistive Plate Chamber (RPC) detectors are extensively used worldwide and at CERN LHC experiments thanks to their excellent time resolution and low cost. RPCs are often operated with a humidified gas mixture made of $C_2H_2F_4$, SF_6 and i-C_4H_{10}. Unfortunately, $C_2H_2F_4$ and SF_6 are greenhouse gases (GHGs) with a global warming potential (GWP) of 1430 and 22800 respectively and they are subject to a phase-down policy in Europe (EU F-gas regulation). It is therefore foreseeable that F-gases availability would be uncertain for the future and their price could raise possibly making gas detectors operation very costly. The reduction of GHG emissions is an objective of paramount importance for CERN and four different strategies have been identified to achieve it. One of these strategies is based on the use of gas recirculation systems. This solution is already implemented in all gas systems supplying gaseous mixtures to the CERN LHC detectors. These recirculation systems are complex and sophisticated apparatus for big detector volumes (tens to hundreds of m^3) that extend from surface to underground cavern and they are controlled through an industrial Programmable Logic Controller (PLC). Their cost is considerable and therefore they are used for large detector apparatus. In order to cope with the increase of small experiments and detector facilities, the CERN gas team has developed two new portable gas recirculation systems at affordable cost. The first gas recirculation unit can be used for several detectors connected in series or parallel flushed with hundreds of liters per hour. It is controlled though a small PLC and it can regulate detector pressure at the level of the mbar. Some of these gas recirculation systems are already in use since several years at CERN GIF++ facility for CSC, GEM and RPC detectors. A second gas recirculation unit has been developed for laboratory purpose where one or two detectors are flushed with few liters per hour. In this case, the unit has to be very cheap and user-friendly in order to allow an easy operation from the final user. Both portable gas recirculation systems can be easily adapted for the different types of detector systems and set-ups thanks to their low price, flexibility and user-friendly operation. An overview of the LHC, medium and small gas recirculation systems will be given in this contribution.

1. Introduction

Several gaseous detectors are employed at the CERN LHC experiments. Most gaseous detectors are operated with a well-defined gas mixture, which is defined based on the performance and on the task the detector was designed to perform. Although each detector installation is unique, common gases are employed to accomplish detectors tasks. For instance, Argon is used by tracking chambers and Multi-Pattern Gaseous Detectors (MPGDs) as it provides a large amounts of ion-electron clusters, thus considerable gains with high voltage. CO_2 is typically added to Argon gas mixture to quench photons and suppress photon-feedback induced streamers. Cherenkov detectors are operated with fluorinated gases such as C_4F_{10} or CF_4, whose optical properties ensure a sufficient light yield for particle detection. Transition radiation trackers are usually operated with a high Z gas such as Xenon in order to ensure a high cross-section for the photoelectric effect used to convert transition radiation photons to a signal. Resistive Plate Chambers are typically operated with a $C_2H_2F_4$-based gas mixture, with the addition of SF_6 to ensure a streamer-free operation and with the addition of i-C_4H_{10} in High Pressure Laminate (HPL) RPCs to reduce photon-feedback effects. Furthermore, HPL RPCs are operated with the addition of water vapor to keep the resistivity of the electrodes constant. Several gaseous detectors used at LHC experiments make use of greenhouse gases, as $C_2H_2F_4$, SF_6, CF_4 and C_4F_{10}, because of their specific properties. Furthermore, the gaseous detectors systems at LHC experiments have gas volumes up to hundreds cubic meters. It is therefore fundamental to employ gas recirculation systems to avoid GHG emissions in the environment. All LHC gas systems using GHG recirculate the gas in a fraction varying from 90% up to 100%, reducing drastically Greenhouse Gases (GHG) emissions. In case of small experiments and laboratory set-ups, often the gas after being

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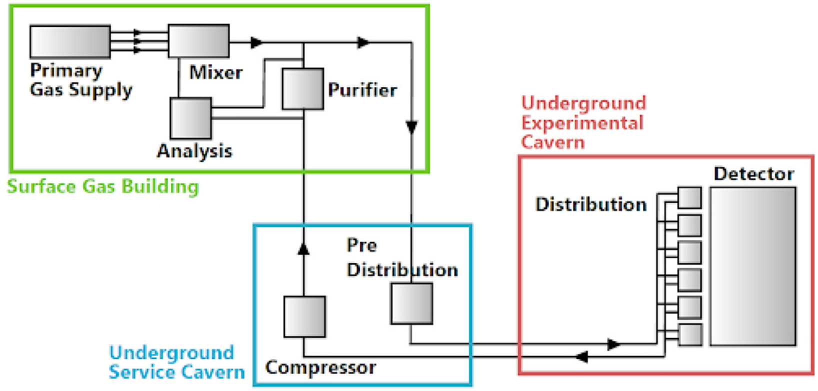

Fig. 1. Simplified gas system schema with its main modules.

used is sent to atmosphere as small-scale recirculation systems for detector application are not available on the market and they could be difficult to design and build. Even if few detectors are used, the GHG emissions could be comparable to a big LHC experiment where the gas is recirculated at 100% and therefore only few liters could be used. Additionally, the availability and price of fluorinated gases is not known for the future, and already today prices are higher than 2014 (start of EU-regulation). It is therefore advisable to reduce also GHG emissions coming from small experiments and laboratory set-ups.

2. Gas systems at LHC

The LHC Gas systems are physical installations located at different LHC sites which are responsible for providing a stable and controlled gas mixture to gaseous detectors [1]. A correct and monitored gas mixture is fundamental for the detector's operation as a slight variation of gas in terms of composition, pressure and quality may affect detector's performance.

Gas systems typically extend in three main locations of an LHC experiment: the first is the surface building, where primary gas supply points are located and the gas is mixed. The gas is then sent to the underground service room, where the gas is split into several pre-distribution lines. Pumps can also be found in service rooms if gas systems make use of gas recirculation. Finally, the gas arrives to the experimental cavern where it is further split into more granular distribution lines that send and retrieve the gas to the detector's chambers.

2.1. Gas systems modules

More than 30 gas systems are operated across different LHC experiments. In order to simplify the construction, costs, maintenance and the operation of such systems, the gas systems were designed using a modularized approach. Thus, each gas system can be divided into several gas systems modules, each one responsible of performing a precise task.

Fig. 1 shows a simplified schema of a gas system with its main modules, while the mechanical installations of a gas systems can be seen in Fig. 2. Each module has a specific function. The main modules of gas systems can be summarized into the followings:

Mixer

The mixer unit takes individual gases from the primary gas supply and creates the required gas mixture using a set of Mass Flow Controllers (MFC). Mixer can be set to inject a constant flow or to inject based on specific conditions.

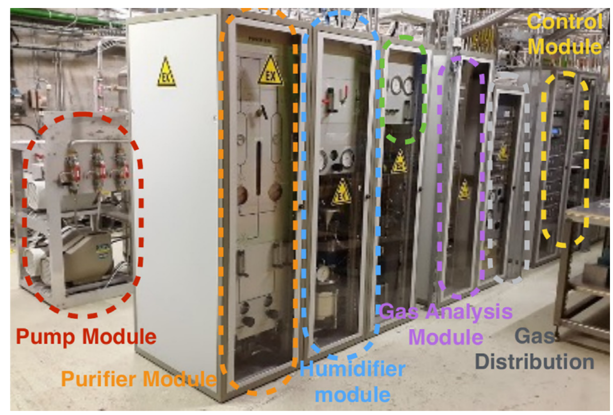

Fig. 2. Rack installation of the ALICE-MID gas system.

Pre-distribution and distribution

These modules are responsible for providing the gas mixture directly to the chamber at the required pressure and flow. The gas is split into one or more channels and the flow is measured by a set of individual input and output flow meters. Often, multiple distribution racks are used in large installations to allow a more precise distribution of the gas to different sectors of the detector complex. Distribution racks are usually equipped with different pressure transmitters measuring the pressure at the input of the rack, at the chamber level and at the output level. Control valves can be employed regulate the pressure of the detector with a precision of the order of 0.1 mbar.

Pump

The pump module is used in gas recirculating systems. A loop bypass valve is installed on the pumps to ensure that they can be operated at a constant input pressure, ensuring a stable a constant extraction of the gas.

Exhaust

The gas returning from the pump module is collected by the exhaust module. A buffer volume is used to allow recirculating gas systems to operate in a stable way during sudden changes of atmospheric pressure. Also, an MFC is used to eventually exhaust the excess of gas, keeping the high pressure part of the loop at a constant pressure.

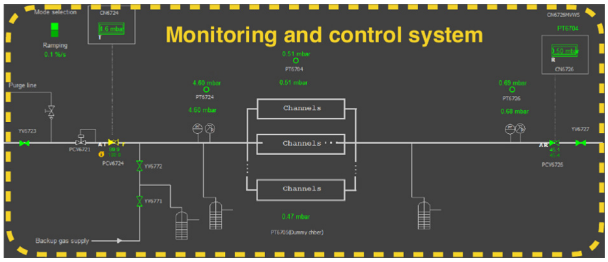

Fig. 3. SCADA panel of one distribution rack of the ATLAS RPC gas system.

Purifier

The purifier module is responsible for removing possible gas pollutants accumulating in the loop. Main impurities that can be found in gas systems are Air, H_2O and fluorinated radical. H_2O and O_2 are efficiently removed by means of microporous absorbing materials and copper-oxide catalysts such as Cu R-11, while no simple method exists for the removal of N2.

Analysis

Gas analysis modules perform a constant measurement of the gas quality among different parts of the gas system. In particular, H_2O and O_2 traces are constantly kept under monitored conditions, but other gases such as i-C_4H_{10}, CO_2, CF_4, SF_6 can be also monitored for human safety and detector performance.

2.2. Gas control systems

Gas Control Systems (GCS) are a fundamental part of gas systems as they allow to operate them by controlling the actuators and monitoring by reading and archiving values of several hundreds of sensors within the different gas modules. GCSs are developed using the CERN-made UNified COntrol System (UNICOS) [2] framework that provides the necessary tools to develop both the software for Programmable Logic Controllers (PLC) and the Supervision, Control and Data Acquisition (SCADA) application, based on the Siemens WinCC-OA software. Fig. 3 shows an example of a SCADA Human Machine Interface (HMI) panel which monitor the pressures and valves statuses of a specific distribution rack.

3. Recirculation systems for small-to-medium sized experiments

Along with large LHC installations, a considerable contribution to GHG emissions is due to setups used for LHC detector upgrade projects, R&D activities and detector production tests and longevity studies. In order to minimize such emissions, a compact and flexible recirculating gas system was developed [3]. The small recirculating system was conceived as a single rack containing the essential gas systems modules such as humidifier, pump, distribution, gas analysis, purifier and control PLC. The system was designed to operate several detectors with volumes up to several tens of liters, with recirculation pumps capable to ensure one or more gas exchange in the detector volume per hour. Fig. 4 shows the front and rear view of a small recirculating unit. It can be noticed that all the essential modules are present and the size of the components was downscaled to allow each module to fit into the rack. Several of these recirculation systems have been built in the last years and are used for RPC, CSC, GEM detectors in laboratory set-ups, test-beam set-ups and at the CERN Gamma Irradiation Facility (GIF++).

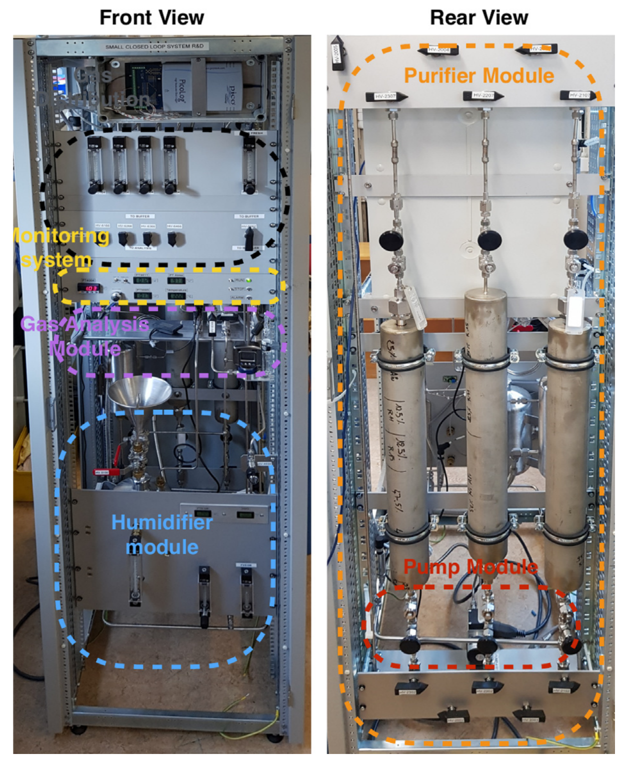

Fig. 4. Picture of the front and rear view of the small gas recirculation system. The different modules are highlighted with colors in the picture.

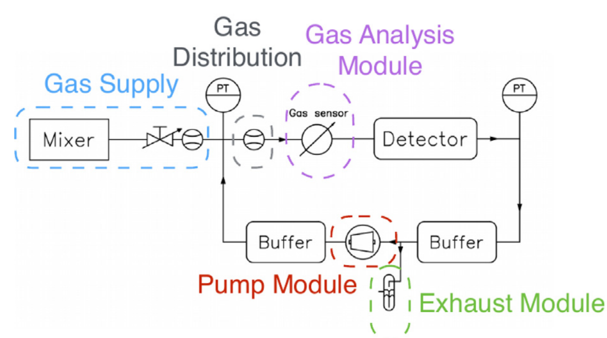

Fig. 5. Piping and Instrumentation Diagram of the Micro recirculating gas system. The modules are highlighted with different colors.

4. A micro-recirculating system for laboratory setups

Together with the development and commissioning of small recirculating system, an even smaller and simpler recirculating unit was designed with the goal of having a portable recirculation system for few detectors as simple and economically suitable for small institutions such as schools, universities and CERN laboratories. The system should also be kept as simple as possible and the operation should require the least amount of manual intervention. Optionally, the system should also be able to be operated by means of a control software or algorithm to further improve the operating conditions. All the systems components used were similar to the ones used at the LHC experiments and new components were validated for usage with straw tubes.

Fig. 5 reports the Piping and Instrumentation Diagram of the micro recirculating loop. The number of modules was reduced to:

- The gas supply and distribution, made by one input rotameter, a pressure sensor that monitors the pressure at the input of the detector and one MEMS mass flow meter;

Table 1
Input flow, recirculation flow, humidity and detector pressure measured at different recirculation fractions of the system.

Recirculation fraction	Input flow [ln/h]	Loop flow [ln/h]	Dew point [°C] (min, max)	Detector pressure [mbar] (mean, std.dev.)
70%	14.5	48.3	1.1, 2.1	1.47 + −0.07
80%	6.5	33.7	2.7, 3.3	1.32 + −0.09
90%	2.9	29.2	3.7, 5.5	1.28 + −0.04
100%	0	30.1	2.3, 3.4	unstable

Table 2
Maximum measured flow in closed loop conditions for three different micro pumps.

	Flow R134a [L/h]	Flow N2 [L/h]	Flow Ar [L/h]	Air flow (data sheet) [L/h]
Xavitech P200-B5C12V	28.2	30.1	42.7	24
KNF NMP03KPDC-B3	26.6	26.7	39.1	19.8
KNF NMP09KPDC-L	74.8	63.6	96.6	54

- An optional gas sensor module. In the tested prototype a Vaisala DMT 242 was used to measured the dew point of the gas mixture in the range [−20, +40] °C. Other sensors, such as relative humidity sensor may also be employed, provided that they are suitable for detector operation, i.e. they do not have outgassing components that may introduce pollutants into the chambers.
- An exhaust module, made of a pressure sensor at the output of the detector, a buffer volume used to stabilize pressure variations, and a bubbler, which provides a safety mechanism to avoid overpressure in the detector's volume.
- A pump module, which consists of a micro pump and two buffer volumes placed right before and after. The purpose of the buffer volumes is to dampen possible pressure fluctuations induced by the pump to the rest of the loop and in particular to the detector.

An example of a micro-loop prototype is showed in Fig. 6. The prototype was tested with a 70 cm × 100 cm × 2 mm single gap Resistive Plate Chamber. At the input a Voegtlin V100 rotameter was used to regulate the input flow to the system. In order to evaluate the recirculation fraction, an Omron D6F flowmeter was installed right after the rotameter to have a digital flow readout. The pressure transmitter used was a Sensor Technics CTE7000 with a [−25, +25] mbarg range and a 4..20 mA signal output. A second Omron D6F flowmeter was used to measure the loop flow and a Vaisala DMT242 Dew Point transmitter was installed to record the dew point of the gas mixture. A second CTE7000 pressure transmitter was installed at the output of the detector and was used to perform simple pump regulation to keep the value of the pressure as stable as possible. Two volumes of 2 l each were installed before and after the pump. Few different pumps were used for tests: the selected ones were a Xavitech P200 and KNF NMP pumps that allowed to recirculate few liters/hour of RPC gas mixture without the need of special equipment to dampen pressure fluctuations.

The monitoring system was designed using a Raspberry Pi computer with a Pi-16ADC board which allowed to measure up to 16 channels in the range 0–5 V with a 16 bit resolution. The board also provided 5 V supply with a sufficient current output to power the mass flow meters. The data was read using a dedicated program that periodically retrieved the ADC values and stored them into a dedicated time-series database run with InfluxDB 1.7. The visualization of the different parameters, together with the scaling and conversion of the raw values to physical values was done using a hosted Grafana application. An example of the dashboard used to monitor the micro loop system is shown in Fig. 7.

The dedicated dashboard allowed to monitor the system pressures, flows, as well perform simple calculation such as the recirculating fraction, defined as $f = \frac{\phi_{injection}}{\phi_{loop}}$.

4.1. Tests on different recirculating fractions

Different recirculating fractions were tested on the system to monitor the stability of the loop. The gas used for all tests was R-134a. The pump was run at 100% of power. The tests with 70%, 80%, 90%

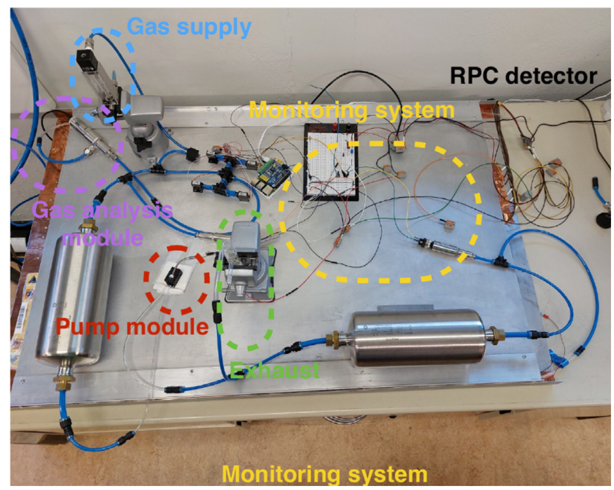

Fig. 6. Micro-loop recirculating system prototype applied to a single gap Resistive Plate Chamber of 1.5 l.

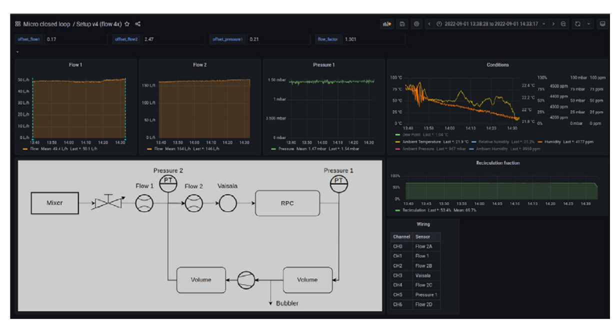

Fig. 7. Grafana monitoring page for the micro-loop gas recirculation system where the monitoring of the different sensors is shown.

recirculation fraction were performed for few hours, while the test at 100% run over night. Table 1 reports a summary of the performed tests with different recirculation fractions.

It can be observed that for each test the loop flow was around 8–13 ln/h, enough to exchange around 1.5–1.9 volumes/hour of the entire gas system. The tests at 70%, 80%, 90% show that the detector pressure stability was better than 0.1 mbar. The tests done at 100% showed some instabilities at the level of detector pressure and loop pressures, as show in Fig. 8.

- Pressure fluctuations could be mitigated by controlling the pump speed with a closed-loop control system algorithm, such as a Proportional–Integral–Derivative (PID) controller.

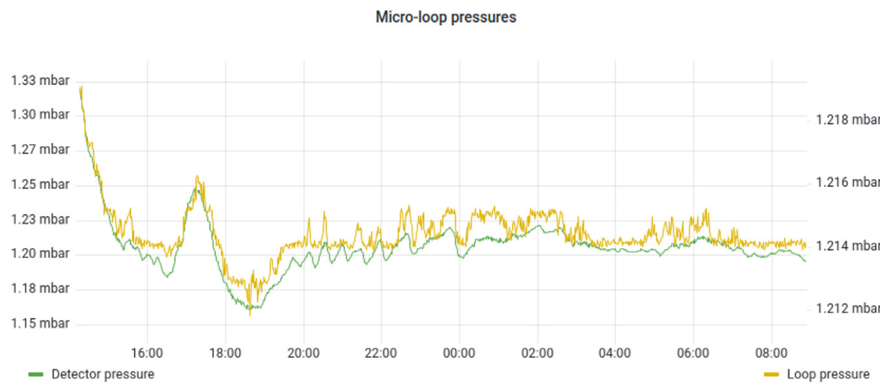

Fig. 8. Micro-loop recirculating system prototype applied to a single gap Resistive Plate Chamber of 1.5 l.

4.2. Studies on different pump performances

In order to have the possibility of use the setup with different detector volumes and recirculation flows, different micro pumps were tested. The maximal flow of the selected pump were measured and compared with the provided datasheets from the manufacturers. The studies were conducted with three different gases: Ar, N_2 and R-134a. For each gas, the input flow was set at about 1 ln/h and a correction factor on the readout of the Omron flowmeter was applied: 0.2944 for R-134a, 1.001 for N_2 and 1.403 for Ar.

Table 2 reports the maximal flows obtained by operating the pump in closed loop conditions. The maximal flow strongly depends on the gas used. It can be noticed that for all the three tested pumps there is no significant different between R-134a and N_2, while the flow in Ar is significantly higher. The Xavitech and KNF NMP03 pumps show similar performance, while the KNF NMP09 show a factor three higher in the flow, suggesting that the pump could be used for setup with larger volumes or requiring a high exchange rate of gas.

5. Conclusions

Gas systems are fundamental for the operation of gaseous particle detectors. LHC Gas systems were designed for detector installation of few to several hundreds of cubic meter, with a modular-oriented approach in order to minimize costs and ensure optimal operation. Recirculating gas systems were designed from the beginning to allow to save costs from the usage of expensive gases, as well as to reduce possible greenhouse gases emissions in particular detectors. Medium and small size recirculating gas systems with the capacity of operating tens of detectors were also developed in the past mainly for small experiments or R&D activities for gaseous detectors. A new, micro gas system was designed to be economically affordable and suitable for operating few detectors under gas recirculation. Preliminary tests were conducted by researching and testing different components and by designing the monitoring infrastructure for operating the gas system. Several tests were conducting on the performance on the gas system, while studies on the correlation between the gas system and the detector performance are ongoing. Encouraging results showed that systems can be regulated without the need of particular control loops at recirculation fractions up to 90%, while higher recirculation fractions may require a more accurate control to improve pressure stability.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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