A portable gas recirculation unit for gaseous detectors

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ABSTRACT: The use of greenhouse gases (usually C2H2F4, CF4 and SF6) is sometimes necessary to achieve the required performance for some gaseous detectors. The consumption of these gases in the LHC systems is reduced by recycling the gas mixture thanks to a complex gas recirculation system. Beyond greenhouse gas consumption due to LHC systems, a considerable contribution is generated by setups used for LHC detector upgrade projects, R&D activities, detector quality assurance or longevity tests. In order to minimise this emission, a new flexible and portable gas recirculation unit has been developed. Thanks to its low price, flexibility and user-friendly operation it can be easily adapted for the different types of detector systems and set-ups.

KEYWORDS: Gas systems and purification; Gaseous detectors; Materials for gaseous detectors

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1 Introduction

Several gaseous detector systems are nowadays operational at the CERN LHC experiments for muon trigger, particle tracking and particle identification. Due to well-defined specific requirements, each detector has its proper gas system, which ensures an extremely high reliability in terms of stability and quality of the gas mixture [1]. In the simplest case, the mixture is exhausted to atmosphere after being passed through the detector (open mode system) while for large detector volume where expensive or greenhouse gases (GHGs) are used, the gas is collected at the output of the detector and it is continuously recuperated and reinjected into the supply lines (recirculation system). Gas recirculation systems allow reducing operational costs and emissions by 90% or more.

At the CERN LHC experiments the use of some GHGs (mainly C$_2$H$_2$F$_4$, CF$_4$ and SF$_6$) is necessary to achieve the required detector performance. The reduction of emissions and operational costs is obtained by operating the detectors with gas recirculation mode. Beyond the GHG emission coming from LHC gaseous detectors [2], a considerable contribution is generated by setups used for LHC detector upgrades projects and laboratories at CERN. For example, during the first LHC Long Shutdown (LS1) 10% of the total emission was due to R&D and detector quality assurance activities.
Nowadays R&D activities with gaseous detectors are ramping up as part of the LHC detector upgrade programs, as for example long-term detector tests at the CERN Gamma Irradiation Facility (GIF++) [3], detector quality assurance before installation in the experiments, test-beam and laboratories tests.

In order to minimise GHG emissions, the EP-DT gas system team has developed a compact and flexible gas recirculation unit, which is about ten times less expensive than a standard LHC gas recirculation system. The main features of this gas recirculation unit are its flexibility and its user-friendly operation: it can be easily adapted for all types of gases and detectors as well as for specific requirements (recirculation fraction, low/high flow rates, detector working pressure, gas cleaning agents, etc.).

2 The gas recirculation unit

The gas recirculation unit can be divided into several logic modules, similarly to the LHC gas recirculation systems. Thanks to this modularity, it is easily possible to adapt the unit to users’ requirements. Figure 1 shows the basic drawing of the unit, where the different modules can be identified: gas supply, gas distribution, exhaust, pump, purifier system. Figure 2 shows a picture (front and rear view) of the recirculation unit. In the following a brief description of each module will be provided. The principle of operation of the unit is based on a pump ensuring the gas circulation and extraction from the detector. Several settings allow to choose the recirculation fraction in the system as well as the detector pressure, flows, etc.

The choice of instruments and materials has been done considering the experience on the LHC gas systems, the quality-price relation and the availability on the market. In this way, even companies outside CERN can produce this gas recirculation unit by their own. Table 1 shows a list of the main components used for the gas recirculation units at CERN.

2.1 Gas supply

The gas is supplied to the system through a flow-meter (FIV-1005), which gas flow range is chosen according to the maximum gas flowed needed by the gas system and the maximum recirculation fraction that the user needs to achieve. Usually the gas mixture going into the supply is prepared with a gas mixer unit made up of mass flow controllers (MFCs), which allow to mix the gas components in the correct ratio. In case a gas mixer is needed, it can be fitted in the gas recirculation unit.

2.2 Gas distribution

The gas injected by the supply (fresh gas mixture) and the gas coming out of the purifier module (recycled gas) are mixed and sent to the distribution module, where the main line splits into four gas lines. The first three lines are used to send the mixture to the detectors. A flow-meter is inserted in each line allowing to set the desired gas flow for each detector from few to hundred litres per hour. The fourth line can be used with or without detector. In the second case it allows to directly analyse the gas coming from the purifier module. On each return line from detectors, two valves

\footnote{The standard gas recirculation unit has four gas lines, which can be isolated and not used if not necessary. Few more gas lines can be added only during the construction phase. In case the user requires several lines, an alternative solution is proposed, as described in paragraph 3.4.}
Figure 1. Drawing of the basic gas recirculation unit. The different logic modules are indicated in the figure.

Figure 2. Front and rear view of the gas recirculation unit. The different logic modules are highlighted.
(HV6X35 and HV6X66) are installed. HV6X35 allows to isolate the line if it is not used. HV6X66 allows either to send the gas mixture directly to the gas circuit or through the gas analysis module. In this way it is possible to analyse one by one the gas coming from each detector or the total gas flow passing through all detectors. Thanks to the fourth line it is possible to analyse the fresh and recycled gas at the input of the detectors. In case of long gas lines between the detectors and the gas system module, the installation of safety protection bubbler (as close as possible to the detectors) is highly recommended to protect against accidental overpressure.

A pressure sensor (PT5011) is installed at the input of the distribution module to monitor the pressure stability, which is directly linked to the flow stability into the detectors. PT5011 is affected by fresh input flow and gas recirculation fraction (i.e. the gas mixture coming from the gas purification module).

### 2.3 Gas analysis module

The gas analysis module is placed after the distribution module allowing to analyse the gas exiting the detectors or coming from the purifier module and mixed with the fresh mixture. It usually consists of H$_2$O and O$_2$ analysers in series. Both analysers have been carefully selected among a wide range of available devices thanks to their very good performance, reliability and cost-effectiveness. Indeed these analysers are also used in the LHC gas systems.

The H$_2$O analyser has a capacitive thin-film polymer sensor, which absorbs or releases water vapour as the surrounding humidity increases or decreases. The sensor is protected with a metallic mesh and it is immune to particulate contamination, water condensation, oil vapour and most chemicals. Other important positive point of this H$_2$O analysers is the auto-calibration function.

The O$_2$ analyser is a chemical cell analyser containing an advanced galvanic fuel cell that can measure oxygen in four ppm ranges (10, 100, 1,000 and 10,000 ppm) and three percentage ranges (1, 10, and 25%), which are user-programmable. The O$_2$ analyser requires some maintenance like replacing the cell (every year or two, depending on the use) or the calibration of the device.

Since the gas passing through the analysers can be polluted (below ppm level), especially because of the chemical reaction in the O$_2$ analyser, at the output of the analysers a three-way valve (HV-6067) has been installed allowing to exhaust the gas with a bubbler (XBUB-6068) or, if no constrains or no proven sensitivity to the presence of the cell has been observed, to redirect the gas in the recirculation system.

In case of any specific need from the user, other types of gas analysers can be fitted in the gas recirculation system. Furthermore several gas analysis points are available in different part of the recirculation system where it is possible to easily connect analysis devices.

### 2.4 Exhaust module

The exhaust module allows to exhaust to the atmosphere the gas in surplus inside the system. Indeed if for example 90% of the gas is recycled inside the system, it means that 10% of gas has to be sent to exhaust and replaced by 10% of new fresh gas (from the supply module).

The exhaust module is placed after the distribution and gas analysis module. It simply consists of a double-way bubbler (XBUB-6069) to limit both overpressure and underpressure. The correct pressure limitation is ensured by the level of liquid in the bubbler. In the LHC gas systems the exhaust
module consists of a MFC with PID pressure regulation, allowing the exhaust pressure regulation and recording the exhausted gas flow. For the recirculation unit the bubbler has been chosen to keep the system as simple as possible, easier to parametrize by the user (for example increase/decrease pressure by adding/eliminating liquid inside the bubbler) and for economical reason.

2.5 Pump module

The pump module allows the recirculation of the gas inside the loop as well as the control of the recirculation flow.

A simple pump is not enough for stable and reliable operation of the gas system since pressure fluctuations can be produced by changes in the atmospheric pressure and/or ambient temperature. In addition, not all pumps have the possibility to modulate the pump speed and therefore to adapt the pump flow. To solve this issue a by-pass loop has been added across the pump and equipped with a forward mechanical pressure regulator (PCV-4018) and a micrometer valve (HV-4030). The pressure regulator keeps constant the input pressure to the pump (PT4004) by regulating the flow in the by-pass loop. In case a higher by-pass flow is needed (i.e. the detectors connected to the system require a flow much lower than the pump capacity), the micrometer valve is used for a first order regulation while PCV-4018 continues to do the fine adjustment.

2.6 Purifier module

The purifier module aims in cleaning the gas mixture from possible impurities and contaminants that could have been created during detector irradiation or that might enter in the gas and detector systems due to leaks or material permeability. The module is composed of three cartridges that can be filled with different types of materials depending on the contaminants that have to be absorbed. Typical impurities are N\textsubscript{2}, O\textsubscript{2} and H\textsubscript{2}O. The last two are absorbed thanks to metallic catalysts and molecular sieves (MS) [4, 5].

The three cartridges system allows multiple types of operation. It is indeed possible to use only one cartridge at the time as well as two or three cartridges connected in series or parallel. User can also by-pass the whole purifier module if needed. Particle filters are installed at the input and output of each cartridge to avoid the propagation of any dust in the gas system. An additional filter with a very small mesh (0.5 µm) is installed at the output of the module.

The only disadvantage of the purifier module is that the regeneration of the cleaning agents\textsuperscript{2} is manual. The regeneration of the material is achieved either by flushing with Ar/H\textsubscript{2} mixtures (for metallic catalyst) or by vacuum cycles (for molecular sieves), in both cases the process takes place at high temperatures. A dedicated set-up is available at CERN for such operation.

2.7 Monitoring system

Since one of the goal of the gas recirculation unit was the cost-effectiveness, it has been decided to not have any remote control and to limit the use of electronics/software tools. In this gas system three pressure sensors allow to monitor the pressure in the critical points and the gas analysers provide the O\textsubscript{2} and H\textsubscript{2}O concentrations. These values are displayed on displays and an electronic circuit allows the user to receive information in a 4-20 mA format.

\textsuperscript{2}The regeneration of the cleaning agents is needed to recover their absorption capacity once they are saturated.
Remote control and higher automation of the gas recirculation unit can be achieved only by upgrading the user interface. Indeed, as it will be described in next section, the pump speed control and regulation can be improved with a small programmable logic controller (PLC) module. Hand-valves can be replaced with electro-valves for remote control. The gas bubbler in the exhaust module can be substitute with an electronic back-pressure regulator. Also the flow-meters can be substituted with mass flow meter (MFM) or MFCs to read or regulate the gas flow for each detector. All these upgrades can be very useful for a better control of the gas recirculation system but they have not been implemented in the basic recirculation unit to keep the system simple and cost-effective.

| Module          | Component      | Type           | Manufacturer   |
|-----------------|----------------|----------------|----------------|
| Gas Supply      | FIV-1005       | Flowmeter      | Bronkhorst     |
|                 | HV-6x65        | valve          | Rotarex        |
|                 | HV-6x66        | 3-ways valve   | Rotarex        |
|                 | FIV-6x64       | Flowmeter      | Voegtl         |
|                 | PT5011         | Pressure transmitter | Sensortechnics |
| Gas Distribution| HV-6066-8      | 3-ways valve   | Rotarex        |
|                 | O\textsubscript{2} analyser | O2X1          | GE Panametrics |
|                 | H\textsubscript{2}O analyser | DMT242        | Vaisala        |
|                 | XBUB-6068      | Bubbler        | Glass Technology |
| Exhuast         | XBUB-6069      | Bubbler        | Glass Technology |
| Pump            | PUMP-4101      | Membrane Pump  | KNF            |
|                 | PCV-4018       | Pressure Control Valve | Zimmerli      |
|                 | HV-4030        | Micrometer valve | Rotarex       |
|                 | PT4004         | Pressure transmitter | Sensortechnics |
| Purifier        | HV-2xyz        | valve          | Rotarex        |
|                 | FIL-2xyz       | Mesh filter    | Swagelok       |
|                 | Cartridge      | Custom-made    | CERN           |
|                 | PT5005         | Pressure transmitter | Sensortechnics |

### Table 1. Overview of the main components used in the gas recirculation units built at CERN. Equivalent components from other manufacturers can be used if they satisfy the project requirements.

3 Available upgrades for the recirculation unit

The gas recirculation unit has a very high flexibility in terms of design, technical specifications and requirements. Indeed the unit can be used with all types of gaseous detectors, which have different necessities. For this reason several options have been developed and can be integrated in the system if needed. In the following, a brief overview of some options is provided.
3.1 Gas humidifier module

Some gaseous detectors may require a humidified gas mixture. In this case, the recirculation unit can be integrated with a gas humidifier module. Figure 3 shows the schematics of the module, which is connected to the recirculation module before HV-5101 to allow the humidification of the gas mixture. In the humidifier module the gas flow is split into two parts to allow the modulation of the mixture humidity to the desired value: one gas line passes through a water volume while the other is simply kept dry. Afterwards the two portions are put again together and the mixture humidity is measured by means of a water content analyser. The measured water concentration is used as feedback signal to the mass flow controllers that split the gas flow into the wet and dry channels.

The integration of the gas humidifier module implies the use of MS 4 Å in the purifier cartridges. Indeed the easiest way to operate the humidifier module is to inject into it only dry gas. For this reason the gas coming from the detectors is completely dried before sending it back to the humidifier where it will be humidified again.

![Figure 3. Drawing of the humidifier module.](image)

3.2 Pump control system

In basic recirculation unit, the pump speed can only be regulated manually with a potentiometer. In case of sudden pressure changes or wide-range temperature variations, the pressure can vary significantly reducing or increasing the recirculation flow (while the fresh input flow is stable). This variation can be detected with the pressure sensors PT5005 and PT5011, which should be constant for stable operation. A pump control system has been implemented with a basic PLC module. The control system adjusts the pump speed ensuring that both the upstream pressure (i.e. detector pressure) and downstream (i.e. supply to the detector pressure) are constant.

3.3 Gas analysis points

The gas recirculation unit is conceived with a gas analysis module to monitor the O₂ and H₂O contamination in the system, especially at the detector output. Nevertheless it is possible to foresee
other analysis points in different areas of the recirculation unit. They consist of a valve or a simple connector where the user can directly connect other analysis devices or a pipe to extract gas samples. Gas analysis points are usually present at the input and output of the detectors, after the pump module, before and after the purifier module.

### 3.4 Test for multiple detectors

In case of more than four detectors, specific manifolds can be inserted after the flow-meter to split the gas line to the desired number. The gas lines exiting the detectors are afterwards routed together in a second manifolds to have only one gas line going into the two-way valve. The regulation of the flow for each detector gas channel is obtained with addition of a flow-meter on each new line.

### 3.5 Automatic purifier module

An automatic purifier module has been developed for applications with detectors requiring a large absorption capacity for impurities in the gas mixture. This module is a simplified version of the ones used for the LHC experiments. It is designed to allow on-site regeneration of the absorption material. The module contains two twin columns of 6 litres each. One column typically filters the process mixture while the other is either in regeneration (for recovering the absorption capacity) or waiting the saturation of the first one to enter in the process. The module uses time events to trigger the change over between the two available cartridges.

### 4 Conclusions

A gas recirculation unit has been developed to cope with the increasing necessity of reducing GHG emissions from gaseous detectors under test in laboratories or R&D facilities. The main features to address for this unit were user-friendly operation, flexibility and low-cost. The unit is divided in several logic modules, similar to the LHC gas systems, allowing to address the users requirements.

Two recirculation units are operational since more than two years for two different set-ups: CMS Cathode Strip Chamber test at GIF++ and Gas Electron Multiplier operation under gas recirculation. The first few years of operation have confirmed an extremely high reliability and stability of the two recirculation systems, which work in different conditions (recirculation flow, pressure, etc.) and with different detector types. More units are currently under construction for different detectors technologies that will be tested on a long-term basis in laboratories, beam-tests or irradiation facilities.

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